A Conceptual Model for Eight-Hour Ozone Exceedances in Houston, Texas
Part II: Eight-Hour Ozone Exceedances in the Houston-Galveston Metropolitan Area

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Executive Summary: Findings and Recommendations

Key findings and recommendations of general interest are in **boldface.**

From Chapter 2:

1. Background ozone may be defined as the lowest 8-h maximum ozone level on a given day within a region. (page 19)

2. When estimating background ozone for Houston, certain monitors with anomalously low ozone levels must be excluded. (page 19-21)

3. Annual variations in background ozone levels in Houston have a double peak, with high levels in the spring and late summer/early fall and low levels in early winter and early summer. (page 21)

4. The local contribution may be defined as the difference between the background ozone on a given day and the highest 8-h average on that day. (page 21)

5. In Houston, the highest local contributions occur in summer and the smallest occur in winter. (page 21)

6. The 8-h maximum ozone in Houston is a combination of these two annual cycles, resulting in a primary peak in August/September and a secondary, broader peak in May. (page 21)

7. The daily average 8-h maximum ozone in Houston at the August/September peak is 0.089 ppmv, which exceeds the 8-h ozone standard. (page 21)

8. Unlike other parts of central and eastern Texas, average local contributions to 8-h ozone in Houston during the summer are as large as background ozone concentrations. (page 22)

From Chapter 3:

9. 8-h ozone exceedances occur about 10 times per year each in August and September and about 20 times per year during the period April-July. (page 24)

10. The average annual number of 8-h ozone exceedances at the various monitors ranges from 4 per year to 18 per year. (page 26)

11. Because some ozone monitors in Houston are strongly influenced by instrumental or local effects, it is not possible to determine the true spatial distribution of high levels of ozone within Houston. (page 28)

12. Efforts should be made to determine the true cause of the systematic station-to-station variations in ozone concentration. (page 28)

From Chapter 4:

13. The highest 8-h design value for Houston peaked at 0.118 ppmv in 1998 and has fallen every year since then. (page 30)

14. The current (2002-2004) ozone design value for Houston is 0.102 ppmv, at station C53 (Bayland Park). (page 30)

15. A downward trend in design values is found at almost all monitors. (page 30)

16. The characteristics of high ozone days may be determined by compiling statistics on the third through sixth highest 8-h days each year at each monitor. This is more robust than simply tracking the characteristics of the fourth highest 8-h day each year. (page 32)

17. At the individual monitors examined in detail, the background ozone levels on high 8-h ozone days has been steady over the past 11 years at around 0.065 ppmv. Over a shorter (7-year) period of record, the background ozone high 8-h days has been declining. (page 38)

18. The contribution of transient high ozone events to ozone levels on high 8-h ozone days has been relatively minor since 2002. (page 35)

19. The decline in importance of transient high ozone events may simply be a consequence of transient high ozone events preferentially occurring on low ozone days. (page 43)

20. At the examined stations, background ozone comprises 60% to 75% (on average) of the total ozone measured on high 8-h ozone days. This percentage was lower in the past. (page 32-38)

21. The average of the third to sixth highest annual background ozone levels (a measure of the design value in the absence of Houston emissions) has been falling steadily since the late 1990s and now stands at 0.062 ppmv. (page 41)

22. Days that violate the 8-h standard are more frequent than days that violate the 1-h standard. (page 44)

23. It is not clear from the statistical data whether emissions controls that bring Houston into compliance with the 1-h ozone standard would also bring it into compliance with the 8-h ozone standard. (page 44)

From Chapter 5:

24. Background ozone in Houston is most strongly correlated with meteorological parameters relating to a component of wind from the north on the day of the ozone and on each of the previous two days. (page 47)

25. Weaker winds also favor higher levels of background ozone. (page 47)

26. The local contribution to ozone is most strongly correlated with temperature (a positive correlation), with wind speed and the occurrence of precipitation both strongly negatively correlated. (page 47)

27. Temperature is not significantly correlated with background ozone levels. (page 47)

28. The difference in meteorological parameters related to background ozone and local contributions supports the approach of attempting to understand background ozone and local contributions separately. (page 47)

29. When the effects of wind speed and direction are excluded, precipitation appears to be an important suppressor of background ozone levels. (page 48)

30. When meteorological variables are controlled for by stepwise regression, there is significantly less local contribution on Sunday than on other days. (page 50)

From Chapter 6:

31. Regional-scale wind patterns are dominated by the *sea breeze rotation*, in which winds trace a circle or ellipse over the course of a 24-hour period. (page 52)

32. This rotation is not as apparent in surface observations over land, because nighttime winds tend to become calm in the lowest few tens of meters. (page 55)

33. The wind rotation leads to recirculation when large-scale mean resultant winds are smaller in magnitude than the amplitude of the sea breeze rotation, which is about 3 m/s (6 mph). (page 57)

34. The timing of recirculation is determined by the direction of the large-scale wind. (page 57)

35. The wind rotation leads to stagnation when large-scale mean resultant winds are only slightly weaker than the sea breeze rotation. (page 58)

36. Average 1-h maximum ozone levels are 0.090 to 0.110 when the 24-hour mean resultant wind at a nearby offshore buoy is less than 4 m/s (8 mph). (page 60)

37. Background ozone levels are highest (nearly 0.050 ppmv) when the 24-hour mean resultant wind is less than 1 m/s. (page 61)

38. The local contribution to 1-h ozone is nearly independent of wind speed below 4 m/s and decreases steadily at higher wind speeds, consistent with the sea breeze rotation model. (page 60)

39. The background contribution to 8-h ozone levels is larger than the local contribution at all wind speeds. (page 61)

40. The 8-h local contribution is highest (0.035 ppmv) at the lowest wind speeds and is in general less dependent on wind speeds than the 1-h local contribution. (page 61)

41. The north-south component of wind is a better indicator of background ozone levels than is wind speed itself. (page 62)

42. The highest average background ozone levels (0.046 ppmv) occur with a weak wind component from the north, while the lowest background ozone levels (less than 0.020 ppmv) occur with a strong wind component from the south. These wind variations are a reflection of the importance of the large-scale wind patterns in controlling background ozone. (page 62)

43. Background ozone and local contributions are quite variable and cannot be predicted accurately from wind indicators alone. (page 63-64)

44. The highest 1-h local contributions occur at 24-hour resultant wind speeds of 1.5 m/s to 4.5 m/s (3 mph to 8 mph). (page 63)

45. The highest 8-h local contributions occur at 24-hour resultant wind speeds of less than 1.5 m/s. (page 64)

46. Background ozone levels of 0.040 ppmv or greater, which increase the likelihood of an 8-h ozone exceedance, can be reached at almost any wind speed. (page 65)

47. Extremely high background ozone levels (greater than 0.105 ppmv) have occurred when the 24-hour resultant wind is nearly zero. (page 66)

48. High 1-h (and 8-h) local contributions are favored when the wind is light from the southeast, south, or southwest, but not when the wind is light from the north. The southerly winds are associated with daytime stagnation, while the northerly winds are associated with nighttime stagnation. Developing winds would likely carry any pollution blob resulting from nighttime stagnation eastward and southeastward over unmonitored areas. (page 66-69)

49. In all the major local contribution cases, it appears that the meteorological pattern and sea breeze rotation combine to produce local stagnation in the Houston area sometime between 7 AM and 4 PM. (page 69)

50. Background ozone is less strongly dependent on the background wind speed and direction. (page 70)

51. There is a strong tendency for high background ozone with winds from the northeast. (page 70)

52. The largest cluster of extreme background ozone events is found when the 24-hour resultant mean winds are 0.5 m/s (1 mph) or less. Under such conditions, the ozone plume from Houston on a given day would follow a circular path and end up back in Houston on the following day. At no time during this evolution would the actual winds be stagnant. (page 70)

53. Very high background ozone occurrences with winds from the west-southwest are associated with reversals in the 24-hour mean wind from the previous day and probably include the return of the previous day's pollution. (page 71-72)

54. Local contributions to 8-h ozone can be substantial even without pure stagnation, because an elongated but fairly concentrated plume can be as effective as a blob of high ozone in elevating 8-h levels at a fixed monitor. (page 73)

55. In general, the conditions favoring high ozone are similar for 1-h and 8-h exceedances, except that 8-h exceedances are more sensitive to background ozone levels and less sensitive to local contributions. (page 73)

56. Individual days will depart from the idealized wind patterns, but those patterns seem adequate for explaining the general conditions associated with most high ozone events in Houston. (page 73)

From Chapter 7:

57. Demonstration modeling in support of the 8-h standard should consider a broader range of meteorological conditions than 1-h modeling. (page 75)

58. Demonstration modeling should include an episode (or separate episodes) with both high background days and low background days. (page 75)

59. Days in which ozone from the previous day returns to Houston tend to be rare but extreme 8-h ozone events. They are likely to be difficult to model successfully because of the needed wind accuracy. (page 75)

60. Days with high pollution at inland stations are likely to involve different mixes of precursor emissions and different chemical processes than days with high pollution at coastal stations, and both types of events should be modeled. (page 76)

61. Emissions mixtures and photochemistry are unlikely to be substantially different for exceedances at different inland stations, given similar background ozone levels, so that variability need not be considered in episode selection. (page 76)

62. Monitor behavior suggests that the background trace species mixture may be fundamentally different during the spring background ozone peak than during the late summer background ozone peak. Exceedances are common in both seasons. Therefore, events in both seasons should be simulated. (page 76)

63. Modeling should focus not on the most extreme events, but rather events that fall within the third to sixth highest 8-h ozone levels in a given year. (page 77)

64. Several recent ozone episodes are suggested for modeling, including August 3-11, 2004 and May 23-31, 2003. (page 77-78)

65. Accurate simulations of 8-h ozone concentrations are likely to be less sensitive to accurate simulation of wind speed and direction than simulations of 1-h ozone concentrations, because 8-h exceedances are not as sensitive to stagnation. Other factors, such as mixing height, will be proportionally more important for accurate simulations. (page 78)