APPENDIX P

FUTURE DESIGN VALUE CALCULATIONS AND SUMMARY,
ANALYSIS OF BEAUMONT BACK TRAJECTORY AND OZONE DATA WITH REGARD TO HOUSTON/LAKE CHARLES EFFECTS (AUGUST 1999),
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BEAUMONT/PORT ARTHUR ATTAINMENT DEMONSTRATION

APRIL 2000 REVISION

According to EPA's documents *Guidance on the Use of Modeled Results to Demonstrate Attainment of the Ozone NAAQS* (1996), and *Guideline for Regulatory Application of the Urban Airshed Model* (1991), the attainment test is based on the results of photochemical modeling. That is, a future attainment year case is modeled with one or more control strategies and if the modeling shows that all grid cells are less than 125 ppb (0.12 ppm), the area meets the 1-hour ozone NAAQS. However, actual monitored compliance with the standard is based on an area having no more than three expected exceedances at any monitor over a three year period. Due to the discrepancy of the modeled test versus the monitored compliance test, EPA developed the concept of Weight of Evidence (WOE). Weight of Evidence allows states to use additional corroborative information to demonstrate that an area would attain the standard in the future, even though the area could not meet the modeled attainment test. For 1-hour ozone SIPs, WOE approaches may include correlation of modeled results with monitored values, analysis of trends from monitoring data (ozone and precursors), empirical analyses based only on monitoring data (observational data), and other modeling metrics beyond the maximum concentration test.

In EPA's draft guidance document entitled *Use of Models and Other Analyses in Attainment Demonstrations for the 8-Hour Ozone NAAQS (Draft)* (1998), additional WOE approaches are discussed that include methods that relate modeled ozone concentrations to monitored design values for a particular area. This method couples relative model response to controls of precursors back to actual monitored data, thus allowing a more robust comparison between the deterministic model and the probabilistic standard. A problem with using the deterministic test is that model performance can be biased high, yet still meet EPA performance criteria. In cases where model performance is biased high, it can be argued that solely tying attainment to a modeled test would result in over control of ozone precursors. An advantage of being able to tie relative model response to actual monitored values would be to dampen out or account for inherent model overprediction. In EPA's 1998 draft document, this approach is suggested as an integral part of the attainment demonstration. Since this approach is relevant to the 1-hour standard, TNRCC is applying this concept, called the future design value, to the B/PA 1-hour ozone attainment demonstration SIP.

Description of Methodology

The approach used here is based on EPA's *Use of Models and Other Analyses in Attainment Demonstrations for the 8-Hour Ozone NAAQS (Draft)* (1998). Since the ozone modeling conducted over the B/PA 3-county area was based on 4 km by 4 km grid cells, a 15-km radius centered on a particular monitor is best approximated by a 9 cell by 9 cell array about the monitor. The EPA guidance suggests using monitoring data from the 3 year time frame around the modeled episode. Since both B/PA episodes occurred in 1993, monitoring data from 1992 to 1994 was used. The design values (4th highest monitored value at each monitor for 1992-1994) for both TNRCC and SETRPC monitors from that time period are found in Table 1.

Table 1 Design Values for B/PA Area Monitors

Site	UTM Easting	UTM Northing	Description	1992-1994 Design Value (DVC) (ppb)
BMTC	396.4	3323.4	**CAMS2, Beaumont, Jefferson County**	124
PAWC	404.6	3307.3	**CAMS28, Port Arthur West, Jefferson County**	119
WORA	426.6	3328.4	**CAMS9, West Orange, Orange County**	123
S40S	413.2	3287.7	**SETRPC 40, Sabine Pass, Jefferson County**	135
S42S	415.9	3338.8	**SETRPC 42, Mauriceville, Orange County**	134
S43S	403.1	3312.0	**SETRPC 43, Jefferson County Airport, Jefferson County**	136
KTZA	373.6	3361.6	**CAMS85, Kountze, Hardin County**	109

For each of these sites, the 1993 base case maximum modeled concentration, for each day of the two episodes, found within the 9 by 9 cell array surrounding the monitor was selected. This is denoted as P_c. P_c values that met the following criteria were excluded from future consideration: (1) DVc was less than or equal to 125 ppb and P_c was less than 100 ppb or (2) DVc was less than 125 ppb and P_c was less than DVc minus 20 ppb (DVc - 20). This is done because model results will probably not show much response to emission reductions for these scenarios and these values are significantly less than the standard. In addition, it is possible that values listed as the maximum concentration within the 9 by 9 array may actually be greater than the modeled maximum found over the 3-county area. This is because all values within the 9 by 9 array are used, even those that occur outside the 3-county area or occur over water (e.g. Sabine Pass). Table 2 lists the P_c values for each of the monitors, for each of the episode days. The last column is the mean of the maximum modeled values for each monitor over all episode days.

Table 2 Model Predicted Maximum Ozone Concentrations Near B/PA Monitors - 1993 base case

Site	92-94 DVC	9/1/93	9/2/93	9/8/93*	9/9/93	9/10/93	9/11/93**	Mean P_c
BMTC	124	***	114.9	155.8	121.4	140.7	160.7	138.7
PAWC	119	99.6	107.6	155.8	124.1	142.6	145.1	129.1
WORA	123	110.8	132.6	149.3	144.2	138.2	132.1	134.5
S40S	135	103.0	***	149.0	117.8	157.8	122.6	130.0
S42S	134	106.2	129.0	130.8	132.7	130.6	152.6	130.3
S43S	136	***	115.6	155.8	123.3	142.6	152.4	137.9
KTZA	109	***	122.3	120.5	116.9	95.5	162.8	123.6

* Base case model performance for 9/8/93 is outside EPA performance criteria.

** B/PA area affected by rebound of boundary conditions.

*** Data excluded because of DVc <= 125 ppb and P_c < 100 ppb or DVc < 125 ppb and P_c < (DVc -20) ppb

The next step in applying the future design value approach is to develop a similar table, only using future base case and/or additional control strategy model runs. Table 3 has the corresponding modeled concentrations based on the 2007 future base case modeling for both episodes. The predicted values are referred to as P_f. The 2007 future case accounts for both growth, as well as controls that will be in place by this time. As before, the P_f values are based on the maximum modeled concentration within the 9 by 9 array of cells centered on the monitoring site.

Table 3 Model Predicted Maximum Ozone Concentrations Near B/PA Monitors - 2007 Future Base Case

Site	92-94 DVC	9/1/93	9/2/93	9/8/93*	9/9/93	9/10/93	9/11/93**	Mean P_f
BMTC	124	***	104.5	141.6	110.1	129.3	146.8	126.5
PAWC	119	90.5	98.0	141.6	113.3	131.8	133.0	118.0
WORA	123	100.7	120.3	135.7	130.0	126.9	122.7	122.7
S40S	135	96.9	***	133.5	108.8	145.3	112.5	119.4
S42S	134	96.5	116.1	118.7	120.4	115.5	138.3	117.6
S43S	136	***	104.6	141.6	111.9	131.8	141.8	126.3

KTZA	109	***	111.1	110.0	106.7	90.0	147.3	113.0

* Base case model performance for 9/8/93 is outside EPA performance criteria.

** B/PA area affected by rebound of boundary conditions.

*** Data excluded because of DVc <= 125 ppb and P_c < 100 ppb or DVc < 125 ppb and P_c < (DVc -20) ppb

In order to calculate the future design value, DVf, it is necessary to develop a ratio of the predicted future case model results to that of the original base case modeling results. There are two methods proposed to do this. One is referred to as the (1) mean of the ratios, while the other is (2) the ratio of the means. In Method (1), for each combination of monitor location and episode day, the relative reduction factor (RRF) is calculated as the ratio of the modeled maximum concentration for the future condition, P_f in Table 3, divided by the corresponding maximum concentration for the base case, P_c in Table 2. Then the mean of these ratios is calculated for each monitor site.

Table 5 DVf for B/PA sites using Ratio of Means Approach - 2007 Future Base Case

Site	**DVc**	**Mean P_c**	**Mean P_f**	**RRF (P_f/P_c)**	**DVf (1)**
BMTC	124	138.7	126.5	0.91	113.1
PAWC	119	129.1	118.0	0.91	108.8
WORA	123	134.5	122.7	0.91	112.2
S40S	135	130.0	119.4	0.92	124.0
S42S	134	130.3	117.6	0.90	120.9
S43S	136	137.9	126.3	0.92	124.6
KTZA	109	123.6	113.0	0.91	99.7

Table 4 is a list of the Relative Reduction Factors (RRF) for each combination of P_f/ P_c for each day of both episode. The Mean column is the average of each day/monitor's RRF. This value is multiplied by the DVc in column 2 to calculate DVf(2) in the last column.

Table 4 Daily Relative Reduction Factors for 2007 Future Base Case - Means of the Ratios

Site	92-94 DVc	9/1/93	9/2/93	9/8/93*	9/9/93	9/10/93	9/11/93 **	Mean (2)	DVf (2)
BMTC	124	***	0.91	0.91	0.91	0.92	0.91	0.91	113.0
PAWC	119	0.91	0.91	0.91	0.91	0.92	0.92	0.91	108.7
WORA	123	0.91	0.91	0.91	0.90	0.92	0.93	0.91	112.2
S40S	135	0.94	***	0.90	0.92	0.92	0.92	0.92	124.2
S42S	134	0.91	0.90	0.91	0.91	0.88	0.91	0.90	120.9
S43S	136	***	0.90	0.91	0.91	0.92	0.93	0.92	124.5
KTZA	109	***	0.91	0.91	0.91	0.94	0.90	0.92	99.9

Method (2) uses average P_c and P_f values, calculated for each monitor across all episode days. These averages are denoted in the last columns of Tables 1 and 2. Table 5 illustrates the use of the ratio of the means approach to develop the future design value, DVf.
Comparing the results of Table 4 and Table 5, one can see that the results area essentially the same.

For the purposes of the rest of the this analysis, only Method 2, the Ratio of the Means, will be used. In addition, values for September 8 will also be discarded, since base case model performance on this day was outside EPA acceptability criteria. Note that the RRF for this day are similar to the mean, so exclusion will not significantly alter the results.

Application to B/PA Control Scenarios

Table 6 is similar to Table 5, except that instead of the future base case, this reflects modeling results based on control scenario 5b (e.g. lean-burn engines in B/PA). Table 7 uses the ratio of the means to calculate DVfs for scenario 5b.

Table 6 Model Predicted Maximum Ozone Concentrations Near B/PA Monitors - Control Scenario 5b

Site	92-94 DVC	9/1/93	9/2/93	9/8/93*	9/9/93	9/10/93	9/11/93**	Mean P_f
BMTC	124	***	95.6	139.2	100.5	124.8	141.7	120.4
PAWC	119	86.1	89.2	139.2	102.9	127.5	128.1	112.2
WORA	123	97.3	114.6	133.3	121.1	121.1	116.8	117.4
S40S	135	92.6	***	131.3	92	139.0	107.7	112.5
S42S	134	93.1	109.4	116.3	113.1	108.7	133.1	112.3
S43S	136	***	96.7	139.2	101.4	127.5	136.7	120.3
KTZA	109	***	86.3	91.1	89.1	82.5	142.1	98.2

Table 7 DVf for B/PA sites using Ratio of Means Approach - Scenario 5b

Site	**DVc**	**Mean P_c**	**Mean P_f**	**RRF (P_f/P_c)**	**DVf (1)**
BMTC	124	138.7	120.4	0.87	107.6
PAWC	119	129.1	112.2	0.87	103.4
WORA	123	134.5	117.4	0.87	107.3
S40S	135	130.0	112.5	0.87	116.8
S42S	134	130.3	112.3	0.86	115.5
S43S	136	137.9	120.3	0.87	118.6
KTZA	109	123.6	98.2	0.79	86.6

The same approach is also done for scenario 5b1,which includes the Tier I point source controls within the B/PA 3-county nonattainment area. Table 8 lists the maximum predicted ozone concentrations within the 9 by 9 cell matrix around each monitor, and Table 9 shows the DVf calculations based upon the Ratio of the Means.

Table 8 Model Predicted Maximum Ozone Concentrations Near B/PA Monitors - Control Scenario 5b1

Site	92-94 DVC	9/1/93	9/2/93	9/8/93*	9/9/93	9/10/93	9/11/93**	Mean P_f
BMTC	124	***	93.5	133.6	97.6	120.4	136.5	116.3
PAWC	119	85.8	87.4	133.6	101.2	121.8	127.0	109.5
WORA	123	91.7	108.7	127.6	114.7	114.8	116.3	112.3
S40S	135	92.6	***	125.6	91.5	131.3	105.9	109.4
S42S	134	88.7	104.6	112.8	108.6	102.9	129.1	107.8
S43S	136	***	93.0	133.6	98.5	121.8	133.3	116.0
KTZA	109	***	86.3	90.9	89.0	82.2	136.1	96.9

Table 9 DVf for B/PA sites using Ratio of Means Approach - Scenario 5b1

Site	**DVc**	**Mean P_c**	**Mean P_f**	**RRF (P_f/P_c)**	**DVf (1)**
BMTC	124	138.7	116.3	0.84	104.0
PAWC	119	129.1	109.5	0.85	100.9
WORA	123	134.5	112.3	0.83	102.7
S40S	135	130.0	109.4	0.84	113.6
S42S	134	130.3	107.8	0.83	110.8
S43S	136	137.9	116.0	0.84	114.4
KTZA	109	123.6	96.9	0.78	85.5

This technique demonstrates that although the modeled maximum concentration over the domain for Scenario 5b1 is 129 ppb (for September 10), the calculated future design value is 114.4 ppb, which is less than the 1-hour standard of 0.12 ppm (125 ppb). This is illustrated in Table 10.

Table 10 Summary of Modeled Maximum Concentrations vs DVf

Scenario	9/8/93 P_f*	9/9/93 P_f	9/10/93 P_f	9/11/93 P_f**	DVf
1993 Base	165 (P_c)	139 (P_c)	155 (P_c)	162 (P_c)	n/a
2007 future base	150	126	142	147	124.6
5b	139	117	136	142	118.6
5b1	133	111	129	136	114.4

* Base case model performance is outside EPA acceptability criteria within B/PA area for 9/8/93.
** B/PA affected by rebound of overestimated boundary conditions.

Changes to Future Design Values with new Future Base Case

As a result of comments received, TNRCC reran the future base case and control case scenarios to assess the impact of adding back banked and shutdown emissions. This revised modeling also included new boundary conditions to account for the previously overestimated boundary conditions occurring in the B/PA area on September 11. Since the maximum concentrations changed, so did the calculated Future Design Values. Table 11 shows the results of this revised 2007 base case run.

Table 11 Model Predicted Maximum Ozone Concentrations Near B/PA Monitors - Revised 2007 Future Base Case

Site	92-94 DVC	9/1/93	9/2/93	9/8/93*	9/9/93	9/10/93	9/11/93**	Mean P_f
BMTC	124	***	104.5	142.9	112.2	132.5	149.1	128.2
PAWC	119	90.5	98.0	142.9	114.2	134.8	134.6	119.2
WORA	123	100.7	120.3	138.1	133.2	130.3	123.0	124.3
S40S	135	96.9	***	135.0	109.1	149.3	111.7	120.4
S42S	134	96.5	116.1	122.1	122.4	119.0	140.9	119.5
S43S	136	***	104.6	142.9	113.9	134.8	141.9	127.6
KTZA	109	***	111.1	110.0	106.6	89.9	150.3	113.6

* Base case model performance for 9/8/93 is outside EPA performance criteria.

Table 12 lists the future design values, using the ratio of the means approach for the revised 2007 future base case.

Table 12 DVf for B/PA sites using Ratio of Means Approach - 2007 Revised Future Base Case

Site	DVc	Mean P_c	Mean P_f	RRF (P_f/P_c)	DVf (1)
BMTC	124	138.7	128.2	0.92	114.6
PAWC	119	129.1	119.2	0.92	109.8
WORA	123	134.5	124.3	0.92	113.6
S40S	135	130.0	120.4	0.93	125.0
S42S	134	130.3	119.5	0.92	122.9
S43S	136	137.9	127.6	0.93	125.8
KTZA	109	123.6	113.6	0.92	100.2

Similarly, Tables 13 and 14 show the maximum predicted concentration and ratio of the means-based future design value, respectively, for the revised 5b scenario.

Table 13 Model Predicted Maximum Ozone Concentrations Near B/PA Monitors - Revised Control Scenario 5b

Site	92-94 DVC	9/1/93	9/2/93	9/8/93*	9/9/93	9/10/93	9/11/93**	Mean P_f
BMTC	124	***	95.6	140.7	101.2	125.9	142.5	121.2
PAWC	119	86.1	89.2	140.7	102.8	129.1	128.2	112.7
WORA	123	97.3	114.6	135.7	123.5	123.6	115.4	118.3
S40S	135	92.6	***	132.8	92.9	142.0	105.5	113.2
S42S	134	93.1	109.4	119.1	113.1	111.6	134.2	113.4
S43S	136	***	96.7	140.7	102.5	129.1	136.0	121.0
KTZA	109	***	86.3	91.1	89.1	81.9	143.5	98.4

Table 14 DVf for B/PA sites using Ratio of Means Approach - Revised Scenario 5b

Site	DVc	Mean P_c	Mean P_f	RRF (P_f/P_c)	DVf
BMTC	124	138.7	121.2	0.87	108.3
PAWC	119	129.1	112.7	0.87	103.8
WORA	123	134.5	118.3	0.88	108.2
S40S	135	130.0	113.2	0.87	117.5
S42S	134	130.3	113.4	0.87	116.6
S43S	136	137.9	121.0	0.88	119.3
KTZA	109	123.6	98.4	0.80	86.8

Finally, Tables 15 and 16 show the maximum predicted concentration and ratio of the means-based future design value, respectively, for the revised 5b1 scenario.

Table 15 Model Predicted Maximum Ozone Concentrations Near B/PA Monitors - Revised Control Scenario 5b1

Site	92-94 DVC	9/1/93	9/2/93	9/8/93*	9/9/93	9/10/93	9/11/93**	Mean P_f
BMTC	124	***	93.5	136.2	98.1	121.6	137.5	117.4
PAWC	119	85.8	87.4	136.2	100.7	123.2	125.4	109.8
WORA	123	91.7	108.7	130.1	116.8	116.5	114.2	113.0
S40S	135	92.6	***	127.8	91.1	133.5	105.4	110.1
S42S	134	88.7	104.6	114.0	109.6	105.0	128.7	108.4
S43S	136	***	93.0	136.2	98.9	123.2	133.9	117.0
KTZA	109	***	86.3	91.0	89.0	80.8	137.3	96.9

Table 16 DVf for B/PA sites using Ratio of Means Approach - Revised Scenario 5b1

Site	DVc	Mean P_c	Mean P_f	RRF (P_f/P_c)	DVf
BMTC	124	138.7	117.4	0.85	104.9
PAWC	119	129.1	109.8	0.85	101.2
WORA	123	134.5	113.0	0.84	103.3
S40S	135	130.0	110.1	0.85	114.3
S42S	134	130.3	108.4	0.83	111.5
S43S	136	137.9	117.0	0.85	115.4
KTZA	109	123.6	96.9	0.78	85.4

This technique demonstrates that although the modeled maximum concentration over the domain for Scenario 5b1 is 131 ppb (for September 10), the calculated future design value is 115.4 ppb, which is less than the 1-hour standard of 0.12 ppm (125 ppb). This is illustrated in Table 17.

Table 17 Summary of Modeled Maximum Concentrations vs DVf (for revised 2007 base case)

Scenario	9/8/93 P_f*	9/9/93 P_f	9/10/93 P_f	9/11/93 P_f	DVf
1993 Base	165 (P_c)	139 (P_c)	155 (P_c)	162 (P_c)	n/a
2007 future base	150	128	146	150	125.8
5b	140	119	139	143	119.3
5b1	136	113	131	137	115.4

* Base case model performance is outside EPA acceptability criteria within B/PA area for 9/8/93.

Analysis of Beaumont Back Trajectory and Ozone Data with Regard to Houston/Lake Charles Effects

By Thomas W. Sager[1]

August 31, 1999

Summary

MAIN ISSUE: What do the Beaumont back trajectories tell us about whether Houston and/or Lake Charles ozone is being transported to Beaumont?

METHODOLOGY:
Two sources of data were integrated:

- **Back trajectory endpoint file**. This dataset contains back trajectories generated by the Hysplit (Eta) model for a terminating endpoint 50 meters above the ground in Beaumont. One trajectory per day, beginning in 1996 and continuing into 1999. Some days are missing or represented by placeholders in the file. Most trajectories begin 48 hours before termination and include the modeled location of the air parcel in latitude and longitude on an hourly basis. Each trajectory ends at the same point (latitude 30.04 degrees, longitude –94.07 degrees). The data were provided as a SAS dataset by John Jarvie from Dan White.
- **Ozone file**. Two ozone measurements were provided for each day of operation from 1991 through 12-31-98: The maximum across three TNRCC Beaumont area monitoring stations of the maximum hourly ozone (OZ1), and maximum 8-hour average (OZ8)

The ozone data were matched to the trajectories by day of termination of the trajectory. After integration of the two files, "placeholder" trajectories having no data were eliminated. From the remaining set, a subset was selected by taking all trajectories with final endpoint between 11-1-96 and 10-31-98, inclusively. The subset therefore includes the two most recent contiguous high ozone seasons (May 1 through October 31) and low ozone seasons (November 1 through April 30). A small percentage of this subset had "short" trajectories (less than 48 hours duration). Short trajectories were retained for the analysis. The final dataset contained 654 trajectories [see Table 1].

Trajectories were classified into four groups, according to the level of OZ1 at termination [see Table 2]:

- Group 1 $0 < OZ1 < 75$ ppb
- Group 2 $75 \leq OZ1 \leq 100$ ppb
- Group 3 $100 < OZ1 <= 125$
- Group 4 $125 < OZ1$

Ungrouped analysis was also conducted.

Each lat/long endpoint was converted into 3-dimensional spherical coordinates in order to calculate its distance in miles from the Beaumont terminal endpoint along the arc of the Great Circle joining the endpoint with Beaumont. Similarly, the distance of each endpoint from Houston and Lake Charles was calculated. For this purpose a Houston lat/long reference point was obtained from other trajectory endpoint files. This point (latitude 29.8 degrees, longitude –95.3 degrees) was used uniformly for the distance calculations. The Houston point appears to

[1] This work was supported by the Texas Natural Resource Conservation Commission (TNRCC) under contract number 5829-00760. The views and analysis expressed herein are those of the author and do not necessarily represent TNRCC positions or views.

be slightly to the northeast of downtown Houston. Similarly, a common lat/long location was used for calculating distances from Lake Charles: latitude 30.13 degrees, longitude –93.22 degrees.

Among the metrics calculated for the trajectories, the most notable are:

- MINDHOU = the closest distance in miles that a trajectory came to Houston.
- MINDLCH = the closest distance in miles that a trajectory came to Lake Charles.
- NTCLOS2H = the number of hours that a trajectory spent within a user-specifiable distance of Houston.
- NTCLOS2L = the number of hours that a trajectory spent within a user-specifiable distance of Lake Charles.

The intuition for these metrics is that for the trajectory to be involved in transport of ozone from Houston to Beaumont and/or from Lake Charles to Beaumont, the trajectory should come close enough to Houston and/or Lake Charles and spend enough time there to be influenced by Houston and/or Lake Charles conditions.

With these metrics, trajectories can be further classified by whether or not they enter a circle around Houston and/or Lake Charles of user-specifiable radius, and by the number of hours each trajectory spends within such a circle.

Additionally, a circle can be drawn around Beaumont of user-specifiable radius and the points and times at which the trajectories cross the circle can be recorded. In this regard, it is especially interesting to specify the radius to be equal to the surface distance between Beaumont and Houston (75.5822 miles) and to the surface distance between Beaumont and Lake Charles (51.2513 miles). Then tally the number of trajectories by crossing point in the meteorological octants (measured clockwise from north; NE is 22.5° to 67.5°, E is 67.5° to 112.5°, …, ending with N as 337.5°-360° and 0°-22.5°), and calculate the mean Beaumont OZ1 for the trajectories crossing in each octant. [See Tables 3-6.]

FINDINGS and OBSERVATIONS:

- Seasonal equivalencies: Mean OZ1 levels are significantly higher in the two summers than in the two winters [see Table 7]. Mean OZ1 levels are statistically indistinguishable between the two winters [see Table 8]. However, mean OZ1 levels were somewhat higher in summer of 1997 than in summer of 1998 [see Table 9].
- 40 of 312 winter trajectories come within 50 miles of Houston. 67 of 342 summer trajectories come within 50 miles of Houston. For each season, the near-Houston trajectories result in significantly higher mean OZ1 in Beaumont than the far-Houston trajectories do (61.8 ppb vs 44.0 ppb for winter, and 76.1 ppb vs 53.1 ppb for summer). [See Table 10.]
- 166 of 312 winter trajectories come within 50 miles of Lake Charles. 191 of 342 summer trajectories come within 50 miles of Lake Charles. For neither season do the near-Lake Charles trajectories result in significantly higher mean OZ1 in Beaumont than the far-Lake Charles trajectories do (45.7 ppb vs 47.0 ppb for winter, and 59.7 ppb vs 54.8 ppb for summer), although the summer difference is close to statistical significance. [See Table 11.]
- When the minimum distance from Houston and the minimum distance from Lake Charles were used to predict OZ1, the regression was statistically significant (p=.0001). The regression equations were: [see Table 12]

$$\text{(Winter) OZ1} = 76.05 - .33\ \text{MINDHOU} - .19\ \text{MINDLCH}$$

(Summer) OZ1 = 119.69 -.65 MINDHOU -.58 MINDLCH

- This indicates (for summer trajectories) that for each mile further from Houston the closest approach is, the Beaumont OZ1 is estimated to average 0.65 ppb lower. And for each mile further from Lake Charles the closest approach is, the Beaumont OZ1 is estimated to average 0.58 ppb lower. Thus, a summer trajectory that approaches to within 10 miles of Houston and 20 miles of Lake Charles, would be estimated to have Beaumont OZ1 of 119.69 -.65x10 - .58x20 = 101.59 ppb. The coefficients in these two equations are all statistically extremely significant – meaning it is not believable that they are zero. However, the R-squares are not high: 10.4% for winter and 18.8% for summer [see Table 12]. Thus, many factors other than mere proximity to these cities are more important in determining the level of Beaumont OZ1.
- The regression model diagnostics are somewhat better when OZ1 is replaced by log(OZ1).
- Trajectories pass over Houston infrequently. Only 6 + 7 = 13 of 159 + 169 = 328 summer trajectories passed through the W octant [see Table 3]. This is many fewer than the 328 ÷ 8 = 41 that would have been expected with a random distribution. But the W octant trajectories averaged much higher OZ1 levels in Beaumont (82.8 ppb). The neighboring SW and NW octants were also significantly elevated. [See Table 4.]
- Trajectories pass over Lake Charles about as frequently as expected by a random distribution. But the mean OZ1 levels of the E octant trajectories at a distance of Lake Charles from Beaumont are not especially high, whether summer or winter. [See Tables 5 and 6.]
- The four ozone groups were significantly different in terms of their minimum approach to Houston (p=.0001). For summer, the lowest group (0-74 ppb) averaged a closest approach 49.6 + 18.0 = 67.6 miles from Houston; the 75-100 ppb group averaged a closest approach 49.6 + 6.3 = 55.9 miles from Houston; the 101-125 group 49.9 + 0 = 49.9 miles; and the over 125 group 49.9 – 11.3 = 38.6 miles. R-square = 12.6%. Winter was also significant. [See Table 13.]
- The four ozone groups were not significantly different in terms of their minimum approach to Lake Charles. The R-square is also very small. [See Table 14.]
- Finally, it should be noted that the correlation between OZ1 and OZ8 (or between log(OZ1) and log(OZ8) is very high: 91-93%. Thus, results analogous to these would almost certainly hold for OZ8 (or log(OZ8)) as well.

CONCLUSION:

The conclusion based on this analysis is that Beaumont trajectories associated with Houston result in higher average ozone in Beaumont. The closer the association of the trajectory with Houston, the higher the Beaumont ozone. This analysis does not show that transport from Houston is a cause of elevated Beaumont ozone. But the analysis does make a *prima facie* case that transport could be a cause. The evidence for transport from Lake Charles is much weaker than the case for Houston: Some analyses suggest that there may be the possibility of an effect; other analyses do not find anything. Therefore, the verdict on an association between elevated Beaumont ozone and proximity of Beaumont trajectories to Lake Charles based on this analysis is: not proven.

TABLE 1: Beaumont trajectories analyzed

SEASONYR	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Winter97	175	26.8	175	26.8
Summer97	172	26.3	347	53.1
Winter98	137	20.9	484	74.0
Summer98	170	26.0	654	100.0

TABLE 2: Tally of Beaumont trajectories by ozone level, season and year

OZLEVEL	SEASONYR				
Frequency, Percent, Row Pct, Col Pct	Winter97	Summer97	Winter98	Summer98	Total
0- 74	162	121	132	130	545
	24.77	18.50	20.18	19.88	83.33
	29.72	22.20	24.22	23.85	
	92.57	70.35	96.35	76.47	
75-100	10	33	5	26	74
	1.53	5.05	0.76	3.98	11.31
	13.51	44.59	6.76	35.14	
	5.71	19.19	3.65	15.29	
101-125	2	16	0	10	28
	0.31	2.45	0.00	1.53	4.28
	7.14	57.14	0.00	35.71	
	1.14	9.30	0.00	5.88	
>125	1	2	0	4	7
	0.15	0.31	0.00	0.61	1.07
	14.29	28.57	0.00	57.14	
	0.57	1.16	0.00	2.35	
Total	175	172	137	170	654
	26.76	26.30	20.95	25.99	100.00

TABLE 3: Number of trajectories at radius = 75.5822 miles (Beaumont-Houston distance), by octant, season and year

```
SEASONYR     OCTANT
Frequency,
Percent  ,
Row Pct  ,
Col Pct  ,N        ,NE       ,E        ,SE       ,S        ,SW       ,W        ,NW       ,  Total
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Winter97 ,     23 ,     27 ,     23 ,     26 ,     27 ,     19 ,      8 ,     16 ,    169
         ,   3.65 ,   4.28 ,   3.65 ,   4.12 ,   4.28 ,   3.01 ,   1.27 ,   2.54 ,  26.78
         ,  13.61 ,  15.98 ,  13.61 ,  15.38 ,  15.98 ,  11.24 ,   4.73 ,   9.47 ,
         ,  37.10 ,  32.53 ,  26.44 ,  22.81 ,  20.93 ,  25.00 ,  27.59 ,  31.37 ,
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Summer97 ,      7 ,     19 ,     25 ,     35 ,     39 ,     21 ,      7 ,      6 ,    159
         ,   1.11 ,   3.01 ,   3.96 ,   5.55 ,   6.18 ,   3.33 ,   1.11 ,   0.95 ,  25.20
         ,   4.40 ,  11.95 ,  15.72 ,  22.01 ,  24.53 ,  13.21 ,   4.40 ,   3.77 ,
         ,  11.29 ,  22.89 ,  28.74 ,  30.70 ,  30.23 ,  27.63 ,  24.14 ,  11.76 ,
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Winter98 ,     28 ,     16 ,     14 ,     21 ,     17 ,      3 ,      8 ,     27 ,    134
         ,   4.44 ,   2.54 ,   2.22 ,   3.33 ,   2.69 ,   0.48 ,   1.27 ,   4.28 ,  21.24
         ,  20.90 ,  11.94 ,  10.45 ,  15.67 ,  12.69 ,   2.24 ,   5.97 ,  20.15 ,
         ,  45.16 ,  19.28 ,  16.09 ,  18.42 ,  13.18 ,   3.95 ,  27.59 ,  52.94 ,
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Summer98 ,      4 ,     21 ,     25 ,     32 ,     46 ,     33 ,      6 ,      2 ,    169
         ,   0.63 ,   3.33 ,   3.96 ,   5.07 ,   7.29 ,   5.23 ,   0.95 ,   0.32 ,  26.78
         ,   2.37 ,  12.43 ,  14.79 ,  18.93 ,  27.22 ,  19.53 ,   3.55 ,   1.18 ,
         ,   6.45 ,  25.30 ,  28.74 ,  28.07 ,  35.66 ,  43.42 ,  20.69 ,   3.92 ,
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Total          62        83        87       114       129        76        29        51      631
            9.83    13.15    13.79    18.07    20.44    12.04     4.60     8.08   100.00
============================================================
```

TABLE 4: Beaumont OZ1 means by octant of trajectory crossing and season, at radius = 75.5822 miles (Beaumont-Houston distance)

SEASON	OCTANT	N Obs	N	Mean	Std Dev	Minimum	Maximum
Winter	N	51	51	42.5686275	14.0858154	17.0000000	75.0000000
	NE	43	43	41.0232558	16.6024788	13.0000000	92.0000000
	E	37	37	48.2432432	14.8910962	17.0000000	76.0000000
	SE	47	47	46.5957447	11.4429769	26.0000000	89.0000000
	S	45	45	44.7333333	14.7515793	20.0000000	80.0000000
	SW	22	22	64.1818182	35.4342266	20.0000000	169.0000000
	W	16	16	57.5000000	21.2383301	30.0000000	91.0000000
	NW	43	43	44.4883721	13.9187645	15.0000000	80.0000000
Summer	N	11	11	51.7272727	24.2820547	28.0000000	96.0000000
	NE	40	40	67.2250000	27.8949380	19.0000000	123.0000000
	E	50	50	58.3400000	23.6268699	22.0000000	108.0000000
	SE	67	67	45.6417910	21.8817078	21.0000000	121.0000000
	S	84	84	45.3214286	24.2756066	16.0000000	113.0000000
	SW	54	54	65.8703704	26.6479822	23.0000000	143.0000000
	W	13	13	82.8461538	32.8654990	30.0000000	130.0000000
	NW	8	8	90.1250000	26.0956346	42.0000000	113.0000000

TABLE 5: Number of trajectories at radius = 51.2513 miles (Beaumont-Lake Charles distance), by octant, season and year

```
SEASONYR     OCTANT
Frequency,
Percent  ,
Row Pct  ,
Col Pct  ,N        ,NE       ,E        ,SE       ,S        ,SW       ,W        ,NW       ,  Total
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Winter97 ,      22 ,      28 ,      22 ,      28 ,      30 ,      13 ,       8 ,      19 ,     170
         ,    3.45 ,    4.39 ,    3.45 ,    4.39 ,    4.70 ,    2.04 ,    1.25 ,    2.98 ,   26.65
         ,   12.94 ,   16.47 ,   12.94 ,   16.47 ,   17.65 ,    7.65 ,    4.71 ,   11.18 ,
         ,   34.38 ,   33.33 ,   26.51 ,   22.95 ,   22.90 ,   19.70 ,   25.00 ,   33.93 ,
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Summer97 ,      10 ,      19 ,      23 ,      38 ,      35 ,      20 ,      10 ,       9 ,     164
         ,    1.57 ,    2.98 ,    3.61 ,    5.96 ,    5.49 ,    3.13 ,    1.57 ,    1.41 ,   25.71
         ,    6.10 ,   11.59 ,   14.02 ,   23.17 ,   21.34 ,   12.20 ,    6.10 ,    5.49 ,
         ,   15.63 ,   22.62 ,   27.71 ,   31.15 ,   26.72 ,   30.30 ,   31.25 ,   16.07 ,
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Winter98 ,      25 ,      18 ,      16 ,      22 ,      19 ,       2 ,       7 ,      25 ,     134
         ,    3.92 ,    2.82 ,    2.51 ,    3.45 ,    2.98 ,    0.31 ,    1.10 ,    3.92 ,   21.00
         ,   18.66 ,   13.43 ,   11.94 ,   16.42 ,   14.18 ,    1.49 ,    5.22 ,   18.66 ,
         ,   39.06 ,   21.43 ,   19.28 ,   18.03 ,   14.50 ,    3.03 ,   21.88 ,   44.64 ,
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Summer98 ,       7 ,      19 ,      22 ,      34 ,      47 ,      31 ,       7 ,       3 ,     170
         ,    1.10 ,    2.98 ,    3.45 ,    5.33 ,    7.37 ,    4.86 ,    1.10 ,    0.47 ,   26.65
         ,    4.12 ,   11.18 ,   12.94 ,   20.00 ,   27.65 ,   18.24 ,    4.12 ,    1.76 ,
         ,   10.94 ,   22.62 ,   26.51 ,   27.87 ,   35.88 ,   46.97 ,   21.88 ,    5.36 ,
ƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Total          64        84        83       122       131        66        32        56       638
            10.03     13.17     13.01     19.12     20.53     10.34      5.02      8.78    100.00
============================================================
```

TABLE 6: Beaumont OZ1 means by octant of trajectory crossing and season, at radius = 51.2513 miles (Beaumont-Lake Charles distance)

SEASON	OCTANT	N Obs	N	Mean	Std Dev	Minimum	Maximum
Winter	N	47	47	40.9361702	14.7948350	13.0000000	75.0000000
	NE	46	46	42.0652174	16.4254574	14.0000000	92.0000000
	E	38	38	49.0789474	18.1872863	17.0000000	115.0000000
	SE	50	50	47.0800000	12.1484693	23.0000000	89.0000000
	S	49	49	46.3877551	14.7828960	20.0000000	80.0000000
	SW	15	15	59.2666667	36.8848917	20.0000000	169.0000000
	W	15	15	59.3333333	27.4373746	30.0000000	124.0000000
	NW	44	44	45.4545455	14.2542601	15.0000000	80.0000000
Summer	N	17	17	58.5294118	26.4979189	28.0000000	105.0000000
	NE	38	38	68.3157895	28.2068664	19.0000000	123.0000000
	E	45	45	60.5333333	27.9948047	22.0000000	149.0000000
	SE	72	72	47.5416667	22.7985282	21.0000000	121.0000000
	S	82	82	44.3292683	23.6241427	17.0000000	115.0000000
	SW	51	51	65.8823529	29.8440259	16.0000000	143.0000000
	W	17	17	71.1764706	23.5961737	30.0000000	114.0000000
	NW	12	12	86.7500000	23.1403819	42.0000000	113.0000000

TABLE 7: Do mean OZ1 levels differ between summer and winter?

TTEST PROCEDURE

Variable: OZ1 Ozone: 1hr max

SEASON	N	Mean	Std Dev	Std Error	Variances	T	DF	Prob>|T|
Winter	312	46.27243590	18.09850174	1.02462589	Unequal	-6.1332	585.7	0.0001
Summer	342	57.57894737	28.34110247	1.53251131	Equal	-6.0158	652.0	0.0000

TABLE 8: Do mean ozone levels differ between the two winters?

TTEST PROCEDURE

Variable: OZ1 Ozone: 1hr max

SEASONYR	N	Mean	Std Dev	Std Error	Variances	T	DF	Prob>|T|
Winter97	175	45.10857143	20.96945468	1.58514178	Unequal	-1.3518	299.6	0.1775
Winter98	137	47.75912409	13.50899784	1.15415158	Equal	-1.2851	310.0	0.1997

TABLE 9: Do mean ozone levels differ between the two winters?

TTEST PROCEDURE

Variable: OZ1 Ozone: 1hr max

SEASONYR	N	Mean	Std Dev	Std Error	Variances	T	DF	Prob>|T|
Summer97	172	61.00000000	27.84984803	2.12353100	Unequal	2.2586	339.6	0.0245
Summer98	170	54.11764706	28.49453877	2.18543136	Equal	2.2589	340.0	0.0245

TABLE 10: Do trajectories passing within 50 miles of Houston result in higher Beaumont OZ1?

TTEST PROCEDURE

SEASON=Winter

Variable: OZ1 Ozone: 1hr max

CLOS2HOU	N	Mean	Std Dev	Std Error	Variances	T	DF	Prob>|T|
< 50 from HOU	40	61.75000000	29.13254414	4.60625968	Unequal	3.7850	41.9	0.0005
> 50 from HOU	272	43.99632353	14.60159678	0.88535185	Equal	6.1232	310.0	0.0000

SEASON=Summer

Variable: OZ1 Ozone: 1hr max

CLOS2HOU	N	Mean	Std Dev	Std Error	Variances	T	DF	Prob>|T|
< 50 from HOU	67	76.07462687	26.70053537	3.26198957	Unequal	6.3137	101.2	0.0001
> 50 from HOU	275	53.07272727	26.90484350	1.62242311	Equal	6.2844	340.0	0.0000

TABLE 11: Do trajectories passing within 50 miles of Lake Charles result in higher Beaumont OZ1?

TTEST PROCEDURE

SEASON=Winter

Variable: OZ1 Ozone: 1hr max

CLOS2LCH	N	Mean	Std Dev	Std Error	Variances	T	DF	Prob>|T|
< 50 from LCH	166	45.65662651	15.72055742	1.22015189	Unequal	-0.6296	270.2	0.5295
> 50 from LCH	146	46.97260274	20.50363978	1.69689330	Equal	-0.6402	310.0	0.5225

SEASON=Summer

Variable: OZ1 Ozone: 1hr max

CLOS2LCH	N	Mean	Std Dev	Std Error	Variances	T	DF	Prob>|T|
< 50 from LCH	191	59.74345550	28.06931545	2.03102439	Unequal	1.5890	319.6	0.1131
> 50 from LCH	151	54.84105960	28.53911765	2.32248046	Equal	1.5921	340.0	0.1123

TABLE 12: What is the relationship between miles of proximity to Houston and Lake Charles, and Beaumont OZ1?

```
SEASON=Winter

Dependent Variable: OZ1        Ozone: 1hr max

    Root MSE      17.18718     R-square       0.1040
    Dep Mean      46.27244     Adj R-sq       0.0982
    C.V.          37.14344

Parameter Estimates
                 Parameter      Standard    T for H0:                 Variable
Variable  DF      Estimate         Error   Parameter=0    Prob > |T|     Label
INTERCEP   1     76.047330    5.29784685        14.354        0.0001  Intercept
MINDHOU    1     -0.334596    0.05726972        -5.842        0.0001  Min dis fr Hou
MINDLCH    1     -0.187903    0.06716930        -2.797        0.0055  Min dis fr LCh


SEASON=Summer
Dependent Variable: OZ1        Ozone: 1hr max

    Root MSE      25.61170     R-square       0.1881
    Dep Mean      57.57895     Adj R-sq       0.1833
    C.V.          44.48101

Parameter Estimates
                 Parameter      Standard    T for H0:                 Variable
Variable  DF      Estimate         Error   Parameter=0    Prob > |T|     Label
INTERCEP   1    119.690298    7.38336403        16.211        0.0001  Intercept
MINDHOU    1     -0.650209    0.07601554        -8.554        0.0001  Min dis fr Hou
MINDLCH    1     -0.528465    0.09992482        -5.289        0.0001  Min dis fr LCh
==========================================================
```

TABLE 13: Do the higher OZ1 groups approach Houston more closely than the lower groups?

SEASON=Winter

R-Square	C.V.	Root MSE	MINDHOU Mean
0.073979	25.65392	17.05193298	66.46911641

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		29.90236838 B	2.48	0.0137	12.05753744
OZLEVEL	>125	6.64808553 B	0.32	0.7505	20.88426747
	0- 74	37.66594907 B	3.11	0.0020	12.09847996
	75-100	21.89255157 B	1.71	0.0891	12.83622882
	101-125	0.00000000 B	.	.	.

SEASON=Summer

R-Square	C.V.	Root MSE	MINDHOU Mean
0.126070	28.87838	18.40748506	63.74139642

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		49.62463970 B	13.75	0.0001	3.61000483
OZLEVEL	>125	-11.33452094 B	-1.36	0.1749	8.33694903
	0- 74	18.02733216 B	4.75	0.0001	3.79237091
	75-100	6.28945003 B	1.45	0.1476	4.33302545
	101-125	0.00000000 B	.	.	.

==========

TABLE 14: Do the higher OZ1 groups approach Lake Charles more closely than the lower groups?

SEASON=Winter

R-Square	C.V.	Root MSE	MINDLCH Mean
0.007016	37.54571	15.05526778	40.09850142

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		27.28565744 B	2.56	0.0108	10.64568194
OZLEVEL	>125	23.96562233 B	1.30	0.1947	18.43886200
	0- 74	12.94082879 B	1.21	0.2266	10.68183037
	75-100	11.26920213 B	0.99	0.3208	11.33319387
	101-125	0.00000000 B	.	.	.

SEASON=Summer

R-Square	C.V.	Root MSE	MINDLCH Mean
0.012104	38.07131	14.88815265	39.10596620

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		36.73580743 B	12.58	0.0001	2.91980696
OZLEVEL	>125	5.83055412 B	0.86	0.3878	6.74300533
	0- 74	3.22771243 B	1.05	0.2934	3.06730641
	75-100	-0.58550586 B	-0.17	0.8674	3.50459306
	101-125	0.00000000 B	.	.	.

==========