EPISODE SELECTION FOR THE DENVER EARLY ACTION OZONE COMPACT

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Executive Summary

This document presents the methods and procedures used for determining the episodes that will be used for Denver's Early Action Ozone Compact. Based on these methods and procedure, ozone episodes that will be used in the air quality modeling analysis are also presented in this document.

Monitored ozone data from the period of 1999-2002 was used to identify elevated 8-hour ozone episodes in the Denver metropolitan area. All days in which any ozone monitors in the Denver area that had a daily maximum 8-hour ozone concentration that was 80 ppb or higher was examined. Particular emphasis was placed on those ozone episodes that exceeded the 8-hour ozone standard (i.e., 85 ppb or higher for monitored concentrations).

The recommended order of episodes in their importance to Denver ozone is as follows:

- July 18-21, 2002
- June 25-July 1, 2002
- June 8-12, 2002
- July 4-July 9, 2001
- August 3-4, 2001.

The first two episodes, July 18-21, 2002 and June 25-July 1, 2002 are equally important. A second options would be to run MM5 and the air quality model from June 23 through July 21 (~30 days) to cover the two most important episodes. A third option would be to run MM5 and the air quality model from June 1 through July 31, 2002 to capture to top three episodes (~60 days). Of course cost, computer resources, and time should also weigh in on this decision. Each episode needs to have two additional days of MM5 data in order to initialize the air quality model and to set boundary conditions prior to the actual episode days. For example, the July 18-21, 2002 episode would need to have the MM5 runs cover the period of July 16-21, 2002.

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EPISODE SELECTION FOR DENVER's EARLY ACTION OZONE COMPACT

Introduction

This document presents the methods and procedures used for determining the episodes that will be used for Denver's Early Action Ozone Compact. Based on these methods and procedure, ozone episodes that will be used in the air quality modeling analysis are also presented in this document.

Monitored ozone data from the period of 1999-2002 was used to identify elevated 8-hour ozone episodes in the Denver metropolitan area. All days in which any ozone monitors in the Denver area that had a daily maximum 8-hour ozone concentration that was 80 ppb or higher was examined. Particular emphasis was placed on those ozone episodes that exceeded the 8-hour ozone standard (i.e., 85 ppb or higher for monitored concentrations).

8-Hour Ozone Trends

The Colorado Department of Public Health and Environment operates 13 ozone monitors along the Front Range. Nine of these monitors are located in the Denver metropolitan area, with the other three in Colorado Springs, Ft. Collins, and Weld County. Highest ozone concentrations in the Denver area generally occur at monitors located along the foothills. Historically, the NREL monitor on Table Mountain in Golden and the Rocky Flats monitor in northern Jefferson County consistently record the highest levels. In addition, the Highland Reservoir and Chatfield monitors in Douglas County and the South Boulder Creek monitor in southern Boulder County have also recorded elevated concentrations at times. Figure 1 presents the spatial distribution of ozone monitors in the Denver metropolitan area.

High ozone concentrations can occur on any day of the week, including weekends. Over the last five years, 69% of the 8-hour ozone levels above 75 ppb have occurred on weekdays while 31% have occurred on weekend days. Of the days above 90 ppb, 67% have occurred on weekdays and 33% on weekends. (Reference Reddy)

Table 1 summarizes the fourth maximum ozone values at all monitors in the state since 1996. The summer of 1998 had the highest ozone levels since 1996 with the fourth maximum levels at NREL and Rocky Flats above 90 ppb and values at several other monitors above 80 ppb. In 1999, 2000, and 2001, values were lower, with fourth maximum values less than 80 ppb at most monitors in the low 80's for NREL and Rocky Flats.

Table 1: Fourth Maximum 8-Hour Ozone Concentrations from 1996 through 2002

Site Name	1996 8-hr O3 4th Max. (ppm)	1997 8-hr O3 4th Max. (ppm)	1998 8-hr O3 4th Max. (ppm)	1999 8-hr O3 4th Max. (ppm)	2000 8-hr O3 4th Max. (ppm)	2001 8-hr O3 4th Max. (ppm)	2002* 8-hr O3 4th Max. (ppm)
Welby	0.074	0.071	0.083	0.071	0.062	0.064	0.068
Highland	0.073	0.065	0.084	0.075	0.076	0.077	0.076
S. Boulder Creek	0.075	0.072	0.089	0.075	0.072	0.071	0.078
Carriage	.0.068	0.066	0.085	0.068	0.071	0.072	0.073
Chatfield Res.	0.079	0.075	0.081	0.075	0.080	0.077	0.083
USAF Academy	0.057	0.059	0.062	0.064	0.072	0.070	0.072
Arvada	0.073	0.070	0.089	0.072	0.076	0.074	0.073
Welch	0.069	0.068	0.080	0.066	0.068	0.064	0.069
Rocky Flats North	0.083	0.076	0.092	0.080	0.081	0.082	0.088
NREL	0.082	0.075	0.092	0.080	0.083	0.081	0.081
Fort Collins	0.066	0.064	0.072	0.063	0.070	0.067	0.072
Greeley	0.070	0.069	0.075	0.069	0.069	0.074	---
Weld County Tower	---	---	---	---	---	---	0.080

Data through August 2002

NOTE: An area is considered to be in attainment of the National Ambient Air Quality Standard when the 3-year average *of the annual 4th highest daily maximum 8-hour ozone concentration is less than or equal to 0.08 ppm. Due to rounding, a value of 0.085 ppm or greater would constitute an exceedance of the 0.08 ppm standard.*

Table 2 indicates the highest values at selected ozone monitors during the summer of 2002. There were three days in July (1st, 19th, and 20th) when ozone readings exceeded 90 ppb at one or more monitors in the region. The NREL monitor recorded values above 90 ppb on these three days and the fourth maximum value at the monitor was 81 ppb, which is consistent with historical levels at the monitor.

The Rocky Flats monitor had an unusual pattern and number of high ozone days, when compared with other monitors during the summer of 2002. While the monitor recorded a value above 90 ppb on July 19 when high values were recorded throughout the region, the monitor also recorded values in the high 80's on four days in early and late June, days when other monitors did not register exceptionally high values.

Table 2: Highest Ozone Concentrations at Selected Monitors-2002

Monitor	1st Max	2nd Max	3rd Max	4th Max
NREL	20-Jul	19-Jul	1-Jul	18-Jul
	0.092	**0.091**	**0.091**	**0.091**
Rocky Flats	19-Jul	29-Jun	8-Jun	9-Jun**
	0.092	**0.089**	**0.088**	**0.088**
S. Boulder Creek	19-Jul	30-Jun	9-Jun	29-Jun
	0.086	**0.080**	**0.079**	**0.078**
Highlands Res.	1-Jul	19-Jul	12-Jun	28-Jun
	0.086	**0.086**	**0.076**	**0.076**
Chatfield Res.	1-Jul	19-Jul	28-Jun	20-Jul
	0.094	**0.089**	**0.083**	**0.083**

** Another 0.088 ppm level was recorded on 6/30/02

Table 3 summarizes the 3-year averages of fourth maximum values at selected monitors for 1998-2000 to 2000-2002. These values are comparable to the 8-hour ozone National Ambient Air Quality Standard (NAAQS). Because of the high values recorded in 2002, the Rocky Flats monitor has become the area of most concern since the 2000-02 average is 84 ppb, only one percent less than the violation level of 85 ppb. In 2003, the region would violate the standard if the 4th maximum at Rocky Flats were greater than 84 ppb. There is greater cushion below the standard at the other monitors.

Table 3: Three-Year Average of 4th Maximum Values (ppm)-1998-2002

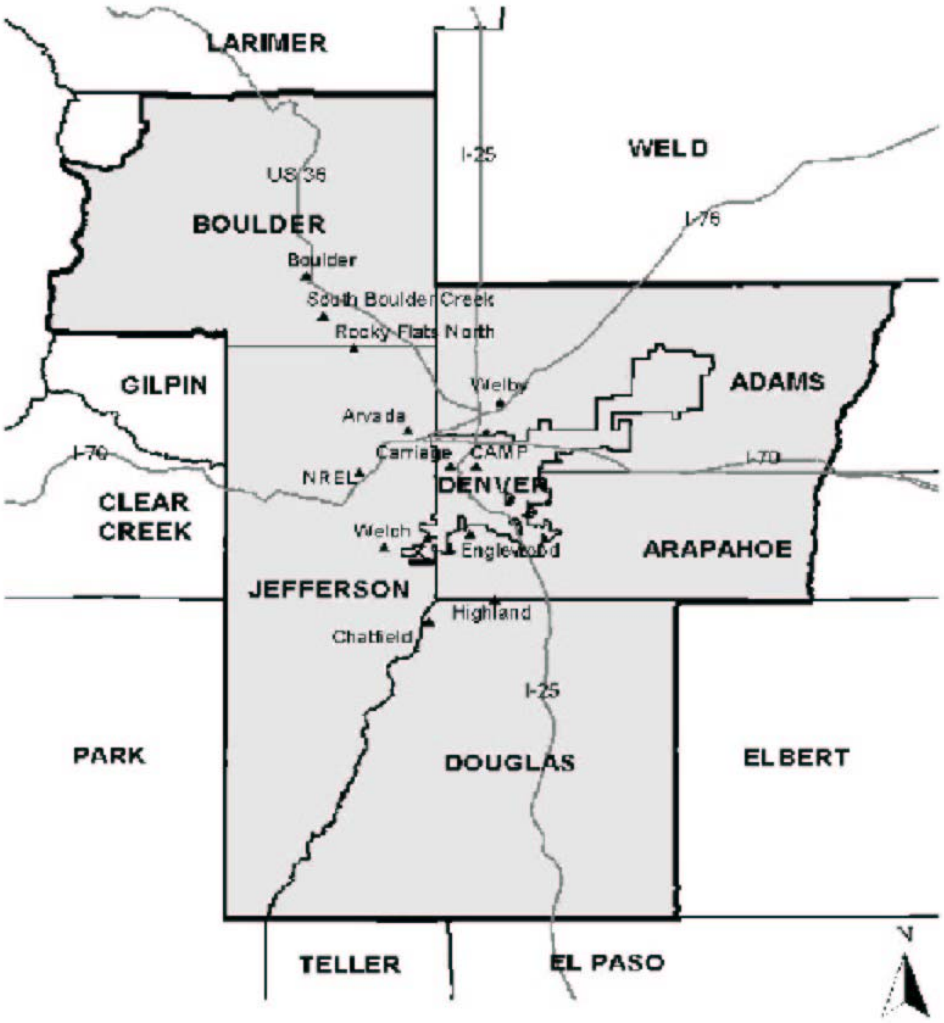
Site Name	1998	1999	2000	2001	2002	98-00 Ave.	99-01 Ave.	00-02 Ave.	2003 (Allow)
NREL	0.095	0.080	0.083	0.081	0.081	0.086	0.081	0.082	0.092
Rocky Flats-N	0.092	0.080	0.081	0.082	0.088	0.084	0.081	0.084	0.084
South Boulder Cr.	0.089	0.075	0.072	0.071	0.078	0.078	0.073	0.074	0.105
Highlands	0.084	0.075	0.076	0.077	0.076	0.078	0.076	0.076	0.101
Chatfield	0.081	0.075	0.080	0.077	0.083	0.079	0.077	0.080	0.094

In addition, elevated 8-hour ozone readings have also been recorded at times in Rocky Mountain National Park (RMNP). The highest ozone concentration in 2002 in the Park was 93 ppb, while the 4th maximum was 87 ppb. There were six days of monitored ozone values of 85 ppb or greater.

Most of these days corresponded with days when high ozone concentrations were also recorded elsewhere in the Denver region. For five of these six days, 8-hour ozone concentrations in RMNP were as high as or higher than values in the remainder of the Denver region.

During the previous four years, the high ozone concentrations in RMNP ranged from 80 ppb (2001) to 90 ppb (2000), while the annual fourth maximum values ranged from 70 ppb (2001) to 80 ppb (1998).

Figure 1: Map of the Denver Metropolitan One-Hour Ozone Attainment/Maintenance Area and Monitoring Locations



EPA's Guidance for Episode Selection

EPA's draft 8-hour ozone modeling guidance has four primary criteria for selecting meteorological episodes for 8-hour ozone attainment demonstration modeling (EPA, 1999):

Select a mix of episodes that reflect a variety of meteorological conditions that frequently correspond with observed 8-hour daily maximum ozone concentrations >84 ppb at different monitoring sites;

1. Select periods during which observed 8-hour ozone concentrations are close to the 8-hour ozone Design Value (i.e., three-year average of fourth highest 8-hour ozone concentration) at each key monitor;
2. Select periods for which extensive air quality/meteorological databases exist; and;
3. Model sufficient number of days so that the model attainment test can be applied at all of the key ozone monitoring sites.

As noted in the draft EPA guidance, these four criteria may conflict with each other, and there may be other secondary criteria that can be used in the episode selection:

- Prior experience modeling an episode may result in it being chosen over an alternative. For the Denver Front Range, there are no prior modeled episodes;
- Choosing episodes corresponding to the three-year period being used to make the 8-hour ozone attainment designation may be desirable;
- May want to choose a modeling period in which days have 8-hour ozone concentrations near the 8-hour ozone Design Values at all violating monitors;
- If observed 8-hour ozone exceedances occur on weekends, weekend days should be considered.

Episode Selection Procedure used for Denver

The procedures for selecting 8-hour ozone modeling episodes for the Denver area are as follows:

- Tabulate all days from 1999 to 2002 that any ozone monitor in the six county area that had an 8-hour ozone concentration of 80 ppb or higher.
- Identify multi-day episode periods in which exceedance of the 8-hour ozone standard occurred for several days at monitors in Denver area along with multiple monitors experiencing 8-hour ozone of 80 ppb or higher:
    - Eliminate days in which the 8-hour ozone exceedance is an isolated occurrence at one monitor with low ozone values at others;
    - Focus first on 8-hour ozone episodes for the Rocky Flats and NREL monitors whose ozone episodes are preferred.
- For each multi-day episode identified, summarize daily maximum 8-hour ozone concentrations at each Denver area monitor tabulating the number of exceedance days and high (> 80 ppb) 8-hour ozone days at each monitor.
- If meteorological data is available, perform back trajectory modeling from

locations of 8-hour ozone exceedances during each candidate episode using the Hysplit model to:
    - Identify potential local versus transport ozone episodes;
    - Identify general direction of winds; and
    - Help classify the 8-hour ozone exceedance days into meteorological regimes.
- Select a subset of the most promising episodes as the final candidates that:
    - Have high and wide-spread 8-hour ozone concentrations with multiple exceedances in the Denver area;
    - Some candidate episodes also have high 8-hour ozone and 8-hour ozone exceedances in Weld County and in Rocky Mountain National Park;
    - Represent the different types of meteorological conditions that lead to elevated 8-hour ozone concentrations in Denver, Weld County and Rocky Mountain National Park areas; and ;
    - Satisfy the EPA four episode selection with the criteria listed above.
- Analyze the meteorological conditions of the final candidate 8-hour ozone episodes and develop a Conceptual Model of the ozone exceedance days.
- Rank episodes for appropriateness for developing 8-hour ozone control plans for the Front Range and make recommendations on which and number of episodes to be modeled to assure that all meteorological types that lead to exceedances of the 8-hour ozone standard are captured.

Tabulation of High Ozone Days from 1999 to 2002

Table 4 presents a tabulation of all days that had a least one monitor with ozone concentrations greater than or equal to 80 ppb in the Denver area. Numbers in bold text are the maximum 8-hour ozone concentrations for the day. Shaded boxes in Table 4 are all additional 8-hour average ozone concentrations greater than 80 ppb. To the right of each date is the beginning hour of the 8-hour period for the maximum ozone concentration (bold text) for that day. Dates with boxes around them are potential episodes considered for meteorological and air quality modeling.

As seen in Table 1, there were 51 days between 1999 and 2002 that had at least one monitor along the Front Range with an ozone concentration greater than or equal to 80 ppb. The highest concentration for a given day is identified in Table 1 in bold text. Ozone concentrations that are less than the maximum daily ozone concentration but greater than 80 ppb are identified by shaded boxes.

During the 1999 to 2002 time frame, there were five episodes of two days or greater that can be used for episode selection. These episodes are identified in Table 1 with boxes drawn around the date. The five episodes that were considered for further analysis include:

- July 18-21, 2002
- June 25 – July 1, 2002
- June 8-12, 2002

- August 3-4, 2001
- July 4-9, 2001

Table 4: Day With at Least One Monitored Ozone Concentrations Greater Than or Equal to 80 ppb in the Denver Area

	Hour of Max.	Welby Daily Max Sample Value	Highland Daily Max Sample Value	S. Bldr. Crk. Daily Max Sample Value	Carriage Daily Max Sample Value	Chatfield Daily Max Sample Value	Academy Daily Max Sample Value	Arvada Daily Max Sample Value	Welch Daily Max Sample Value	RFN Daily Max Sample Value	NREL Daily Max Sample Value	NPS Daily Max Sample Value	Ft. Collins Daily Max Sample Value	Greeley Daily Max Sample Value	WCTower Daily Max Sample Value
09-APR-1999	13	0.069	0.075	0.038	0.069	N / A	**0.081**	0.068	0.068	0.072	N / A	0.073	0.062	0.062	N / A
06-MAY-1999	9	0.075	0.075	0.070	0.062	0.076	0.068	0.070	0.067	0.078	N / A	**0.085**	0.071	0.071	N / A
26-JUN-1999	10	0.064	0.072	0.063	0.062	0.079	0.054	0.068	0.064	0.073	**0.080**	0.056	0.055	0.059	N / A
01-JUL-1999	12	0.061	0.058	0.075	0.063	0.061	0.045	0.069	0.061	**0.087**	0.078	0.038	0.059	0.052	N / A
06-JUL-1999	11	0.066	0.056	0.071	0.065	0.059	0.047	0.067	0.059	0.077	**0.081**	0.042	0.051	0.048	N / A
07-JUL-1999	9	0.069	0.067	0.077	0.065	0.065	0.051	0.072	0.058	**0.081**	0.076	0.056	0.066	0.066	N / A
13-JUL-1999	10	0.081	0.082	0.086	0.077	0.079	0.064	0.081	0.071	**0.092**	0.084	0.064	0.061	0.069	N / A
17-JUL-1999	10	0.070	0.069	0.068	0.065	0.069	0.049	0.072	0.059	0.075	**0.080**	0.063	0.058	0.058	N / A
27-JUL-1999	11	0.068	0.068	0.083	0.068	0.069	0.054	0.076	0.065	0.081	**0.085**	0.063	0.057	0.066	N / A
28-JUL-1999	9	0.071	**0.080**	0.067	0.072	0.075	0.070	0.069	0.064	0.071	0.076	0.061	0.052	0.073	N / A
26-AUG-1999	10	0.069	**0.081**	0.063	0.066	0.077	0.054	0.061	0.060	0.075	0.077	0.065	0.049	0.059	N / A
16-MAY-2000	12	0.066	0.053	0.067	0.069	0.054	0.045	0.076	0.049	**0.082**	0.075	0.068	0.062	0.026	N / A
30-JUN-2000	14	0.055	0.062	0.066	0.063	0.059	0.062	0.061	0.049	0.071	0.070	**0.089**	0.063	0.052	N / A
10-JUL-2000	11	0.058	0.067	0.053	0.069	0.065	0.063	0.072	0.048	0.075	**0.081**	0.067	0.052	0.059	N / A
15-JUL-2000	8	0.062	**0.085**	0.063	0.064	0.083	0.067	0.070	0.071	0.077	0.081	0.068	0.065	0.060	N / A
16-JUL-2000	11	0.058	0.069	0.058	0.065	0.067	0.059	0.070	0.067	0.072	**0.082**	0.062	0.054	0.053	N / A
20-JUL-2000	10	0.056	0.076	0.061	0.069	0.080	0.051	0.076	0.072	N / A	**0.084**	0.063	0.051	0.049	N / A
28-JUL-2000	10	0.062	0.086	0.066	0.076	0.080	0.068	0.079	0.068	0.084	**0.089**	0.076	0.068	0.062	N / A
01-AUG-2000	12	0.053	0.076	0.066	0.067	0.078	0.069	0.068	0.070	0.079	0.083	**0.086**	0.059	0.064	N / A
02-AUG-2000	10	0.050	0.072	0.066	0.071	0.080	0.081	0.061	0.066	0.075	**0.083**	0.078	0.069	0.071	N / A
09-AUG-2000	10	0.055	0.066	0.078	0.057	0.069	0.064	0.063	0.058	**0.081**	0.066	0.080	0.070	0.063	N / A
13-AUG-2000	10	0.054	0.067	0.077	0.069	0.073	0.068	0.070	0.068	0.077	**0.080**	0.069	0.077	0.076	N / A
15-AUG-2000	12	0.062	0.074	0.075	0.078	0.076	0.072	0.078	0.066	**0.083**	0.081	0.075	0.050	0.064	N / A
16-JUN-2001	13	0.056	0.057	0.073	0.067	0.069	0.051	0.071	0.061	**0.083**	0.077	0.042	0.057	0.055	N / A
01-JUL-2001	9	0.062	0.064	0.061	0.058	0.072	0.053	0.072	0.063	0.073	0.081	0.042	0.070	**0.084**	N / A
04-JUL-2001	8	0.066	0.064	0.064	0.072	0.075	0.057	0.077	0.063	**0.081**	0.076	0.045	0.064	0.081	N / A
05-JUL-2001	10	0.062	0.080	0.069	0.072	**0.089**	0.069	0.078	0.063	0.087	0.081	0.045	0.067	0.064	N / A
07-JUL-2001	10	0.063	0.073	0.071	0.073	0.076	0.065	0.074	N / A	0.081	**0.083**	0.063	0.060	0.074	N / A
09-JUL-2001	11	0.065	0.071	0.060	0.066	0.077	0.070	0.040	0.064	**0.084**	0.075	0.058	0.055	0.081	N / A

03-AUG-2001	12	0.054	0.077	0.076	0.051	0.075	0.065	0.062	0.061	**0.082**	0.067	0.080	0.064	0.070	N / A
04-AUG-2001	11	0.063	0.082	0.071	0.078	0.083	0.066	0.083	0.080	0.081	**0.090**	0.061	0.059	0.063	N / A
08-JUN-2002	12	0.065	0.060	0.066	0.069	0.062	0.064	0.074	0.056	**0.088**	0.078	0.073	0.082	N / A	0.077
09-JUN-2002	12	0.057	0.060	0.079	0.059	0.057	0.059	0.069	0.051	**0.088**	0.073	0.088	0.068	N / A	0.073
11-JUN-2002	12	0.054	0.059	0.062	0.044	0.060	0.056	0.053	0.045	0.068	0.058	**0.083**	0.064	N / A	0.066
12-JUN-2002	13	0.069	0.076	0.071	0.059	0.075	0.067	0.072	0.055	**0.083**	0.074	0.077	0.067	N / A	0.071
25-JUN-2002	8	0.059	0.058	0.068	0.068	0.061	0.056	0.065	0.060	**0.080**	0.075	0.075	0.070	N / A	0.070
26-JUN-2002	12	0.068	0.074	0.073	0.073	0.079	0.071	0.068	0.065	N / A	0.077	0.077	0.073	N / A	**0.081**
27-JUN-2002	11	0.062	0.071	0.073	0.066	0.075	0.073	0.065	0.062	N / A	0.071	0.081	0.068	N / A	**0.081**
28-JUN-2002	9	0.064	0.077	0.065	0.071	**0.083**	0.072	0.067	0.065	0.073	0.077	0.069	0.057	N / A	0.071
29-JUN-2002	11	0.067	0.074	0.078	0.072	0.076	0.066	0.070	0.066	**0.089**	0.079	0.069	0.067	N / A	0.079
30-JUN-2002	11	0.067	0.074	0.080	0.071	0.078	0.074	0.070	0.069	0.088	0.080	**0.093**	0.074	N / A	0.068
01-JUL-2002	11	0.068	0.086	0.071	0.077	**0.094**	0.072	0.073	0.075	0.088	0.091	0.085	0.070	N / A	0.082
07-JUL-2002	9	0.062	0.067	0.070	0.067	0.071	0.059	0.066	0.060	**0.081**	0.076	0.069	0.072	N / A	0.080
09-JUL-2002	10	0.062	0.070	0.064	0.065	**0.081**	0.058	0.066	0.060	0.078	0.078	0.081	0.061	N / A	0.056
15-JUL-2002	11	0.062	0.065	0.070	0.064	0.068	0.058	0.066	0.058	0.076	0.074	**0.085**	0.055	N / A	0.063
18-JUL-2002	14	0.063	0.071	0.073	0.069	0.072	0.061	0.067	0.060	0.078	0.081	**0.087**	N / A	N / A	0.069
19-JUL-2002	10	0.074	0.086	0.086	0.083	0.089	0.067	0.084	0.070	**0.092**	0.091	0.092	N / A	N / A	0.069
20-JUL-2002	10	0.071	0.076	0.076	0.082	0.083	0.066	0.081	0.072	0.081	**0.092**	0.080	N / A	N / A	0.072
21-JUL-2002	10	0.065	0.076	0.066	0.070	**0.080**	0.061	0.071	0.066	0.073	0.078	0.069	N / A	N / A	0.067
10-AUG-2002	13	0.062	0.068	0.070	0.066	0.070	0.065	0.064	0.051	**0.082**	0.075	0.076	0.071	N / A	0.073
25-AUG-2002	14	0.060	0.063	0.064	0.063	0.064	0.057	0.059	0.046	0.073	0.071	**0.080**	0.064	N / A	0.066
Max	14.000	0.081	0.086	0.086	0.083	0.094	0.081	0.084	0.080	0.092	0.092	0.093	0.082	0.084	0.082

Analysis of Ozone Episodes

Detailed analyses for the five selected episodes are presented in this section. Meteorological data for those days in the episode were examined to see if there was a consistent or different type of meteorological regime that occurred that resulted in exceedance of the 8-hour ozone standard.

Back trajectories were estimated for each episode by using the NOAA HYSPLIT model (http://www.arl.noaa.gov/ss/models/hysplit.html). Back trajectories were calculated from the NREL site. Back trajectories are calculated starting from the location of the 8-hour ozone exceedance and at three different heights above ground level (AGL): surface, 100-m, and 800-m. Different height levels allows the for the assessment of the transport of low-level air parcels into the area as well as air parcels aloft above ground level. It also provides an indication of the level of wind shear in the atmosphere.

July 18-21, 2002

The highest ozone levels recorded at Rocky Flats North and NREL over the 1999 through 2002-time period characterized this episode. NREL recorded an 8-hour ozone concentration of 92 ppb on July 18. Rocky Flats North recorded a high 8-hour ozone concentration of 92 ppb on July 19. On July 19, seven monitors had monitored concentrations over 84 ppb including Highlands Ranch (86 ppb), South Boulder County (86 ppb), Chatfield (89 ppb), Rocky Flats North (92 ppb), NREL (91 ppb), and Rocky Mountain National Park (92 ppb). Two monitors, Carriage (83 ppb) and Arvada (84 ppb) had 8-hour ozone concentration greater than 80 ppb but less than 85 ppb.

Meteorological Analysis

This period had nine days of temperatures greater than or equal to 90 degrees F. from July 12 through July 20th. On the last day of the episode (July 21) the temperature made it up to 85 degrees. Dryness, subsidence, and stable conditions predominated the episode. An upper level ridge was centered over Colorado. This ridge was nearly stationary for several days. Despite southeast surface flow along the Front-Range, dew point levels were low enough to inhibit thunderstorm activity. There was some thunderstorm activity in the mountains, though.

On Thursday, July 18th, there was a slight increase in mid-level moisture during the day. There was too much stability in the atmosphere for thunderstorm development despite the increase in moisture.

The strength of the upper ridge peaked on Friday, January 19. The peak strength of the upper ridge coincided with the highest area wide ozone concentrations. Eastern Colorado

appeared to be in a dry subsident hole as subtropical moisture extended from Mexico north into Utah and southern Canada.

On Saturday, July 20, a quick moving Canadian/Pacific short wave pushed through Montana and North Dakota. The result of this short wave weakened the northern section of the upper ridge. Subtropical moisture migrated over eastern Colorado. Northeastern Colorado began to see stronger diurnal east to northwest surface flow late on Saturday. The diurnal surface flow was enhanced by rising surface heights overnight.

The ozone episode essentially ended on Sunday, July 21. A short wave crossed the northeastern Colorado plains during the early morning hours with some rain shower activity. The effect of this short wave was to suppress afternoon convective activity. A second, weaker short wave crossed over northeastern Colorado during the afternoon hours. Some shower activity in Larimer and Weld Counties resulted from the passage of the second short wave. For the most part, cooler temperatures resulting from a moist and cooler northeasterly flow suppressed convective activity. Winds aloft were also weak during the day, and, for most of the episode as well.

Trajectory Analysis

Figure 1.A through 1.E present backward trajectories for July 17 through July 21, 2002. Figure 1.A is a composite trajectory that started at 1 A.M on July 17 and went through midnight on July 21 for a total of 120 hours. The subsequent Figures 1.B through 1.E present 36 hour backward trajectories for each day. The 36-hour period begins 36 hours prior to the ending hour of the highest 8-hour ozone concentration on each day.

The composite backward trajectory, Figure 1.A, indicated that at lower levels up to 100 meters, the origin of the air mass was from the south and east during the early days of the episode and then from the north during the late part of the episode. Upper layers of flow were from the northwest and may have originated from Salt Lake City but this may be misleading as the 36-hour back trajectories were from the south. Thirty-six hour trajectories for each day indicated that the Northwesterly flow might be an artifact of the long period the trajectory analysis was ran. The mid-level air mass was mixed down to ground level by the time it reached the Denver area.

Figure 1.B indicates that the flow from the various layers (surface, 100m, and 800m) were generally from the south. Flow at 800 m was very light and did not mix down to the ground. Even at 100m the flow did not mix down to the ground either.

On July 19, the flow at all levels were again from the south. Winds speeds were less than the previous day and appareantly the flow had a tendency to go around the Palmer Divide. The 800m winds did not mix down to ground level but flowed over the Palmer Divide.

On July 20, when NREL had its highest reading over the episode, the ground level flow was very light from the west. There is some indication that flow in the lower levels circulated along the front range. The flow on this day very likely brought in smoke from the Big Elk Fire that was burning near Estes Park. At the 800m level, the flow was from the south over the Palmer Divide.

The general flow shifted on the last day of the episode. Winds at the surface were from the north. At the 800m level, winds were from the northwest.

Figure 1.A: Composite Trajectory Plot for July 14 – 21, 2002

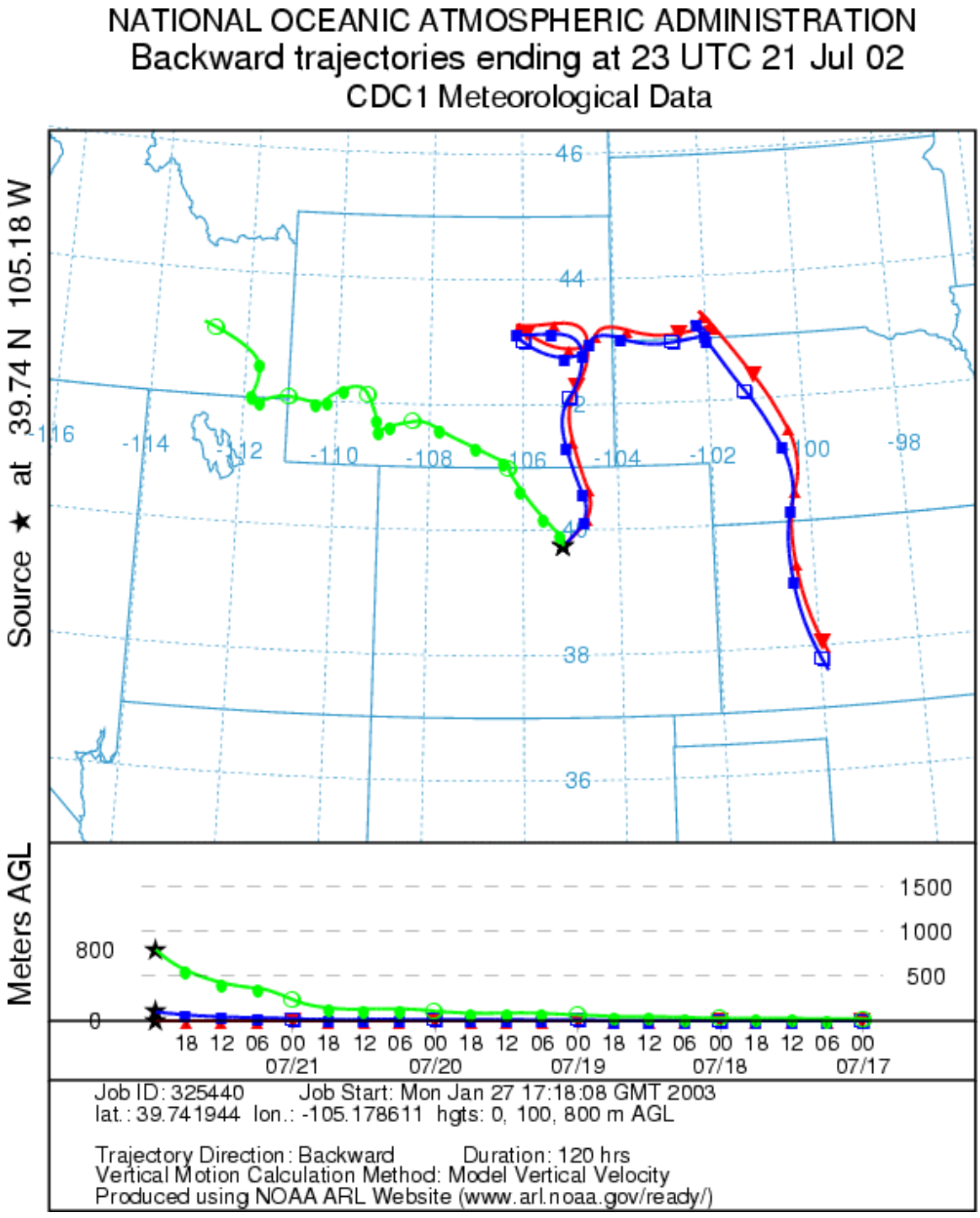


Figure 1.B: Thirty-six Hour Trajectory Plot for July 18 , 2002

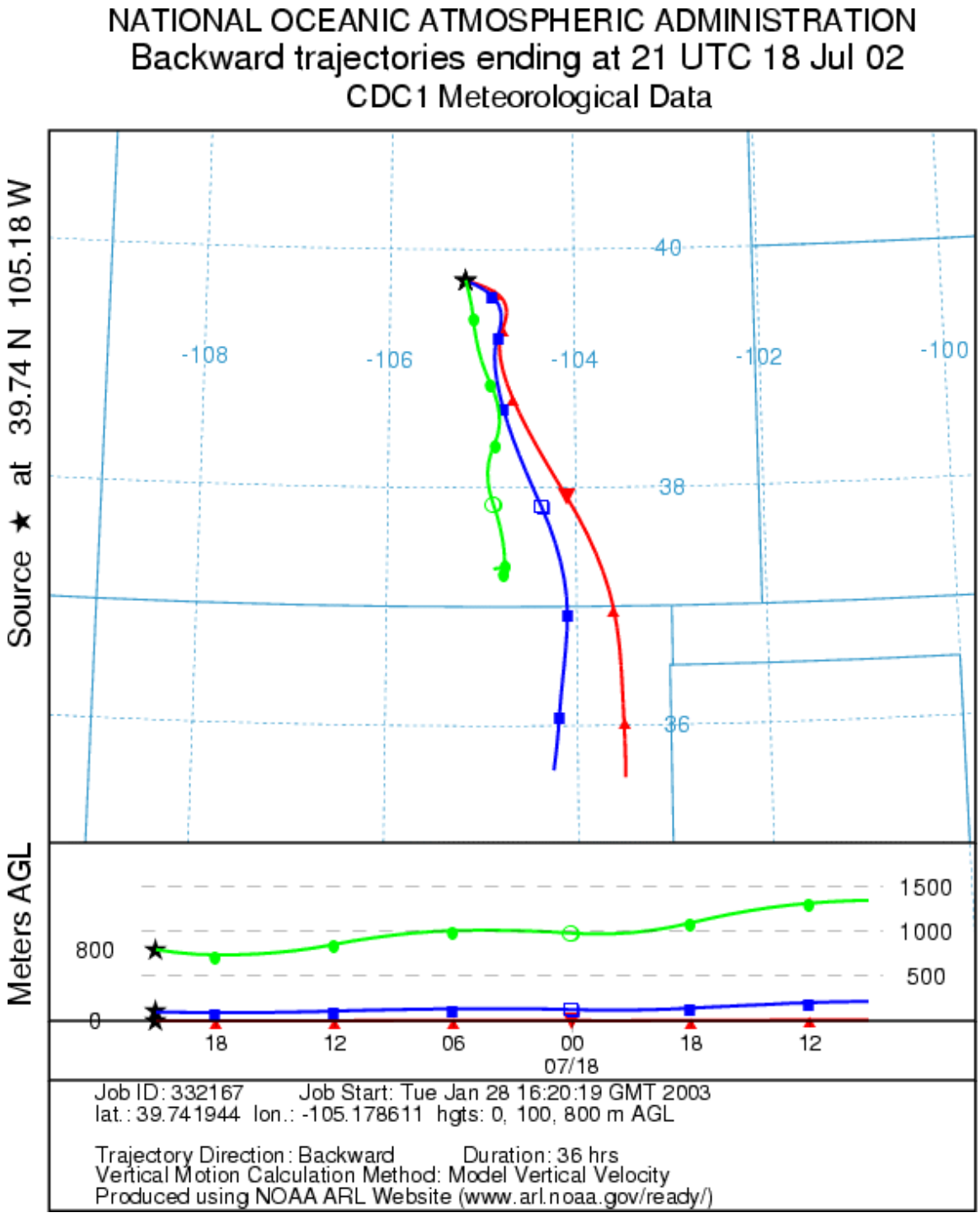


Figure 1.C: Thirty-six Hour Trajectory Plot for July 19 , 2002

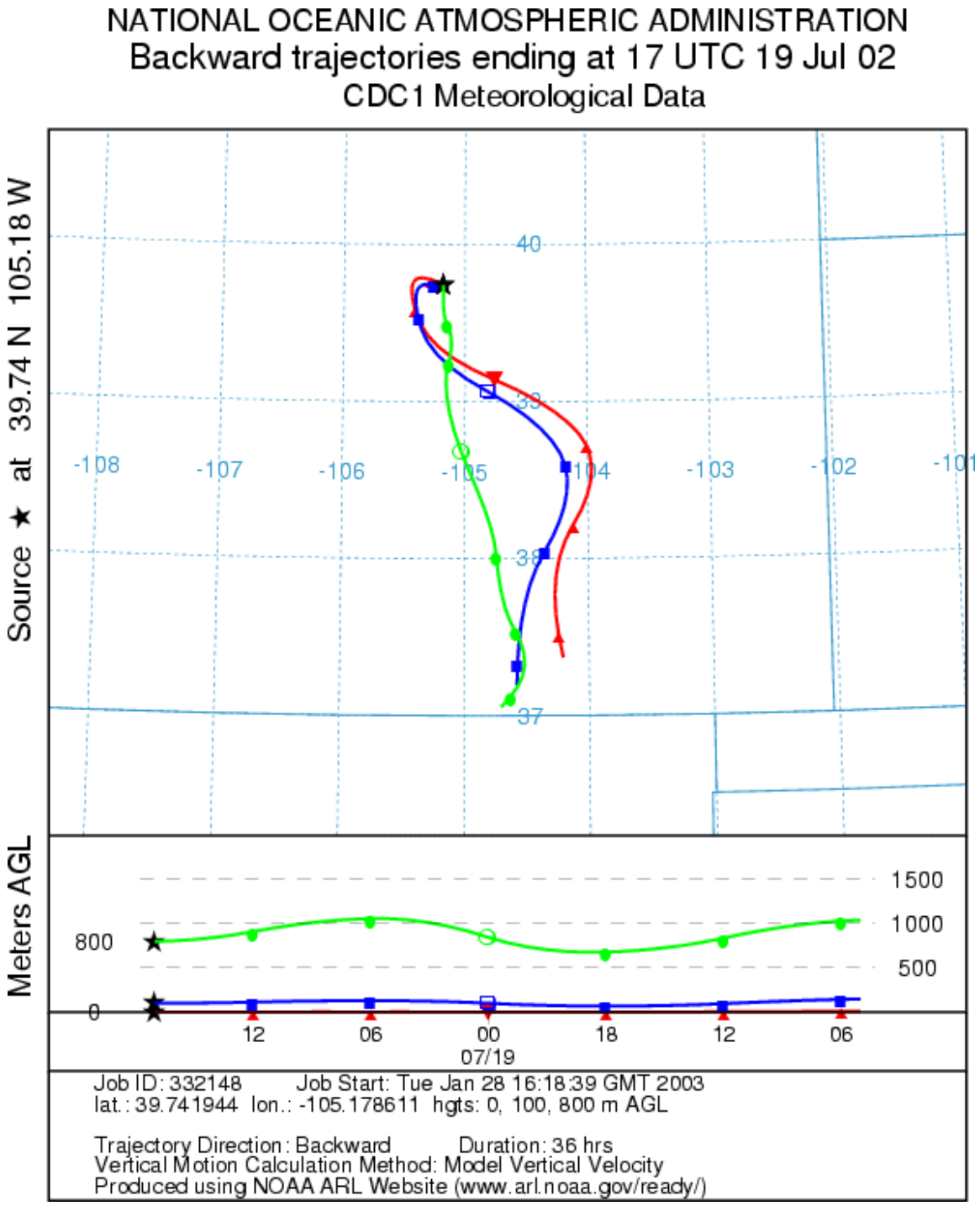


Figure 1.D: Thirty-six Hour Trajectory Plot for July 20 , 2002

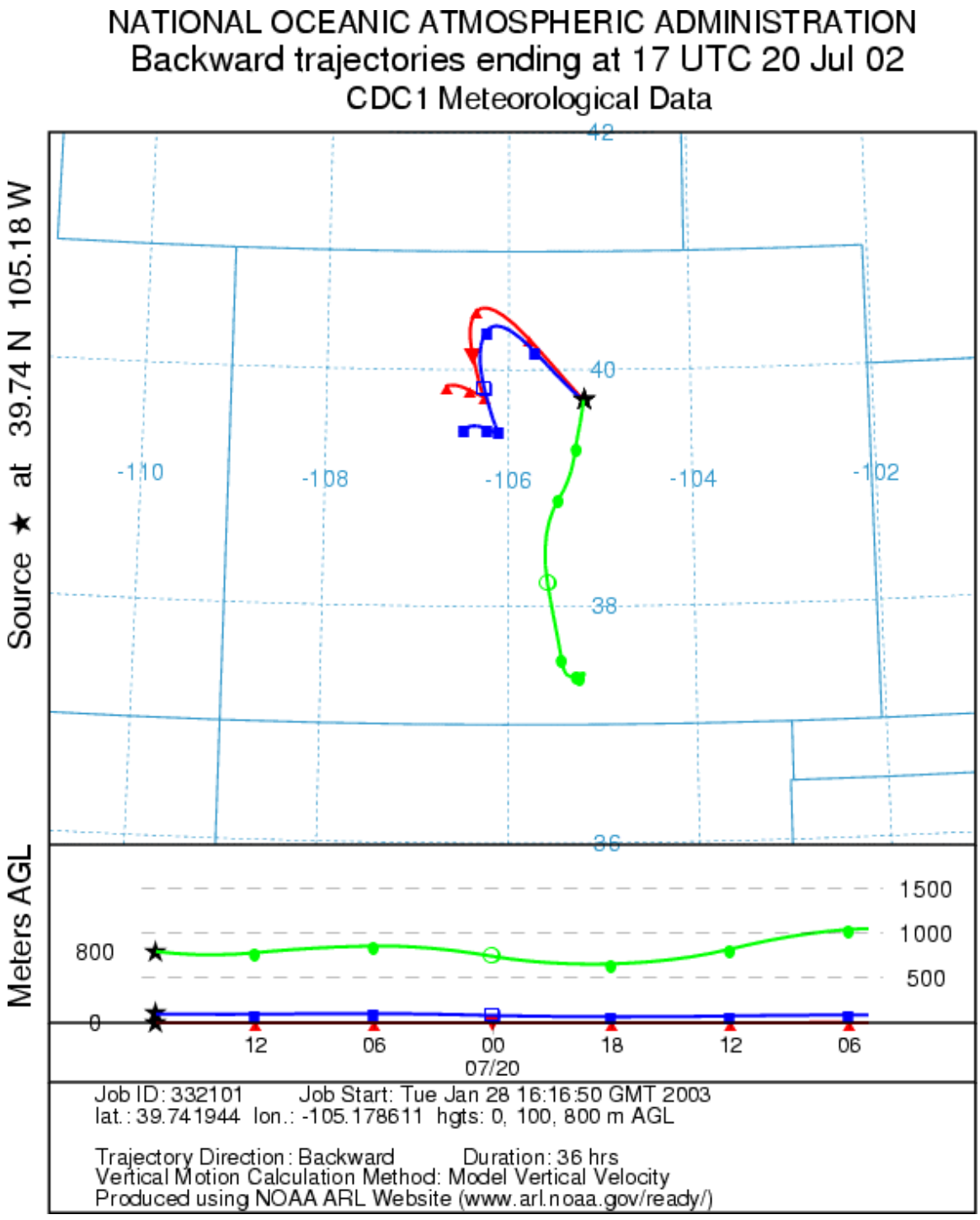
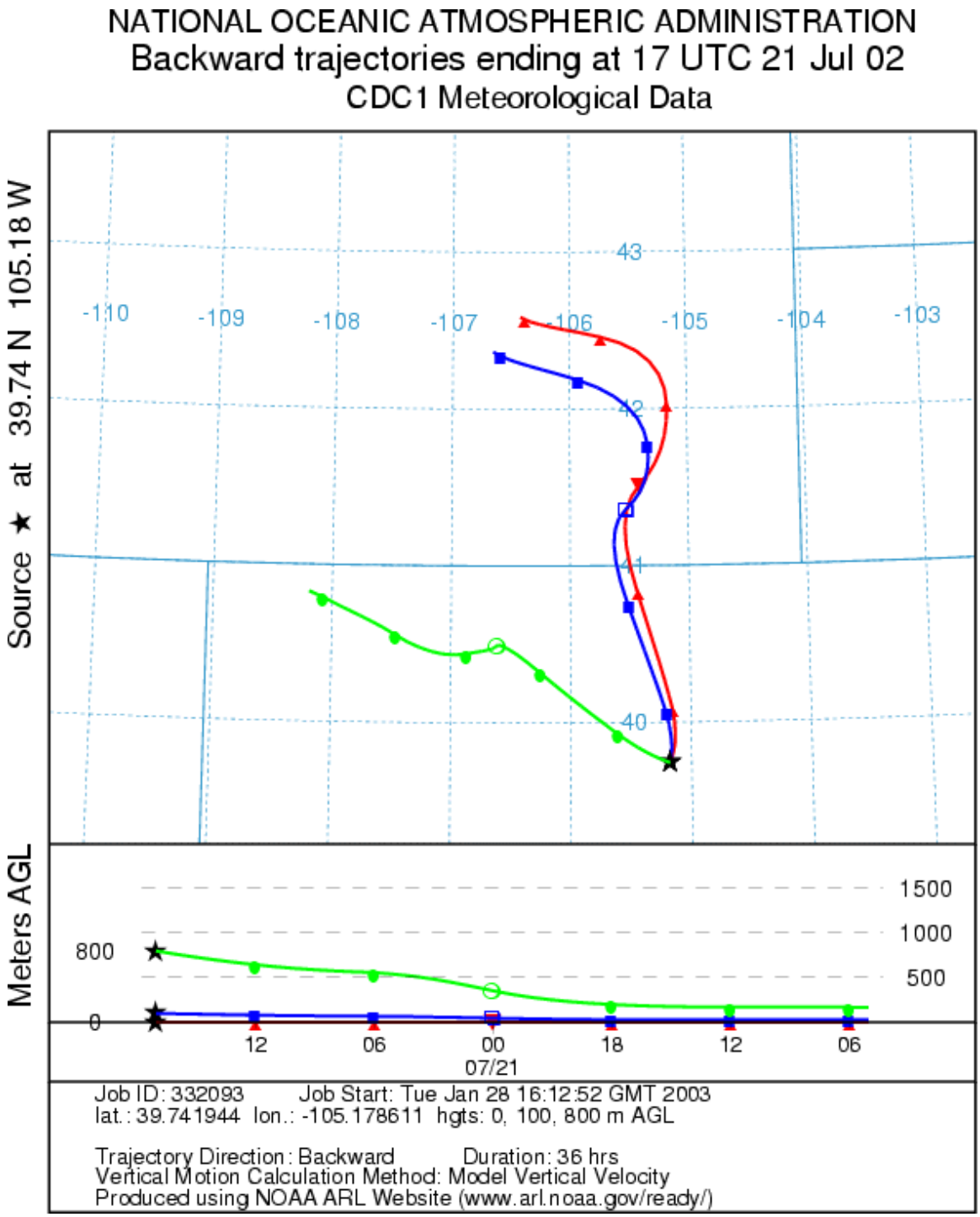


Figure 1.E: Thirty-six Hour Trajectory Plot for July 21, 2002



June 25-July 1, 2002

This episode was lengthy when compared to the other episodes. There were seven days in a row where at least one monitored exceeded 80 ppb. This episode had the highest 8-hour average ozone concentration recorded at Rocky Mountain National Park of 93 ppb recorded on June 30. Three days had at least one monitored concentration that exceeded 85 ppb. On June 29, Rocky Flats North recoded an 8-hour average concentration of 89 ppb. However the rest of the monitores in the network had values less than 80 ppb on this date. On June 30, Rocky Mountain National Park recorded a 93 ppb and Rocky Flats north recorded a value of 88 ppb. Both NREL and South Boulder County had 8-hour ozone concentrations of 80 ppb.

The highest ozone concentration occurred in southwest Denver on July 1 where Chatfield recorded a value of 94 ppb. This is the highest ozone concentration recorded over the entire network during the 1999-2002 periods. Highlands Ranch also exceeded the 8-hour ozone concentration at 86 ppb. Values greater than 85 ppb were also recorded at Rocky Flats North (88 ppb), NREL (91 ppb), and Rocky Mountain National Park (85 ppb). A value of 82 ppb was recorded at the Weld County Tower.

It should be noted that several large wildfires were burning during this period including the Rodeo Fire in Arizona, the Mission Ridge Fire near Durango, the Hayman Fire near Denver, and other fire complexes in western Colorado. Flow during the later parts of this episode, as indicated by the trajectory plots, blew from one or more of these large fires.

Meteorological Analysis

A stretch of 13 consecutive days of 90 degree F or more occurred from June 21 through July 3. The maximum temperature exceeded 95 degrees F on June 26 (96^{o}F), June 29 (27^{o}F), and July 1 (99^{o}F).

On June 25, a warm upper ridge dominated the southwest United States including Colorado through the period. Mid-level winds were weak north to easterly (upslope) to about 700 mb. Surface dew points were fairly moist at 40 to 50 degrees F. Winds aloft were weak and convective storm motion was slow.

The upper level ridge remained intact along the Rockies from Mexico to southern Canada on June 26. Winds from the surface to 600 mb were light and from the east. The eastern plains had a fairly moist air mass (50 degree F dew points) but the stable atmosphere prevented much in the way of thunderstorms on the plains. Cooler air had advected into the 700 to 500 mb levels. Surface winds to 700 mb were more northly and a bit stronger than the day before. The upper level ridge was slightly weaker than the day before and more disorganized but little movement was detected. Winds aloft were weak with slow moving convective storms.

The high-pressure ridge was again in control of the state on June 27. Surface southeast flow on the plains provided for slightly drier air. Convective storms that developed in the mountains died off quickly over the drier and capped air mass over the plains.

Friday, June 28 continued the same weather pattern. The air mass was dry and capped over the eastern plains. Any convective storms that developed over the mountains, quickly dissipated over the eastern plains except for a few very slow moving storms. Heavy rain occurred in some areas because of the slow moving storms. The Platteville profiler indicated light and variable winds from the surface on up.

A convergence zone formed from southeastern Douglas County through eastern Adams County on the afternoon of Saturday, June 29. The convergence zone separated very dry air coming off of the foothills from moist (45-55 degree F) dew points to the south and east. Flow aloft was stronger and more organized than on previous days. The flow aloft was also more from the west and northwest than on the previous days. Despite a dry cold front sliding southward through eastern Wyoming, overnight temperatures did not fall much below 70 degrees F until the early morning hours.

Sunday, June 30 and Monday, July 1 had the highest ozone concentrations over the episode. On Sunday, the air mass over northeastern Colorado was very dry and stable following the cold front passage. Subsidence from the already warm and dry air mass pushed temperatures near the century mark over much of eastern Colorado. A mid-level inversion prevented any thunderstorms from building on the eastern plains. Moderate levels of smoke from several fires burning in the west (Hayman, Missionary Ridge, Rodeo in Arizona, and Million Fire) were reported along the northern Front Range.

Monday, July 1 was more of the same. Strong mid-level subsidence over the northeastern plains continued to dominate the local weather pattern. High ozone readings were widespread over the network.

Ozone levels decreased on July 2 and 3 with temperature continuing over 90 degrees F. Gulf moisture moved into the area across the mountains and foothills. A weak cap around 500 mb was still present over the area. Surface winds shifted to the northeast. No real strong reasons why the ozone episode did not continue on July 2 and 3.

Trajectory Analysis

Figure 2.A indicates that this episode was strongly influenced by flow from the southwestern United States including southern California and Arizona. Subsidence over Colorado mixes surface and 800m layers down to the surface by the time they reach the Front Range.

As indicated in Figures 2.B through 2.E, the flow from June 25 through June 28 was generally from the south. Winds during this period were light at all levels, especially on June 25. During this period, ozone concentrations were the lowest during the episode.

On June 28, winds became stronger from the south. Upper levels winds at 800m started to shift from the southwest. On June 29 through July 1, winds at 800m were from the southwest, originating in Arizona and Utah. Surface winds were light during this period originating from the west and southwest.

Figure 2.A: Composite Trajectory Plot for June 24 – July 1, 2002

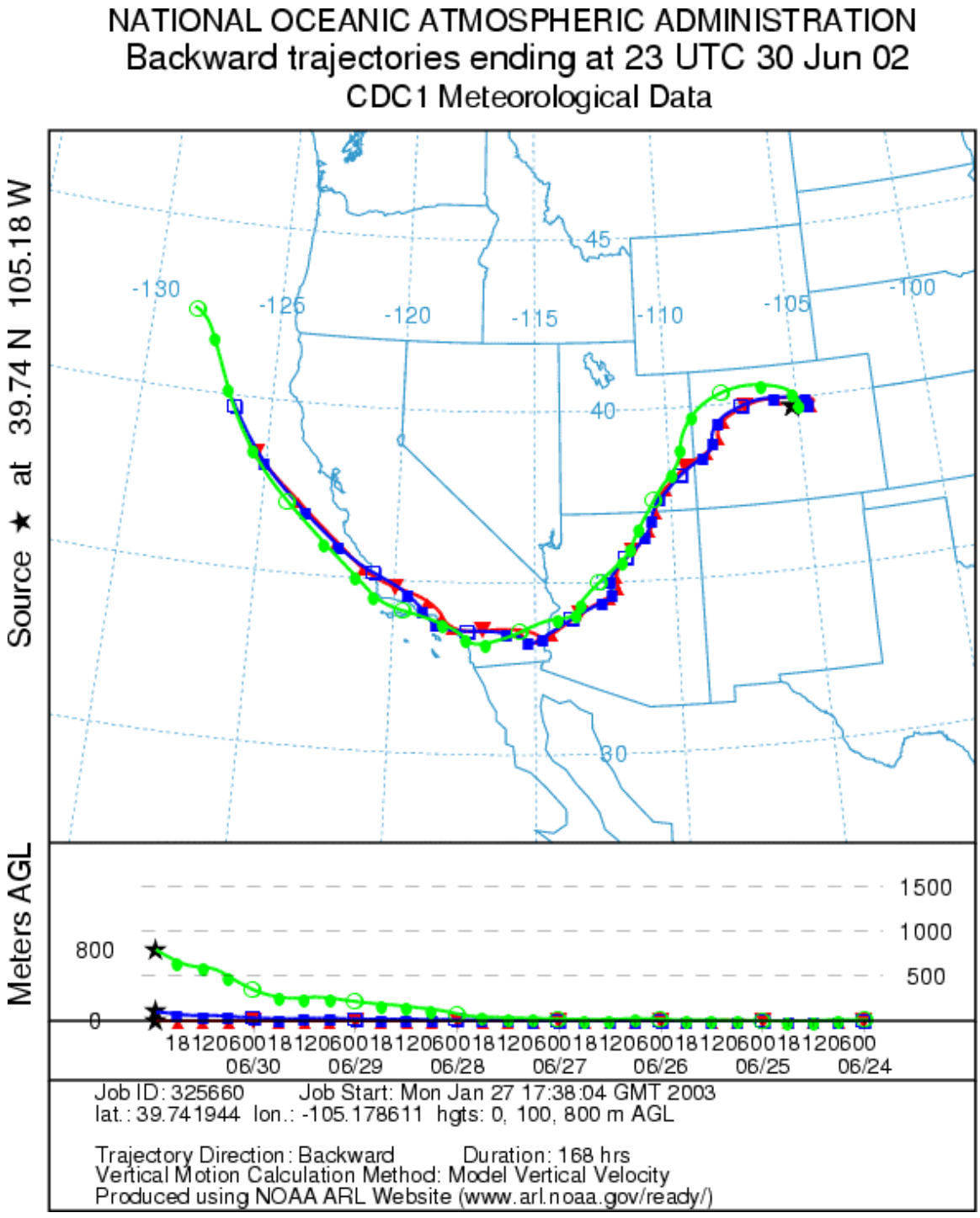


Figure 2.B: Thirty-six Hour Trajectory Plot for June 25, 2002

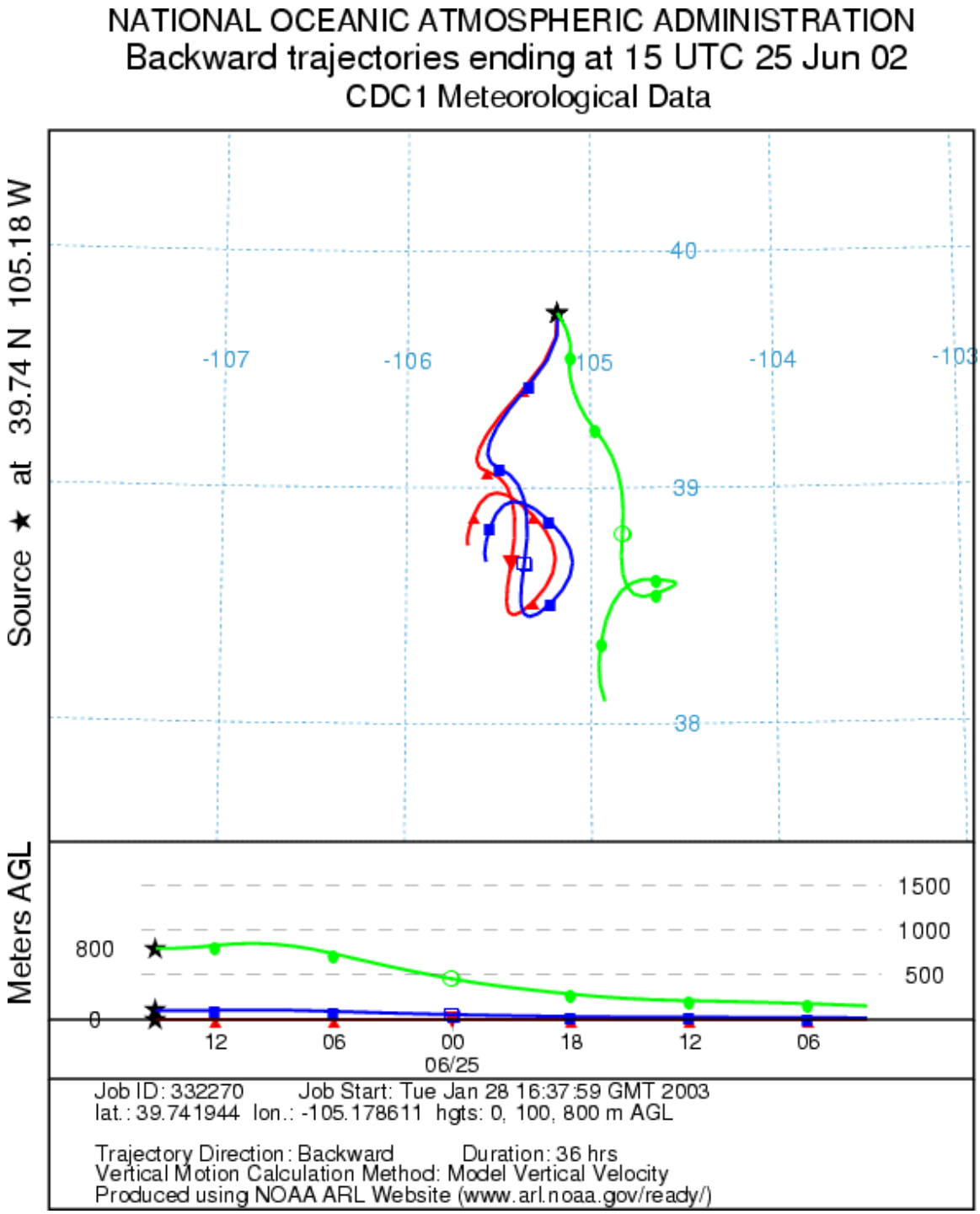


Figure 2.C: Thirty-six Hour Trajectory Plot for June 26, 2002

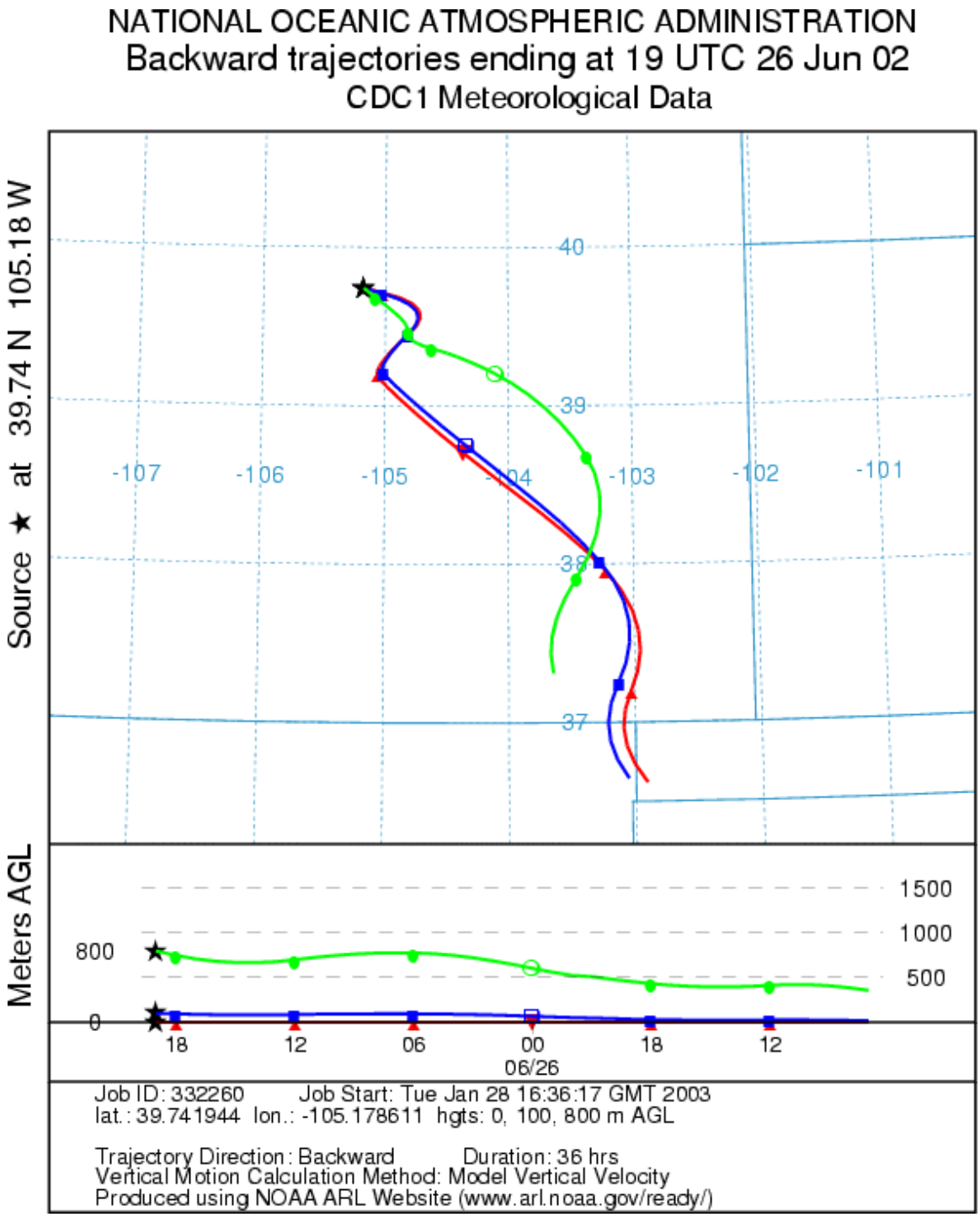


Figure 2.D: Thirty-six Hour Trajectory Plot for June 27, 2002

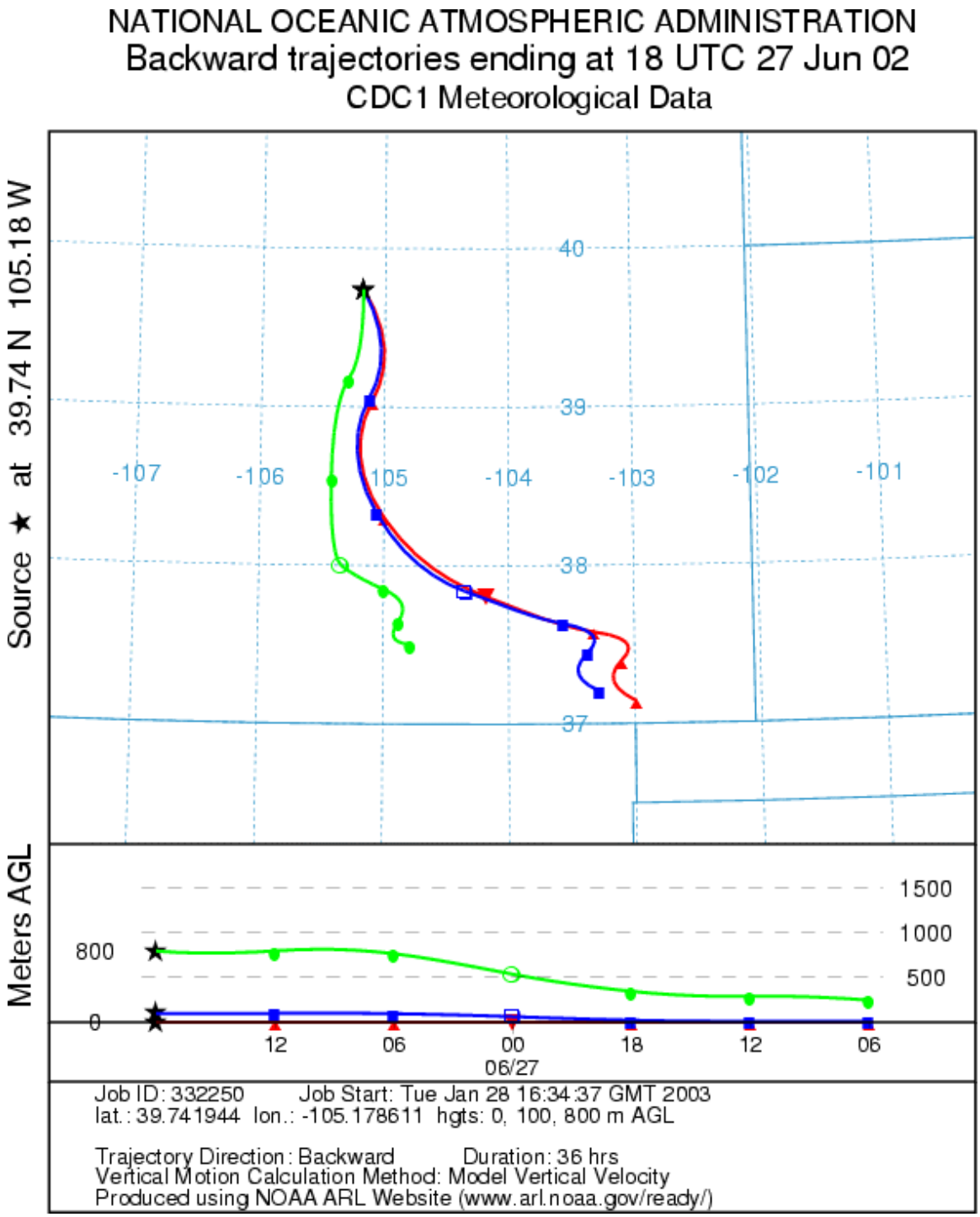


Figure 2.E: Thirty-six Hour Trajectory Plot for June 28, 2002

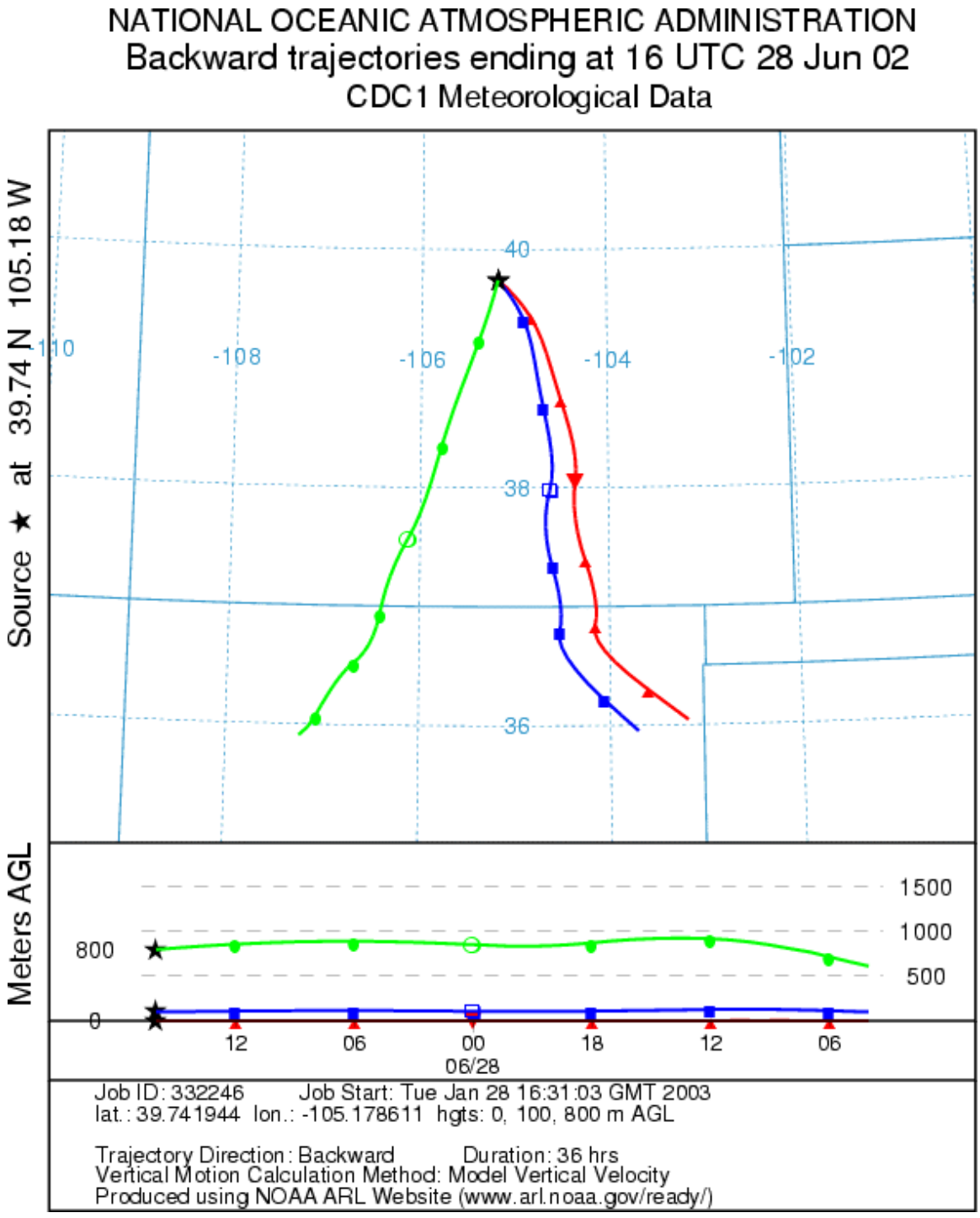


Figure 2.F: Thirty-six Hour Trajectory Plot for June 29, 2002

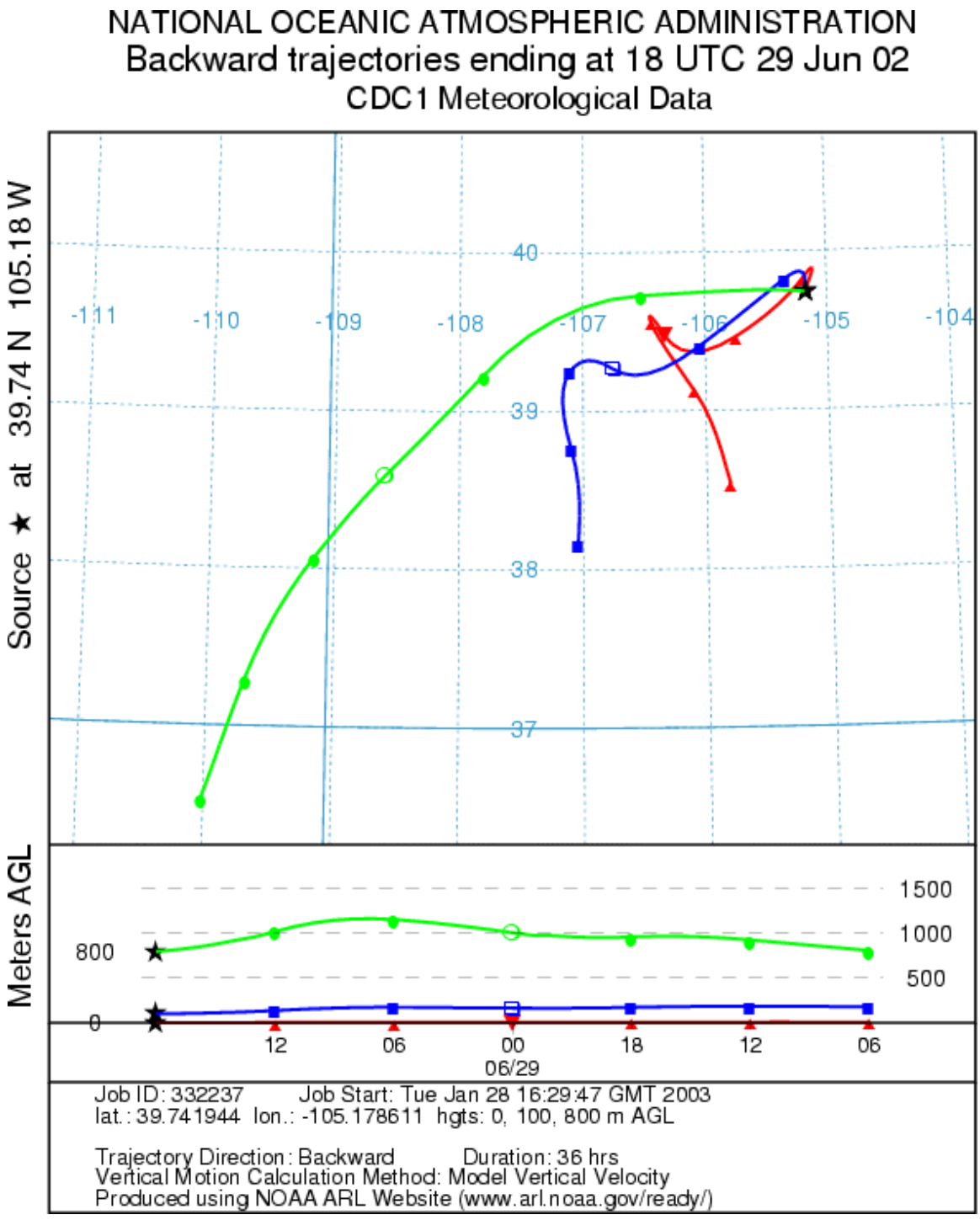


Figure 2.G: Thirty-six Hour Trajectory Plot for June 30, 2002

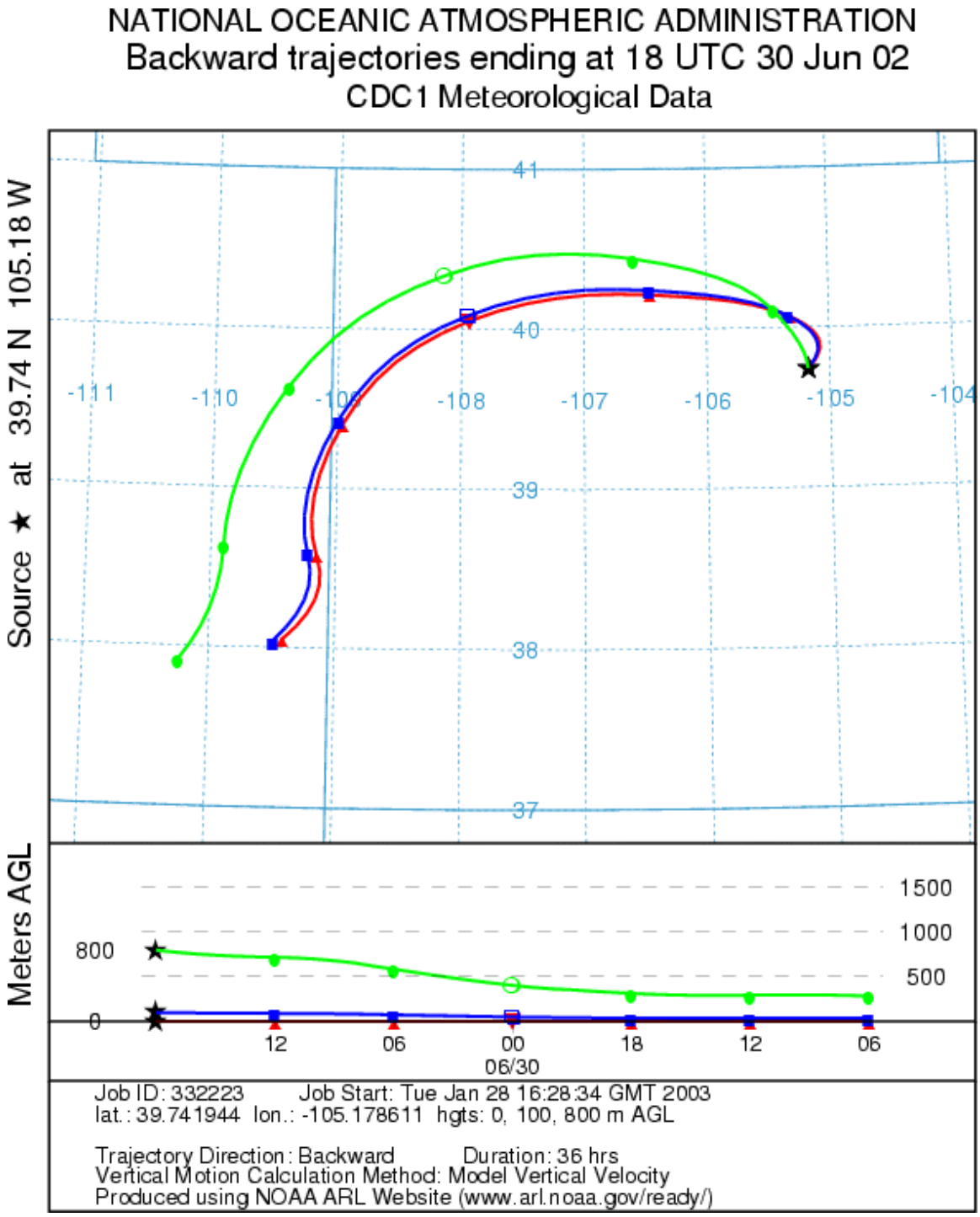
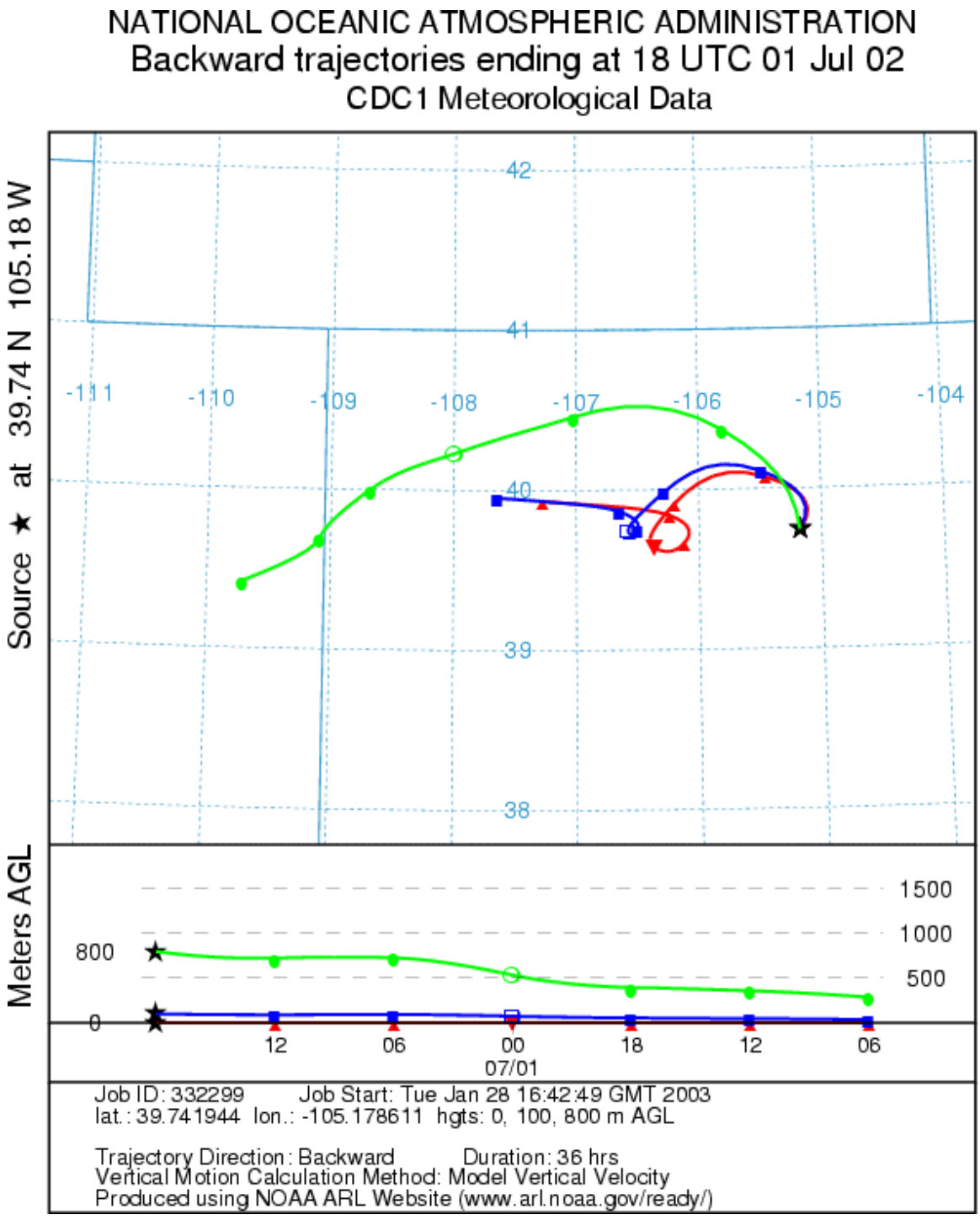


Figure 2.H: Thirty-six Hour Trajectory Plot for July 1, 2002



June 8-12, 2002

This period occurred just three days after the start of the Hayman fire. Very warm temperatures along with smoky conditions characterized this episode. Concentrations of 88 ppb occurred on two days, June 8 and 9, at Rocky Flats North. A value of 88 ppb were recorded at NREL on June 9 as well. A value of 83 ppb occurred at Rocky Mountain National Park on June 11 and at Rocky Flats North on June 12. During this episode, other monitors in the network were all below 80 ppb indicating that this episode was not widespread.

Meteorological Analysis

June 8 and 9, when the highest ozone readings occurred, the maximum temperature reached 96 degrees F and 95 degrees F, respectively. Despite cooler temperature on June 11 and 12, ozone readings above 80 ppb were monitored on these days. The maximum temperatures recorded on June 11 and 12 were 78 degrees F and 82 degrees F, respectively. Ozone readings were below 80 ppb on June 10 when the maximum-recorded temperature was 75 degrees F.

On June 8, shallow moist air covered most of eastern Colorado during the morning hours. This moist air mass mixed out as the day progressed. Very little convective activity occurred over the mountains and northeastern plains.

Smoke from the Hayman fire was observed over the Denver area on June 9. A weak short wave passed north of the area during the evening hours. As a result of the short wave passage, winds aloft shifted to a westerly direction. The inversion layer lowered to about 2000 feet overnight.

Much colder air moved into the area on June 10 with the maximum temperature in Denver recorded at 75 degrees F. Consequently, no ozone readings exceeded 80 ppb. Winds had shifted to the southeast for most of the day.

An inversion persisted for most of the day on June 11. The height of the inversion was around 18 thousand feet. Although ozone readings were low network wide, Rocky Mountain National Park had a reading of 83 ppb.

An ozone reading of 83 ppb was recorded at Rocky Flats north on June 12. Except for smoke in the area from the Hayman Fire, very little else can be said about this day. Warm temperatures over the mountains with cooler temperatures over the plains were indicative of a persistent inversion over the area.

Trajectory Analysis

The composite trajectory presented in 3.A indicated that the air parcels originated in very different areas at the three levels over the 120-hour simulation. At the surface, the flow was from the south from Texas, at 100m the flow was from the southwest from Arizona, and at 800m the flow was from the northwest from Salt Lake City.

The 36- hour plots indicated the flow was from the southwest from Arizona on June 8th through June 10th at all levels. Figures 3.B through 3.D indicate that the southwesterly flow was fairly strong originating in Arizona and southern California at the start of each 36-hour period.

On June 11 and 12, the flow became more westerly at 800m. Figure 3.E indicates that the surface flow was from the Nebraska panhandle on June 11. The northeasterly flow was much less on this date. By June 12 the surface flow had shifted to the southwest with fairly light wind speeds.

Figure 3.A: Composite Trajectory Plot for June 7 – June 12, 2002

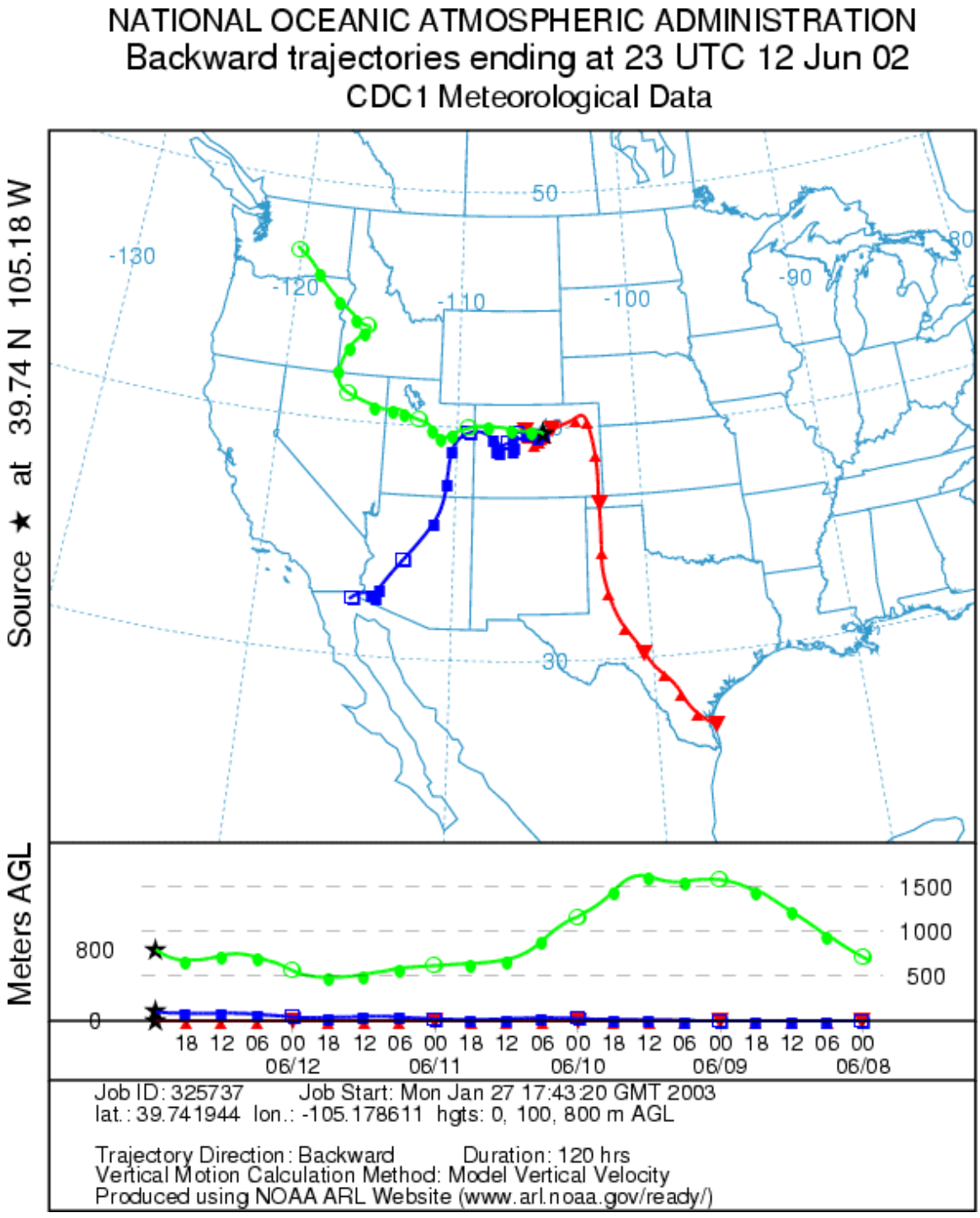


Figure 3.B: Thirty-six Hour Trajectory Plot for June 8, 2002

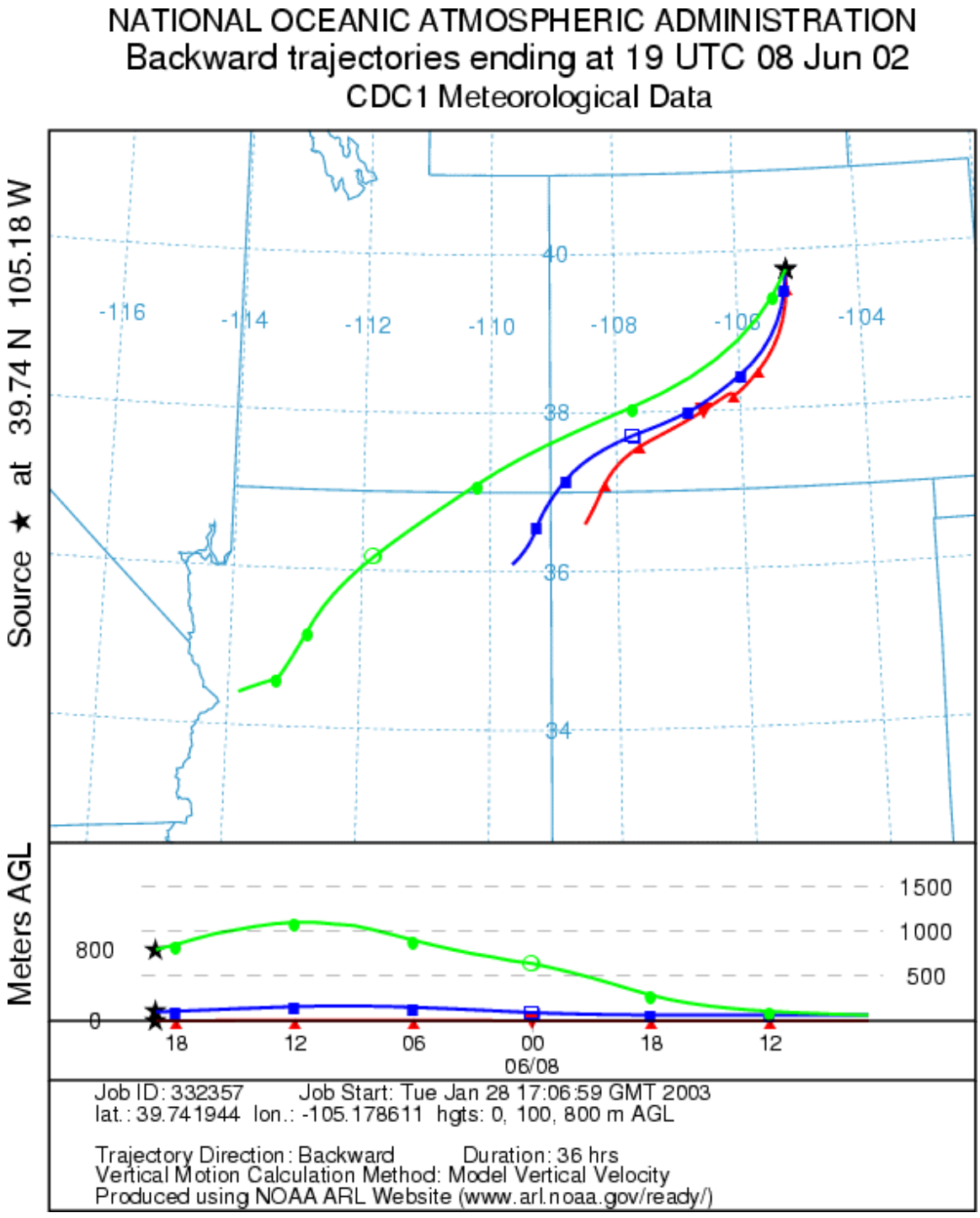


Figure 3.C: Thirty-six Hour Trajectory Plot for June 9, 2002

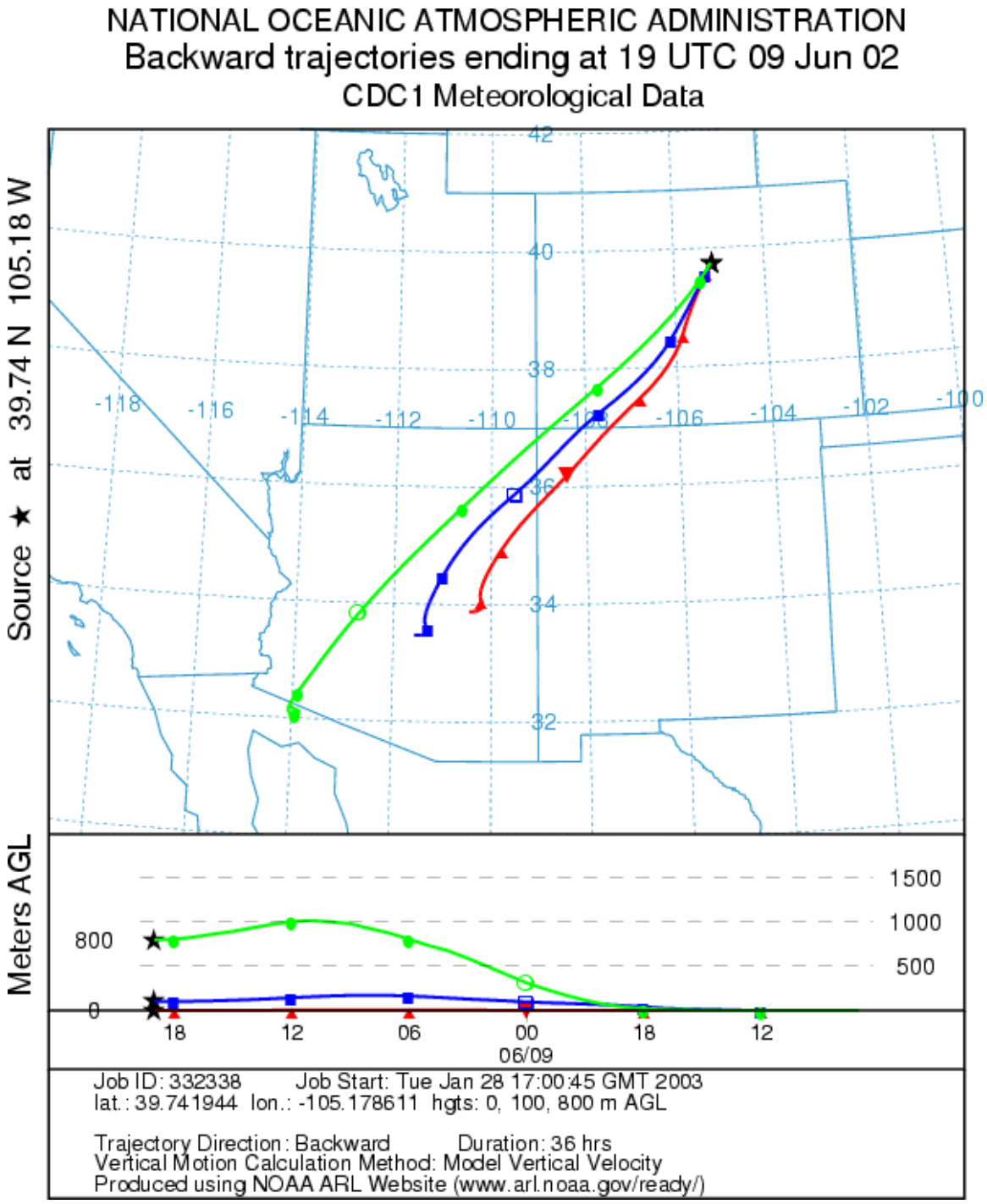


Figure 3.D: Thirty-six Hour Trajectory Plot for June 10, 2002

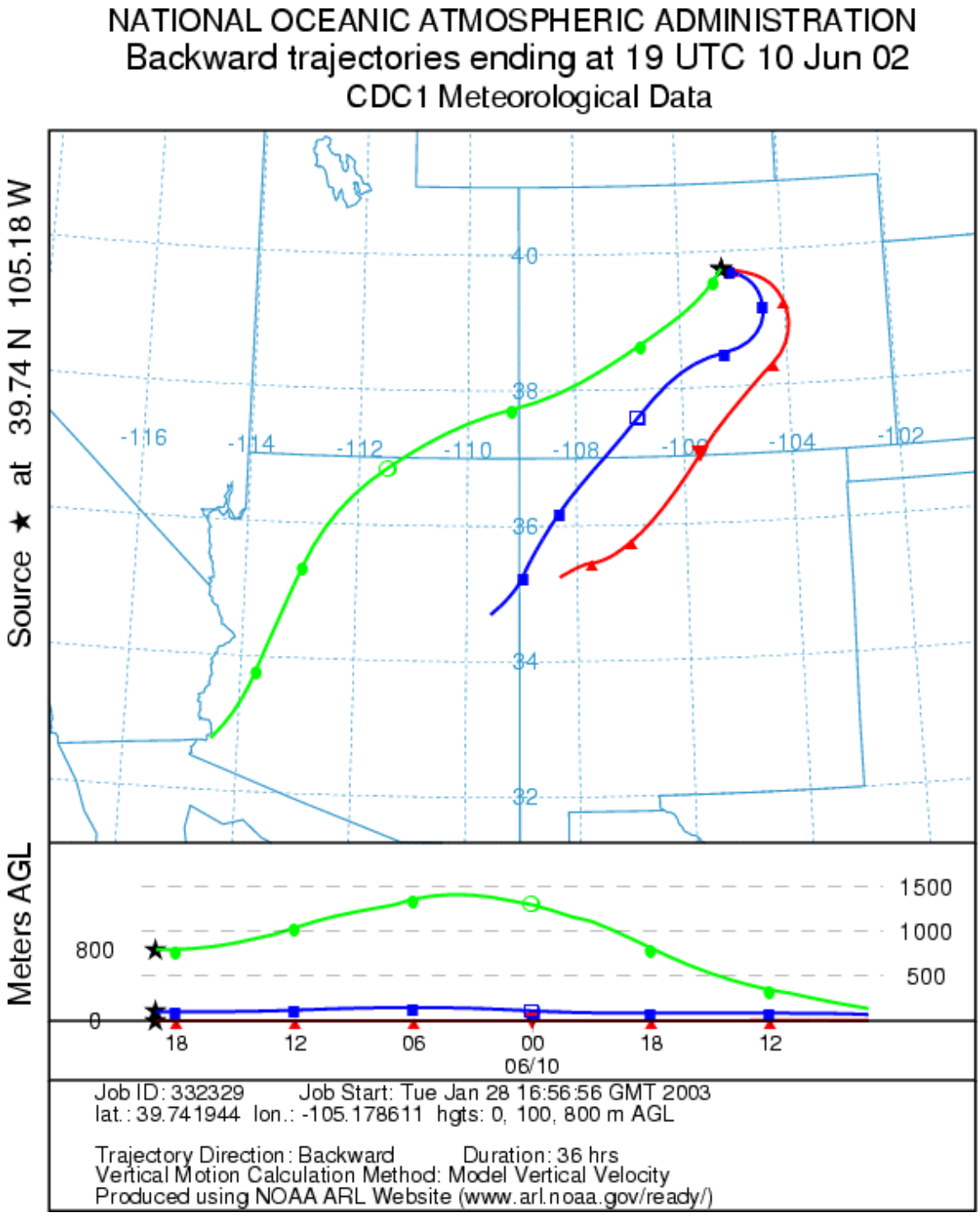


Figure 3.E: Thirty-six Hour Trajectory Plot for June 11, 2002

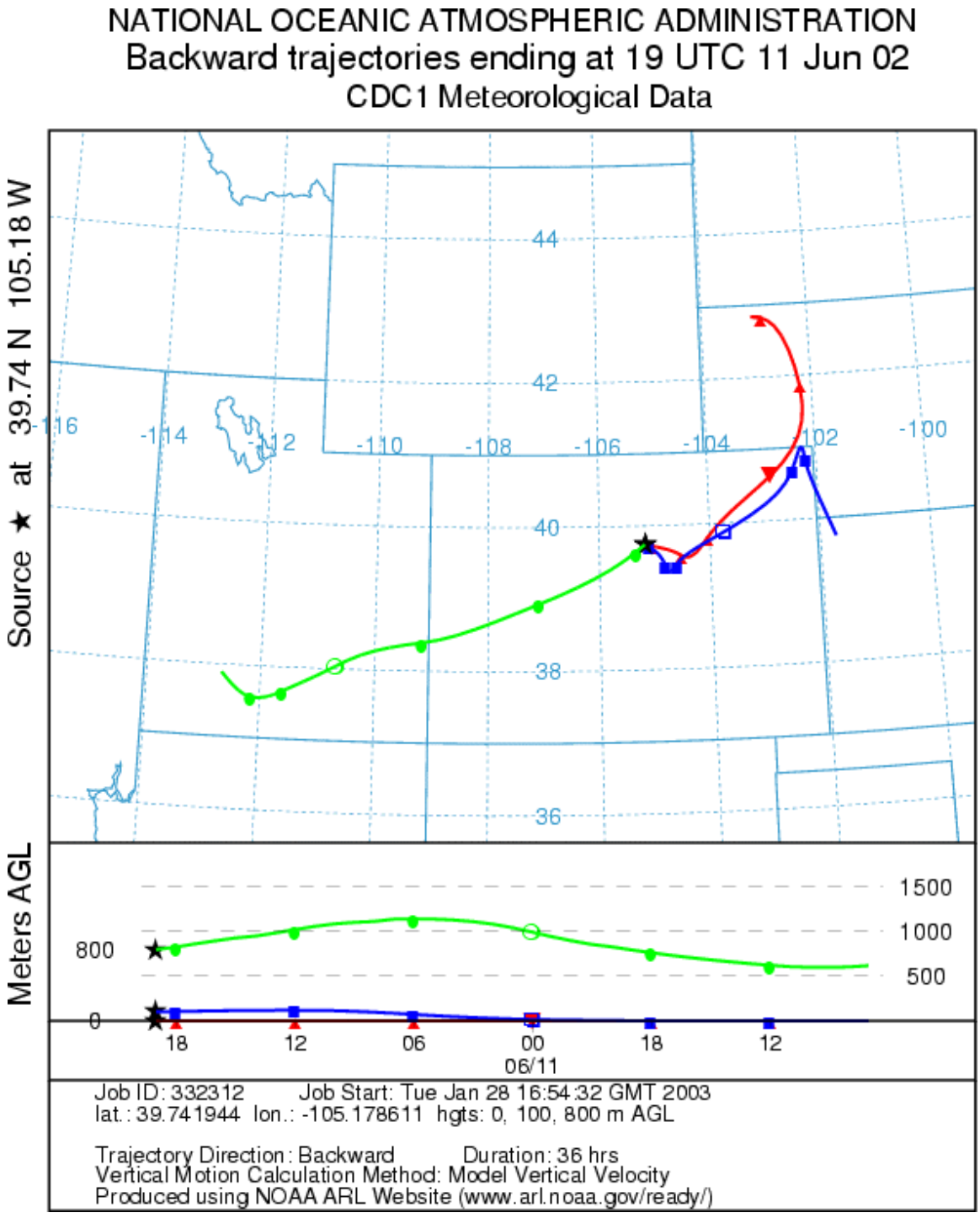
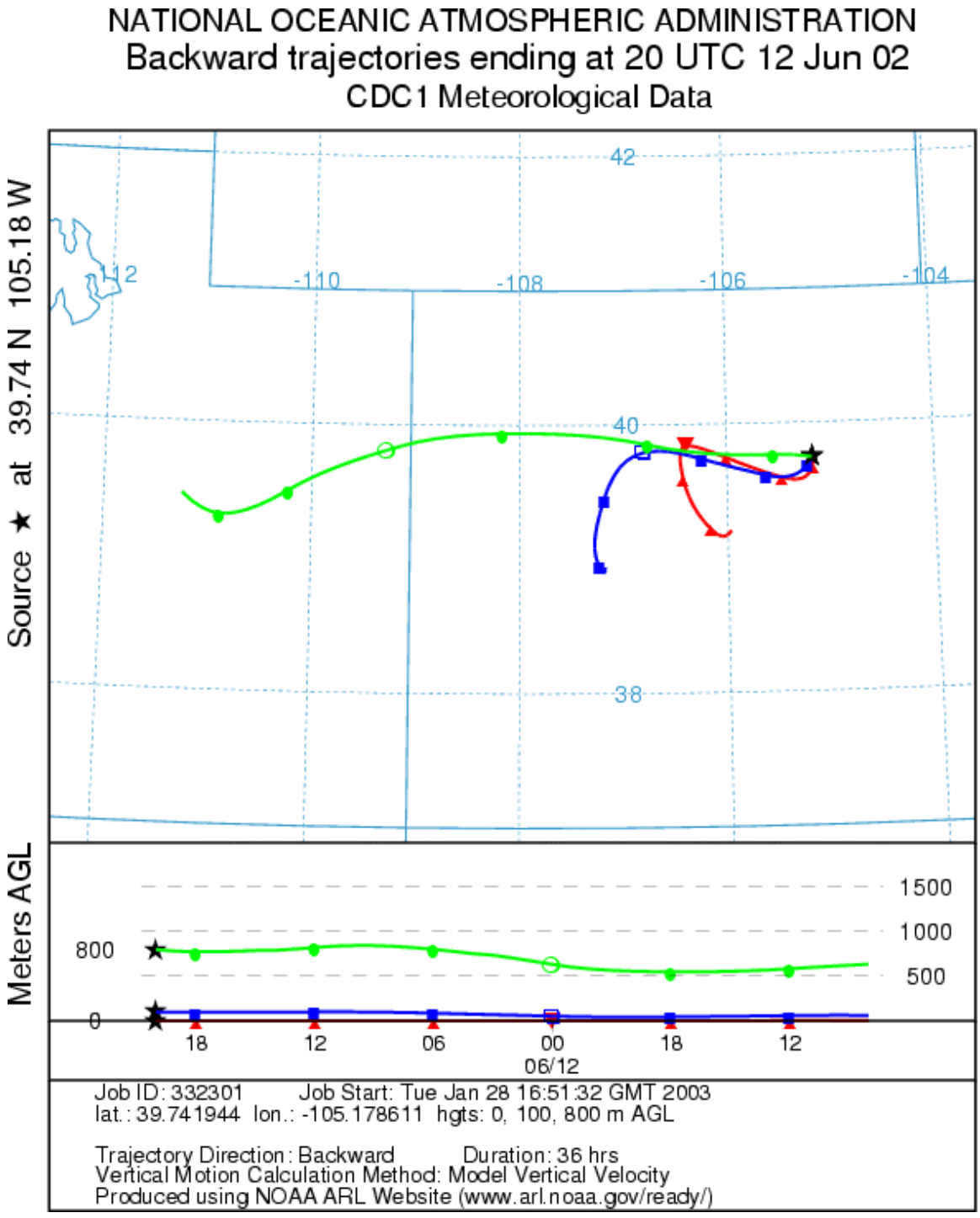


Figure 3.F: Thirty-six Hour Trajectory Plot for June 12, 2002



August 3-4, 2001

This was a short two-day episode where the maximum ozone concentration occurred at NREL (90 ppb) on August 4. Although several monitors were over 80 ppb on August 4, monitored values were less than 85 ppb. Concentrations on August 3 were comparable low with 82 ppb at Rocky Flats North and 80 ppb at Rocky Mountain National Park.

Meteorological Analysis

Maximum temperature on August 3 and 4 were 92^{O}F and 90^{O}F, respectively. Generally, the winds aloft were very weak over this two day period with an upper level inversion. Given the weak upper winds and inversion, convective activity was suppressed. However, the atmosphere was fairly moist with about of inch of precipitable water available if a thunderstorm did break out. Smoke along with good thunderstorm activity was observed on August 2.

The moist air mass was pushed to the southeast on August 5 as a high pressure ridge built over the area and persisted through August 8.

Trajectory Analysis

The 72-hour trajectory plot presented in Figure 4.A indicates that flow at 800m originated from Arizona. Flow at the surface originated from the four-corners area. This general pattern was repeated in Figures 4.B and 4.C. The 36-hour trajectory plots from August 3 and 4 originated over the four-corners area.

Figure 4.A: Composite Trajectory Plot for August 2 – 4, 2001

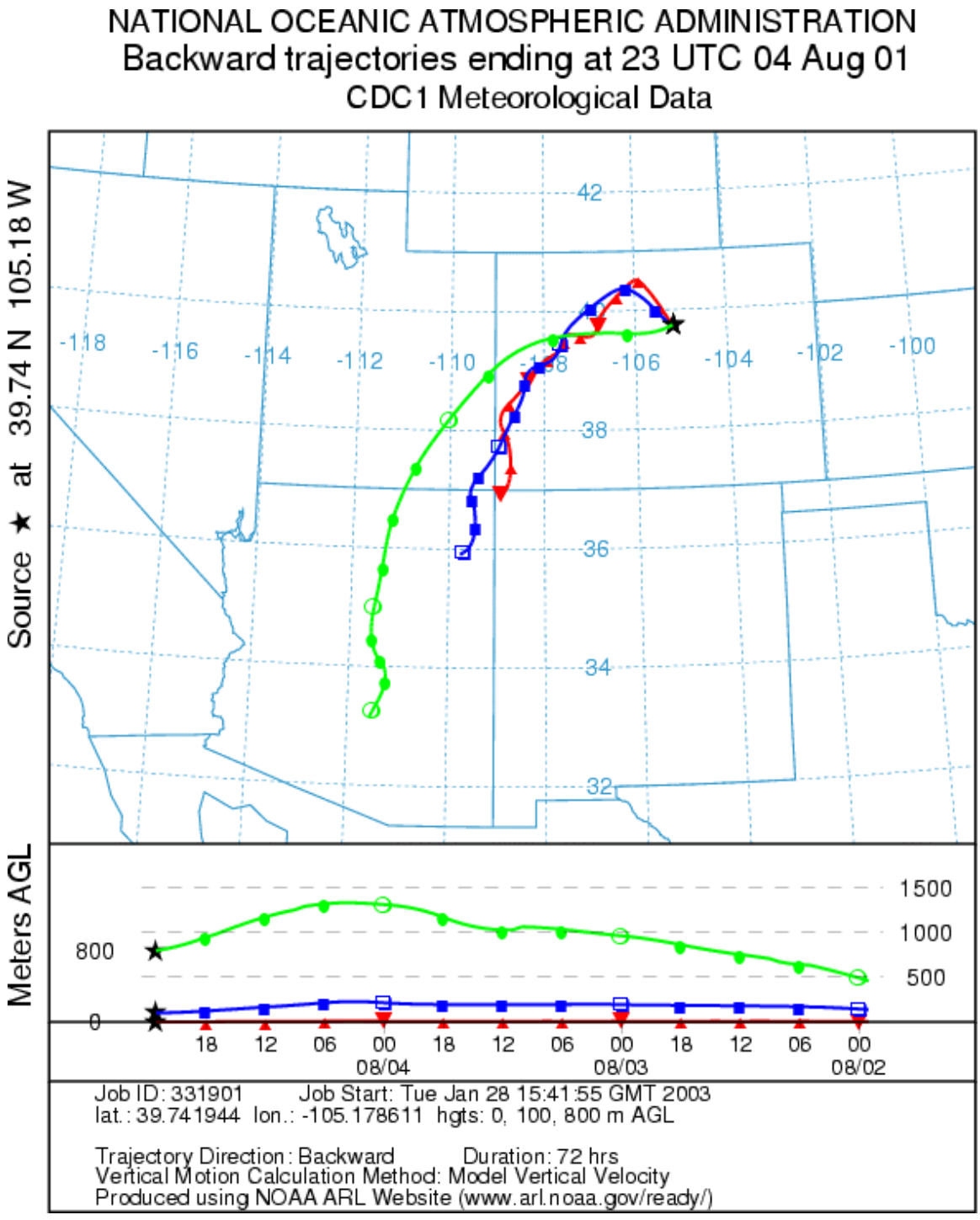


Figure 4.B: Thirty-six Hour Trajectory Plot for August 3, 2001

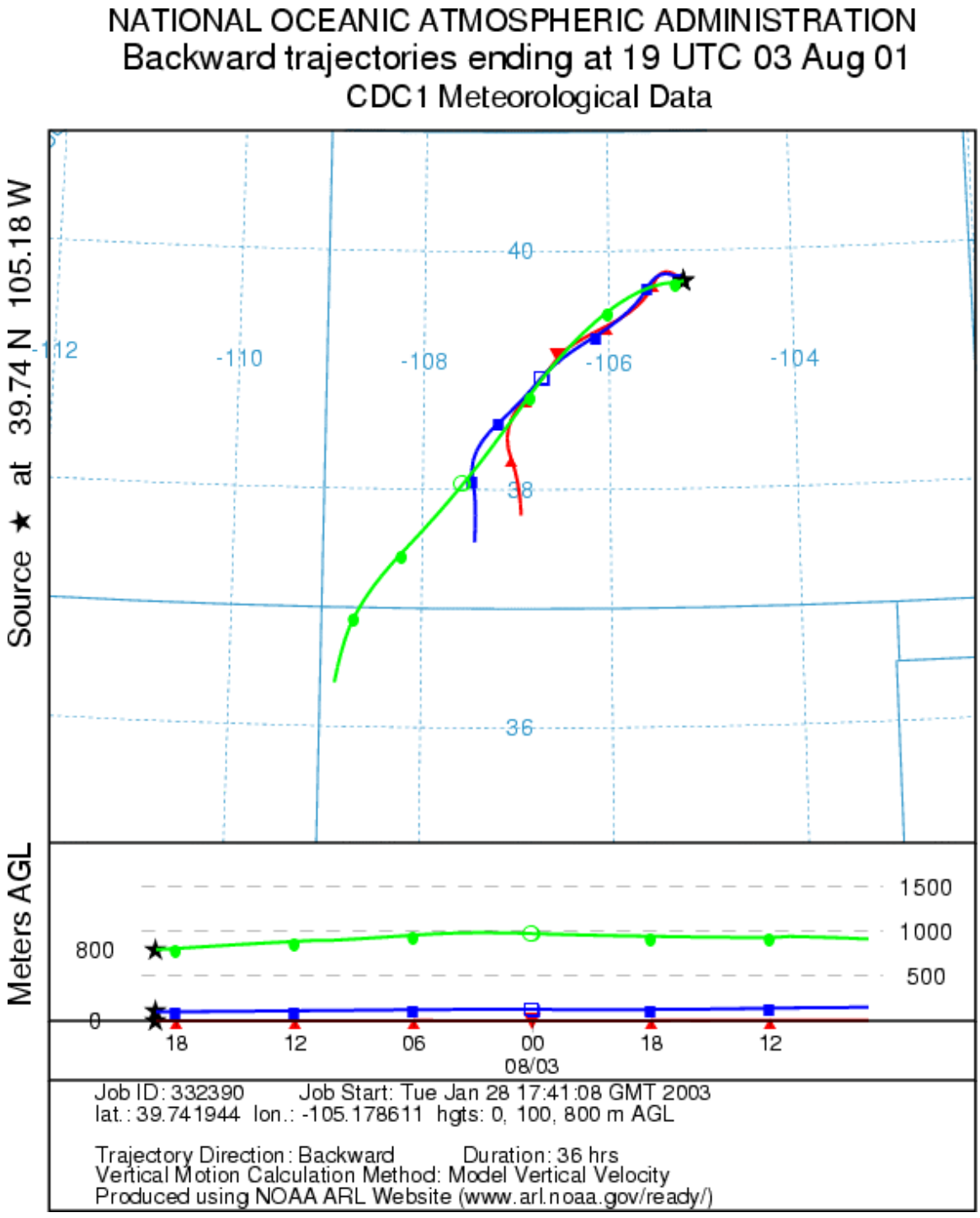
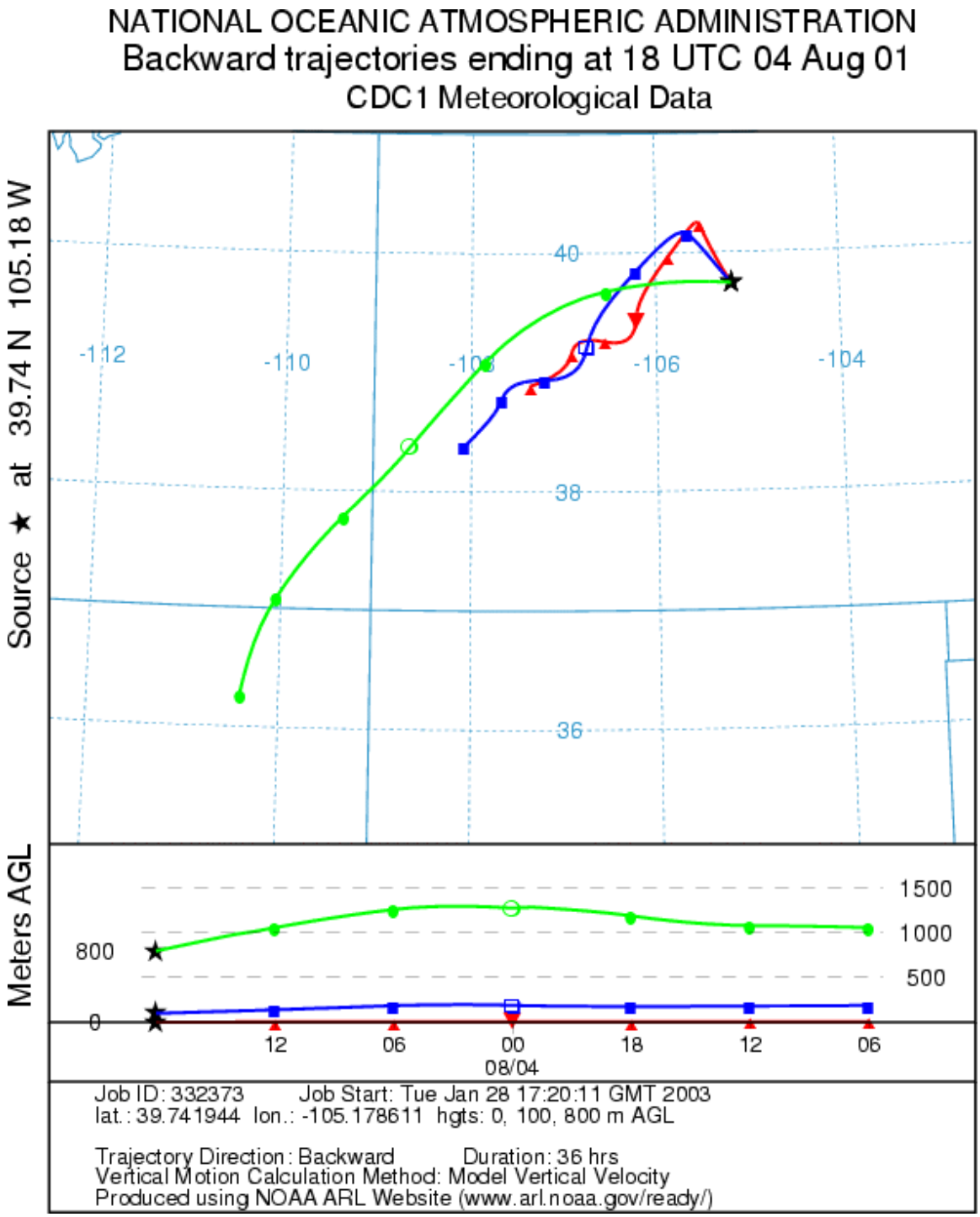


Figure 4.C: Thirty-six Hour Trajectory Plot for August 4, 2001



July 4-9, 2001

Moderate to heavy rain from thunderstorms fell during this period. Ozone concentrations were below 85 ppb at all monitors except for a 89 ppb recorded at Chatfield on July 5. Rocky Flats had a monitored concentration of 87 ppb on July 5.

Meteorological Analysis

A string 10 consecutive days with maximum temperatures of 90 degrees F or more occurred on June 29 through July 8. Temperatures exceeded 95 degrees F on July 1 (101 ^{O}F), July 2 (97 ^{O}F), July 4 (96 ^{O}F), July 5 (98 ^{O}F), and July 6 (96 ^{O}F). During this period maximum ozone values exceeding 80 ppb occurred on July 4 (RFN-81 ppb), July 5 (Chatfield-89 ppb), July 7 (NREL-83 ppb), and July 9 (RFN-84 ppb). Smoke was observed in the area on July 3, July 7, July 8, and July 9.

Even though temperatures were hot during this period, significant thunderstorm activity may have inhibited the 8-hour ozone averages over the period. Timing of when thunderstorm activity occurred versus the peak ozone hours was critical during this period.

A weak cold front pass over northeast Colorado on July 3 that produced significant subsidence over the area. A ridge of high pressure rebuilt over the area on July 4. This produced strong warming aloft to 500 mb which prevented much thunderstorm activity. Surface dew points were in the upper 50s to lower 60s across the eastern plains.

On July 5, the four corners region of the southwest United States had the highest 500 mb heights for the northern hemisphere at 5970 meters. This ridge prevented any short wave from entering into northeastern Colorado. This weather pattern is also indicative of the annual monsoon season. Denver International Airport (DIA) recorded 0.13 inches of rain on this day.

On July 6, the center of the high-pressure ridge moved over northern Texas and the Oklahoma region. A dry slot moved into far eastern Colorado preventing much in the way of thunderstorm activity except for the higher terrain. A localized heavy downpour occurred over DIA creating 1.01 inches of rainfall. Ozone concentration exceeding 80 ppb did not occur on this day.

More moisture was pumped into northeastern Colorado on July 7, as the upper level high-pressure system moved further east over Oklahoma allowing monsoon moisture to move into the area. DIA recorded 0.l8 inches of rain on this day.

The mean position of the upper level ridge started to retrograde back over southeast Colorado on July 8. A thunderstorm passed over the Denver area dumping about 0.36 inches of rain over DIA that inhibited the 8-hour average ozone concentrations.

More of the same occurred on July 9. Later thunderstorm development occurred which allowed the 8-hour ozone concentration to exceed 80 ppb at Rocky Flats North. No rain fell over DIA on this day.

Trajectory Analysis

The 120-hour composite trajectory plot presented in Figure 5.A indicates that the air mass On July 3-9 may have originated in the high plains area of Nebraska and Kansas. The 800m air mass originated from Western Texas and New Mexico.

On July 4 and 5, Figures 5.B and 5.C indicate that the air mass originated from northern New Mexico at all levels starting 36-hours out. A more southwest flow occurred on July 6 as indicated in Figure 5.D.

On July 7 - 9, Figures 5.E-5.G indicate that the surface flow shifted from the north, originating in southeastern Wyoming. The 800m flow was still from the south. Wind speeds at the surface during the July 7-9 period were very light. The mid-level winds at 800m were also light from the south.

Figure 5.A: Composit Plot for July 3-9, 2001

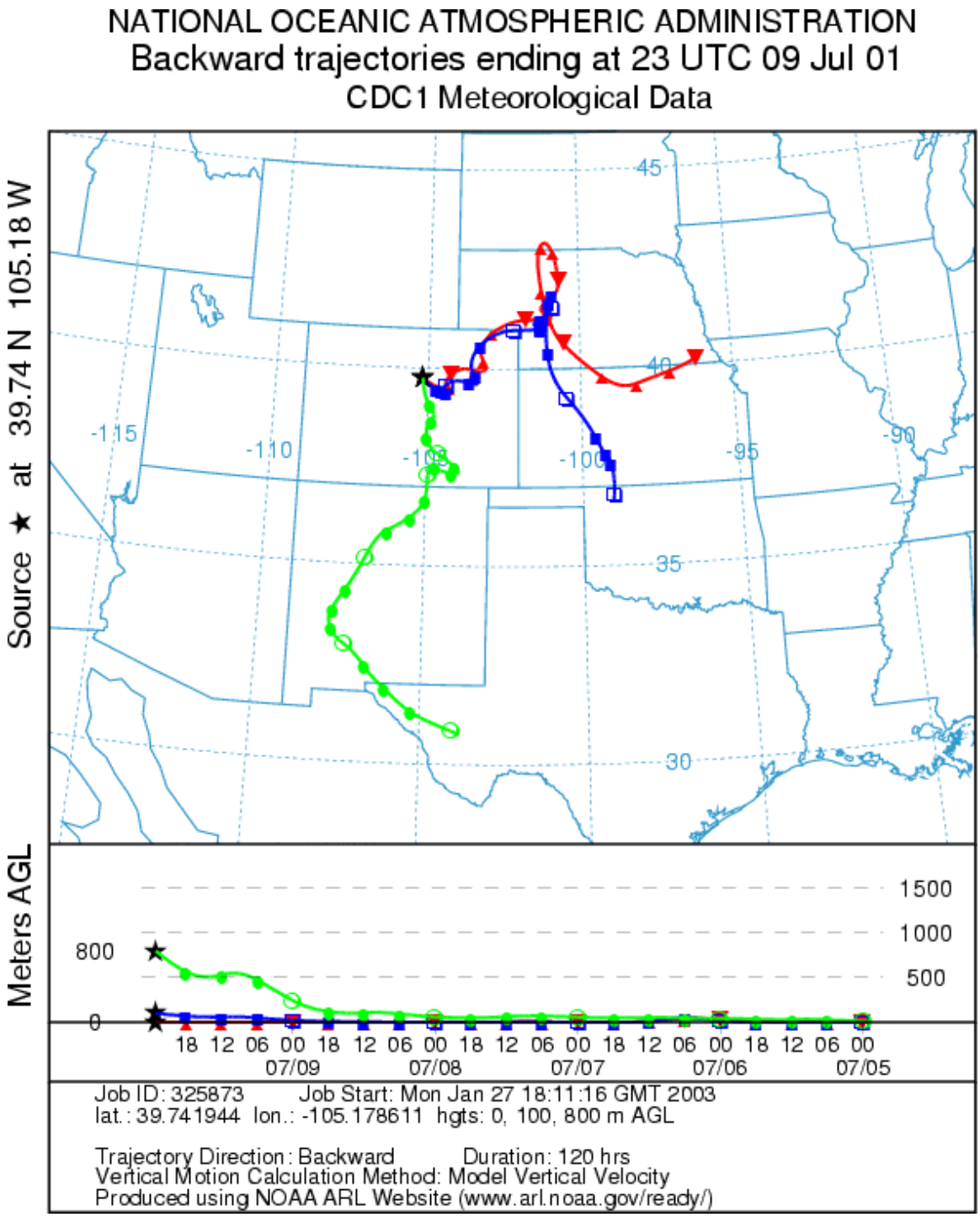


Figure 5.B: Thirty-six Hour Trajectory Plot for July 4, 2001

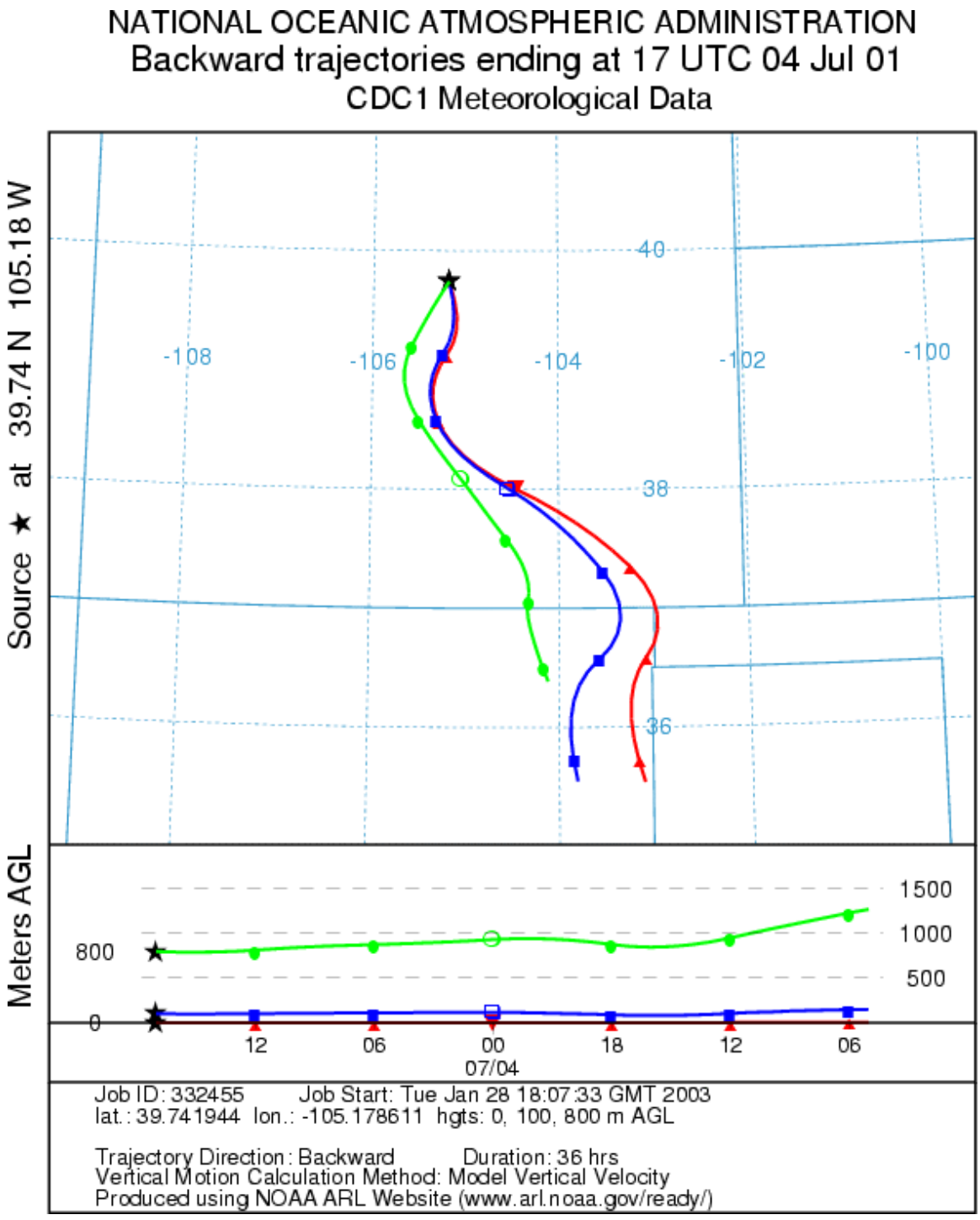


Figure 5.C: Thirty-six Hour Trajectory Plot for July 5, 2001

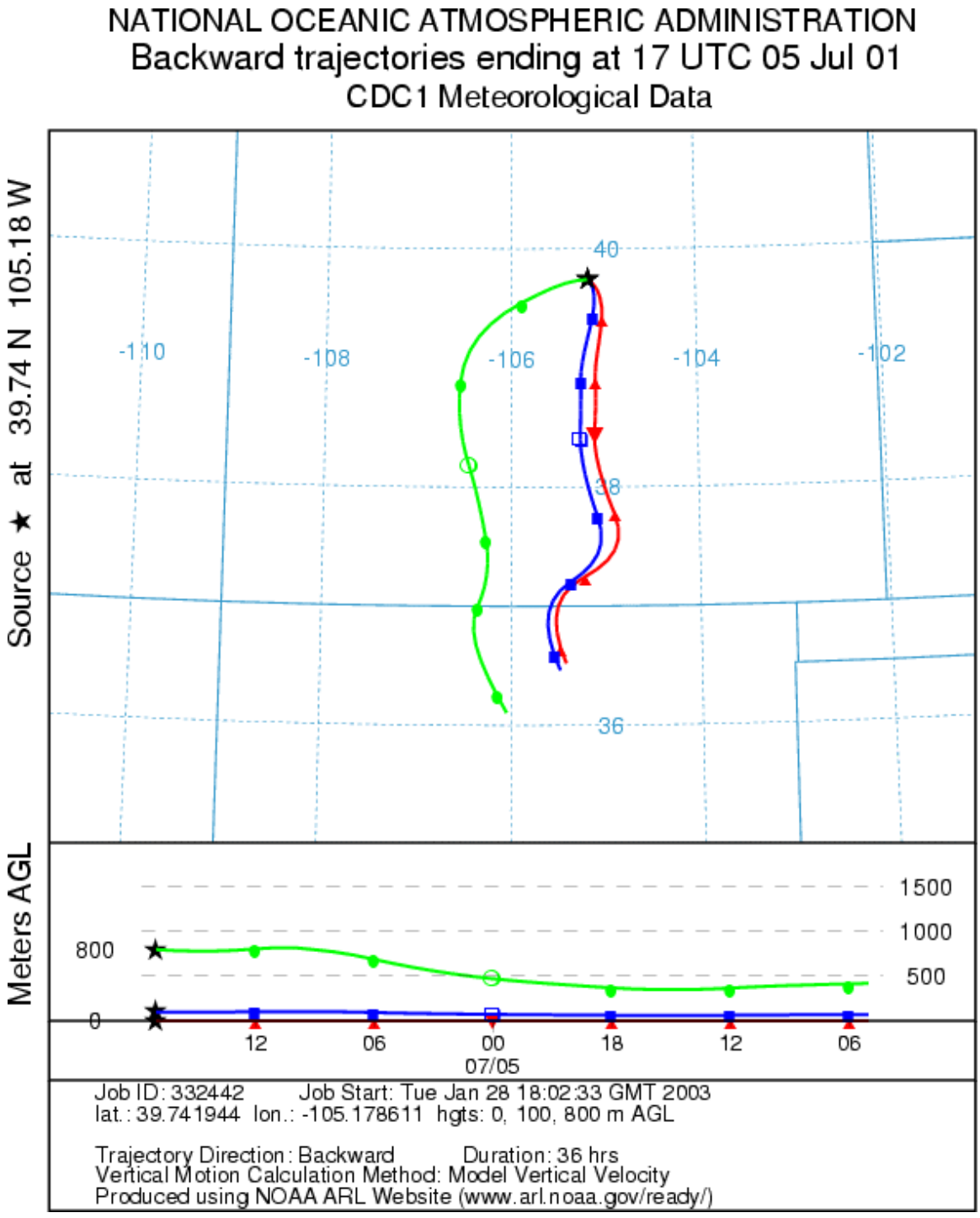


Figure 5.D: Thirty-six Hour Trajectory Plot for July 6, 2001

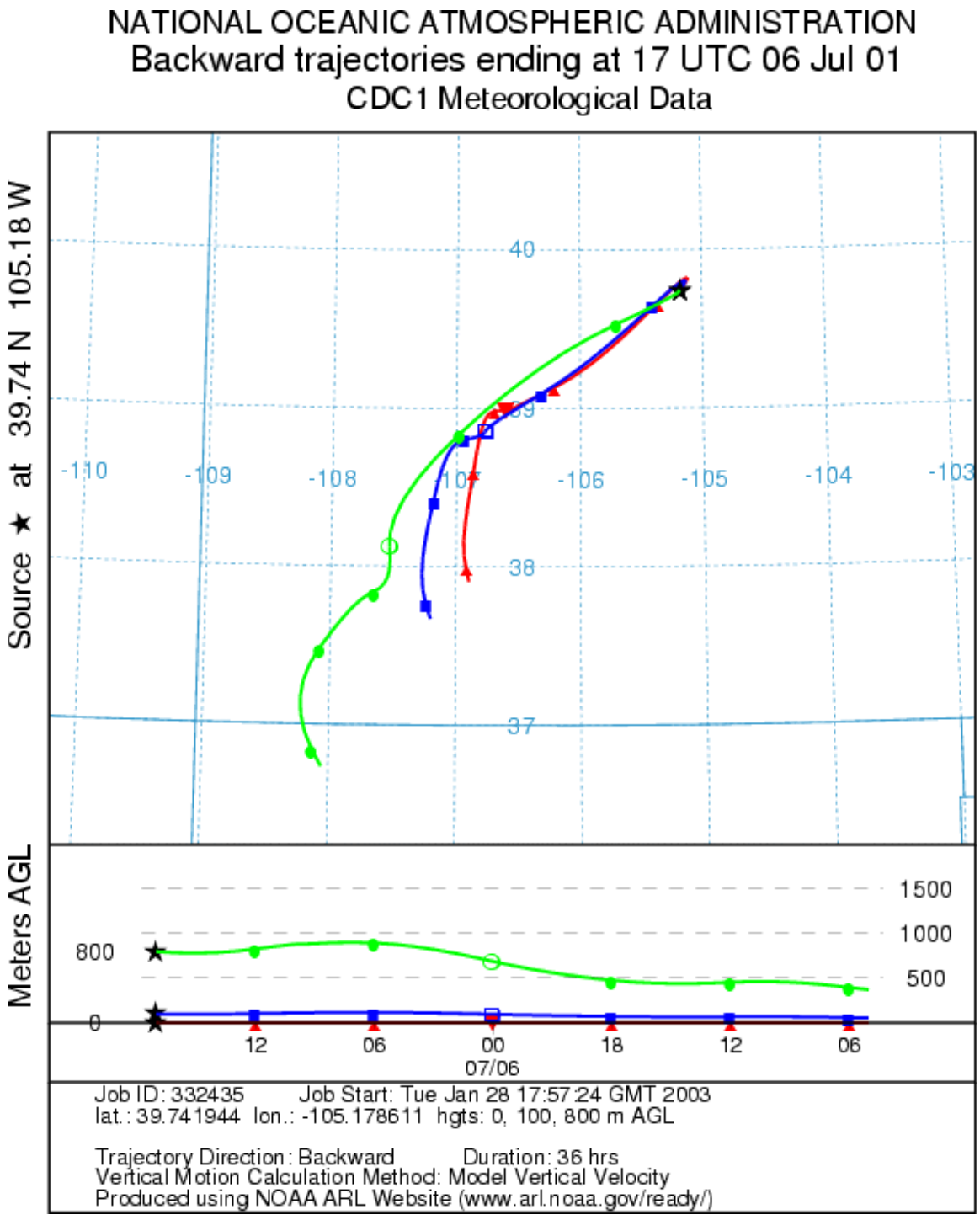


Figure 5.D: Thirty-six Hour Trajectory Plot for July 8, 2001

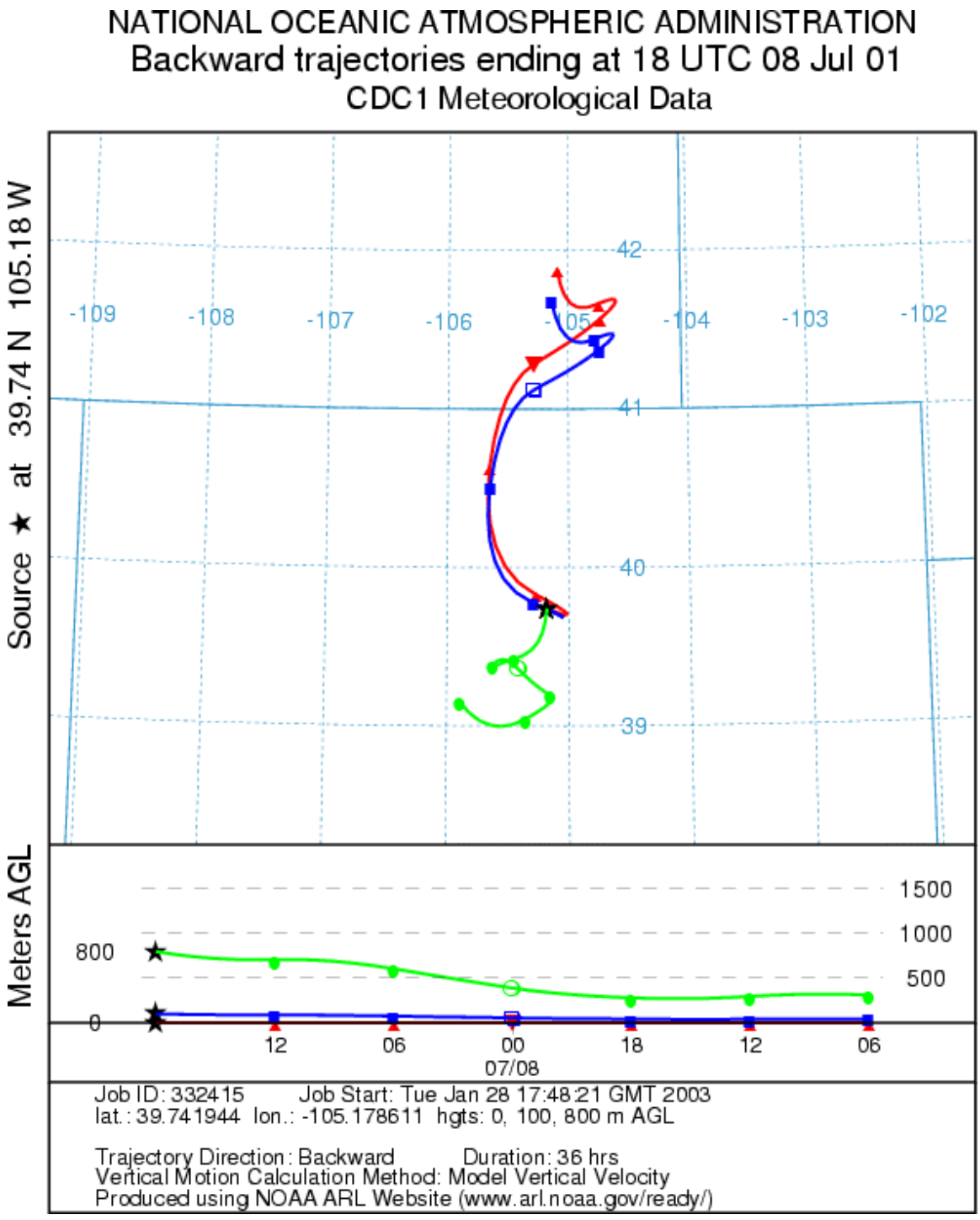
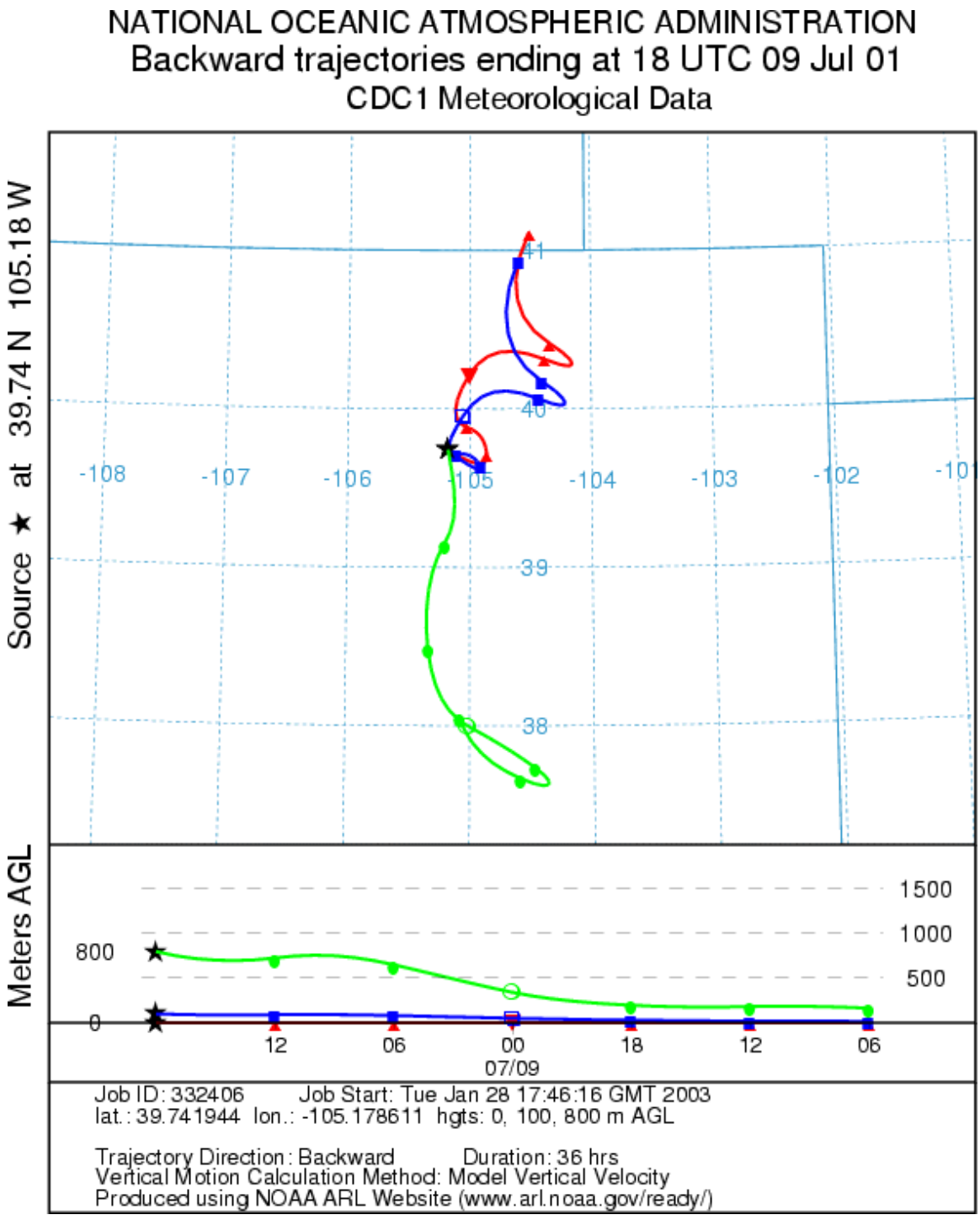


Figure 5.E: Thirty-six Hour Trajectory Plot for July 9, 2001



Days and Episodes Eliminated for Further Consideration

Given the occasional, relatively low ozone concentrations, and lack of network wide exceedances, all of 1999 can be excluded from further consideration. Following are those days or episodes that were immediately eliminated from further consideration for episode selection.

April 9, 1999

An 8-hour concentration of 81 ppb occurred at the Academy monitor in Colorado Springs. This was a single monitor concentration just slightly over 80 ppb, and did not occur at a monitor of the Denver area.

May 6, 1999

An 8-hour maximum concentration of 85 ppb occurred at the monitor in Rocky Mountain National Park. Although the value of 85 ppb exceeds the monitored ozone excedance concentration for NAAQS, this is an isolated day with a single monitored concentration over 80 ppb. Three out of the five selected episodes contain high ozone concentrations at Rocky Mountain National Park.

June 26, 1999

The highest monitored concentration that occurred was 80 ppb at NREL in Golden. Given the relatively low concentration at a single monitor for a single day, this day was eliminated for further consideration.

July 1, 1999

A relatively high concentration of 87 ppb occurred at Rocky Flats North. However, this occurred on a single isolated day and only the monitor at Rocky Flats North exceeded 80 ppb on this day.

July 6-7, 1999

This was a two day episode with relatively low ozone concentrations at isolated monitors. On July 6, NREL recorded an ozone concentration of 81 ppb. On July 7, Rocky Flats North recorded an ozone concentration of 81 ppb.

July 13, 1999

This day had five monitors over 80 ppb. The monitor at South Boulder County had a monitored exeedance of 86 ppb. Although by itself this day may be interesting, it is a single isolated day. The overall network had an average ozone concentration less than 84 ppb.

July 17, 1999

A relatively low ozone concentration of 80 ppb occurred at NREL near Golden. This was also an isolated day.

July 27-28, 1999

On July 27, the NREL monitor had an exceedance value of 85 ppb. Also on July 27, Rocky Flats North had a concentration of 81 ppb. On July 28, Highlands Ranch had a concentration of 80 ppb. Since the episode was short lived (two days) with relatively low concentrations over the network as a whole, this episode was eliminated.

August 26, 1999

An isolated, relatively low concentration of 81 ppb occurred at Highlands Ranch.

May 16, 2000

An isolated, relatively low concentration of 82 ppb occurred at Rocky Flats North.

June 30, 2000

The third highest ozone concentration recorded at Rocky Mountain National Park over the 4-year period occurred on this day. An ozone concentration of 89 ppb was recorded at RMNP. However, this was an isolated occurrence and for a single day. The Denver metro had ozone concentrations in the 60-75 ppb range. Although this is an interesting day for RMNP it is not representative of an ozone episode for the Denver metro area.

July 10, 2000

An isolated, relatively low concentration of 81 ppb occurred at NREL near Golden.

July 15-16, 2000

A two-day episode occurred on July 15 and 16, 2002. Highlands Ranch, Chatfield Reservoir, and NREL had 8-hour ozone concentration of 85 ppb, 83 ppb, and 81 ppb, respectively on July 15. On July 16, NREL had an ozone concentration of 82 ppb. Although the 85 ppb at Highlands Ranch exceeded the monitored ozone standard, the rest of the network had relatively low ozone concentration. The higher ozone concentration at Highlands Ranch and Chatfield are in southwest Denver that is away from the Golden/Rocky Flats focus area.

July 20, 2000

Isolated and relatively low ozone concentrations occurred at NREL (84 ppb), and, Chatfield (80 ppb). This day, however, may represent one of the conceptual high ozone day models in that pollutants are carried along the Platte River drainage to southwest Denver during the day. The ozone that is produced is then carried along the foothills towards Boulder as the day wears on.

July 28, 2000

For a single day, fairly high ozone levels were measure over most of the network. NREL had the highest ozone concentration 89 ppb on this day followed by Highlands Ranch (86 ppb), Rocky Flats North (84 ppb), and Chatfield Reservoir (80 ppb). Although this is an interesting day by itself, it does not represent an episode where the ozone average over several days will violate the standard. The NREL concentration of 89 ppb is the fourth highest concentration there during the 1999-2002 time frame.

August 1-2, 2000

August 1 and 2 were somewhat interesting days as the air mass appeared to come in from the high plains to the east. Several monitor had ozone concentrations over 80 ppb on these days. On August 1, Rocky Mountain National Park had a value of 86 ppb and NREL had a concentration of 83 ppb. Ozone concentrations that exceeded 80 ppb were monitored at Chatfield (80 ppb), Colorado Springs (Academy-81 ppb), and NREL (83 ppb) on August 2. Since this was only a two-day episode, and, the overall network had moderate levels of ozone, it was eliminated from further consideration.

August 9, 2000

Isolated, relatively low concentrations occurred at NREL (81 ppb) and at Rocky Mountain National Park (80 ppb).

August 13, 2000

An isolated, relatively low concentration of 80 ppb occurred at NREL near Golden.

August 15, 2000

Isolated, relatively low concentrations occurred at Rocky Flats North (83 ppb) and at NREL (81 ppb).

June 16, 2001

An isolated, relatively low concentration of 83 ppb occurred at Rocky Flats North.

July 1, 2002

An isolated, relatively low concentration of 81 ppb occurred at NREL. An ozone concentration of 84 ppb occurred in Greeley on this day.

July 7, 2002

Isolated, relatively low concentrations occurred at Rocky Flats North (81 ppb) and at the Weld County Tower (80 ppb).

July 9, 2002

Isolated, relatively low concentrations occurred at Chatfield (81 ppb) and at Rocky Mountain National Park (81 ppb).

July 15, 2002

A monitored exceedance occurred at Rocky Mountain National Park (85 ppb). This was an isolated exceedance with most of the rest of the network less than 80 ppb. The larger episodes would be preferred to this isolated day.

August 10, 2002

An isolated, relatively low concentration of 82 ppb occurred at Rocky Flats North.

August 25, 2002

An isolated, relatively low concentration of 80 ppb occurred at Rocky Mountain National Park.

Conceptual Models Of 8-Hour Ozone

High ozone concentrations generally occur in the Denver region on days that are hot, cloud-free, and with stagnant to light wind speeds at both at the surface and aloft. Most high-ozone events occur on days when high temperatures are above 90 degrees F and when light, up-slope winds occur at the surface and mountaintop level. Episodic events of ozone occur when maximum daily temperatures above 90 degrees F persist for several days in a row. On most high ozone days, dew points on the eastern plains are in the 40-60 ^{O}F range. Relatively high dew point levels are probably necessary for efficient photochemistry production and differentiate those days that are above 90 ^{O}F with high ozone levels, and, dry hot days with lower ozone levels. The absence of cloud cover and thunderstorms promotes ozone formation. Conversely, typical late-afternoon thunderstorms and associated cloud cover retard the formation of ozone and help keep ozone concentrations at levels below the federal standard. Timing of thunderstorms off of the mountains in the late afternoon and evening hours during hot days is another critical piece in determining whether the 8-hour ozone standard is exceeded on a day-to-day basis in the Denver area. The highest ozone levels usually occur in June and July and sometimes-early August.

The APCD uses three ozone forecast regression models to help with summer ozone forecasting. These models use forecast upper level temperatures, winds, dew points and pressure level heights as well as ozone levels seen earlier in the period of interest to estimate peak current and next-day ozone concentrations. The models work well, although they tend to under predict the highest concentrations to some extent. These regression models may also be useful in classifying ozone episodes based on the sensitivity of the regression parameter to the actual conditions.

Summary of Episode Advantages and Disadvantages

Based on EPA's episode selection criteria, here are the advantages and disadvantages for each episode:

July 18-21, 2002 (4 Days)

Advantages

- Somewhat contains three different types of regimes:
    - July 18-19 there was a southerly flow from source types like Texas and New Mexico
    - A localized scenario occurred on July 20 when surface winds were very light. This day may also be used to evaluate the effects of wildfire since winds were consistent from those coming from the Big Elk Fire near Estes Park

    - Northerly flow on July 21 from Wyoming where the effects of flash emissions to Denver ozone could be evaluated
- Contains the highest ozone concentrations at the key receptors NREL (92 ppb) and Rocky Flats North (92 ppb) over the four year period as demonstrated in Table 4.
- Contains the second highest ozone concentration at Rocky Mountain National Park (92 ppb)
- Table 5 shows that the average over the episode at Rocky Flats North (81 ppb) is very close to the average of the fourth highs for 2000-2002 (84 ppb). This is also the case for South Boulder Cr., Highlands, and Chatfield. Although the episode high for NREL is slightly higher than the average of the fourth highest concentrations in 2000-2002, it is consistent with the average of the fourth highest concentrations in 1998-2000.

TABLE 5: Episode (July 18-21, 2002) Average Ozone Concentrations Versus Average of Fourth Highest Concentration from 2000-2002

Monitor	Episode Average Concentration (ppb)	Average of Fourth Highest Concentration from 2000-2002 (ppb)
NREL	86	82
Rocky Flats North	81	84
South Boulder Cr.	75	74
Highlands	77	76
Chatfield	81	80

- The wide spread network excedances on July 19 provides a basis for demonstrating attainment at all of the Denver metro monitors. On July 19, eight out of the 12 Front Range monitors exceeded 80 ppb. This is back up on the follow day, July 20, when 6 monitors were 80 ppb or greater.

Disadvantages

- Four days is a short period.episode
- Possibly contains smoke from the Big Elk Fire near Estes Park

June 25 – July 1, 2002 (7 Days)

Advantages

- Contains the longest string of days when the monitoring network exceeded 80 ppb
- The highest ozone concentration recorded during the 2000-2002 period occurred at Highlands on July 1 with a concentration of 94 ppb
- The highest ozone concentration occurred at Rocky Mountain National Park on June 30 with a value of 93 ppb.

- The last three days of the episode had high ozone concentrations (greater than 85 ppb) Rocky Flats North (89 ppb, 88 ppb, and 88 ppb, respectively). A high ozone concentration (91 ppb) was also monitored at NREL on July 1
- Contains a consistent southerly flow from southern Colorado during the first three days. Contains a second scenario type with southwesterly flow from Arizona and Southern California.
- On June 30, 4 out of 12 monitors were greater than 80 ppb. On July 1, 5 out of 12 monitors exceeded 80 ppb. However, the excedances were at key monitors.
- Table 6 shows that the average over the episode at Rocky Flats North (84 ppb) is the same as the average of the fourth highs for 2000-2002 (84 ppb). The episode average is also very close to the average fourth high values at other key receptors.

TABLE 6: Episode (June 25-July 1, 2002) Average Ozone Concentrations Versus Average of Fourth Highest Concentration from 2000-2002

Monitor	Episode Average Concentration (ppb)	Average of Fourth Highest Concentration from 2000-2002 (ppb)
NREL	79	82
Rocky Flats North	84	84
South Boulder Cr.	73	74
Highlands	73	76
Chatfield	78	80

Disadvantages

- The first three days of the episode had fairly low (below 85 ppb) ozone concentrations over the entire network
- Rocky Flats North did not operate on June 25 and 26.
- Several large wildfires were burning in the southwest and Rockies including the Rodeo fire in Arizona, Missionary Ridge fire near Durango, fire complexes near the Utah and Colorado border, and fire complexes near Steamboat Springs. It would be hard to inventory these fires and to evaluate their effects on Denver ozone.

<u>June 8 – 12, 2002</u>

Advantages

- Concentrations at Rocky Flats North were 88 ppb on two of the episode days (June 8 and 9) which contributes significantly to the average of the fourth highest concentrations between the 2000-2002 period.
- Good case study to evaluate the effects of wildfire on ozone and particulate matter levels.

- Good case study for evaluating the effects of transport from Arizona and Southern California (June 8-10)
- An equally good case study for evaluating the local producation of ozone and transport of ozone from the eastern plains of Colorado (June 11 and 12)

Disadvantages

- Episode occurred just three days after the start of the Hayman fire. It would be hard to create an inventory for this fire and to model its effect on ozone over the Denver area.
- Table 7 shows that the average over the episode at Rocky Flats North (84 ppb) is close to the average of the fourth highs for 2000-2002 (84 ppb). However, at other key receptors line NREL the episode average is far below the average of the fourth highest concentrations.
- The were not widespread ozone concentrations greater than 80 ppb over the entire network.
- Similar to the episode that occurs on June 25 through July 1, 2002

TABLE 7: Episode (June 8 – 12, 2002) Average Ozone Concentrations Versus Average of Fourth Highest Concentration from 2000-2002

Monitor	Episode Average Concentration (ppb)	Average of Fourth Highest Concentration from 2000-2002 (ppb)
NREL	71	82
Rocky Flats North	82	84
South Boulder Cr.	70	74
Highlands	64	76
Chatfield	64	80

July 4 – 9, 2001

Advantages

- Excellent case study to evaluate the effect and timing of ozone formation with the onset of afternoon convective activity. This episode had the most active convective activity compared to the other episodes.
- Although the episode average versus the fourth highest ozone concentrations that are summarized in Table 8 are fair, the episodes of July 18 through 21, 2002, and, June 25 through July 1, 2002 are equally as good.

TABLE 8: Episode (July 4 – 9, 2001) Average Ozone Concentrations Versus Average of Fourth Highest Concentration from 2000-2002)

Monitor	Episode Average Concentration (ppb)	Average of Fourth Highest Concentration from 2000-2002 (ppb)
NREL	79	82
Rocky Flats North	83	84
South Boulder Cr.	66	74
Highlands	72	76
Chatfield	79	80

Disadvantages

- On any given day, the high ozone value only occurred at a couple of monitors. However, over the entire episode, the high ozone values were distributed over the monitoring network.

August 3-4, 2001

Advantages

- Five out of twelve monitors exceeded 80 ppb
- The fourth highest ozone concentration (90 ppb) occurred at NREL on August 4.
- The two day episode averages were consistent with the average of the fourth highest contrations at NREL and South Boulder Cr., as shown in Table 8.

TABLE 9: Episode (August 3-4, 2001) Average Ozone Concentrations Versus Average of Fourth Highest Concentration from 2000-2002)

Monitor	Episode Average Concentration (ppb)	Average of Fourth Highest Concentration from 2000-2002 (ppb)
NREL	82	82
Rocky Flats North	79	84
South Boulder Cr.	74	74
Highlands	80	76
Chatfield	79	80

Disadvantages

- Too short of an episode to demonstrate attainment at all of the key receptors.
- Except for the 90 ppb at NREL on August 4, most of the other concentrations were relatively low for both days.
- Southwesterly flow was similar to the longer episodes that occurred on June 25 through July 1, and, July 4 through July 9, 2001.

Summary and Recommendations

The recommended order of episode selections is as follows:

- June 18-21, 2002
- June 25-July 1, 2002
- June 8-12, 2002
- July 4-July 9, 2001
- August 3-4, 2001.

The first two episodes, July 18-21, 2002 and June 25-July 1, 2002 are equally important. A second options would be to run MM5 and the air quality model from June 23 through July 21 (~30 days) to cover the two most important episodes. A third option would be to run MM5 and the air quality model from June 1 through July 31, 2002 to capture to top three episodes (~60 days). Of course cost, computer resources, and time should also weigh in on this decision. Each episode needs to have two additional days of MM5 data in order to initialize the air quality model and to set boundary conditions prior to the actual episode days. For example, the July 18-21, 2002 episode would need to have the MM5 runs cover the period of July 16-21, 2002.