Case Study of the Late July 2005 Ground-Level Ozone Episode in North Carolina

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1. Introduction

Ground level ozone has been a major air quality issue in North Carolina for the past few decades. Shown in Figure 1 is the number of 8-hour exceedances in excess of the National Ambient Air Quality Standard (NAAQS) of 85 parts per billion in the largest metropolitan regions and statewide from 1994-2005. Ozone peaked in 1998 and 1999 near 70 exceedance days per year, with a smaller peak of 51 exceedances in 2002. The 2003 and 2004 years had very few exceedances, likely due to wet and cool conditions during these ozone seasons. With a return to more favorable meteorology for ozone formation, the number of exceedances rebounded in 2005 to 21, significantly higher than the previous 2 years, but somewhat less than the long-term average.

The most severe high ozone episode of 2005 occurred from July 25-28. This episode was quite different from typical high ozone episodes seen in past years. 8-hour ozone levels for forecast regions throughout North Carolina are shown in Table 1. 8-hour averaged ozone concentrations peaked above 110 parts per billion (ppb) in the Charlotte metropolitan region, and ozone readings above 85 ppb were observed in the Triangle (Raleigh-Durham-Chapel Hill) and Fayetteville metropolitan areas. Meanwhile, the Triad metropolitan region (Winston Salem-Greensboro-High Point) and the North Carolina Foothills and Mountains did not experience 8-hour averaged ozone concentrations in excess of the NAAQS throughout the entire episode. During this episode, ozone data was sampled onboard a University of Maryland air quality research aircraft over the Charlotte metropolitan area. In this study, we conduct an in depth

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analysis of this late July high ozone episode, including an analysis of the ozone model guidance available to the North Carolina Division of Air Quality (NC DAQ).

2. Monitoring Network and Modeling Guidance

The Ambient Monitoring Section of NCDAQ, along with other air quality agencies, uses a network of 42 monitors to gather ground level ozone data (Fig. 2). With one monitor located approximately every 2500 km^2, this network is one of the densest statewide ozone monitoring networks in the nation. The network includes several monitors located near or at the tops of mountains, which can help provide an estimate of regional background and transport of ozone. In addition to the ground based monitors, the University of Maryland air quality research aircraft sampled ozone above the Charlotte metropolitan region (RAMMP 2004) during part of the late July episode as part of a collaborative research project funded by NCDAQ. The aircraft can also measure carbon monoxide, sulfur dioxide, fine and coarse particles, and standard meteorological variables. Vertical profiles are obtained via descending or ascending spirals over an airport. Figure 3 shows the locations where the aircraft performed sampling spirals during the July event.

NCDAQ benefits from an extensive network of standard surface meteorological observations, from the Federal Aviation Administration, the NC Department of Transportation and National Weather Service ASOS and AWOS sites, and the Agricultural Research Service. Through partnerships with the State Climate Office of North Carolina, data from all of these agencies is integrated into the North Carolina Environment and Climate Observing Network, or NC ECONet (SCO 2005). The density of NC ECONet (Fig. 4) helps NCDAQ forecasters identify mesoscale boundaries and lee troughs that may affect ozone concentrations.

NCDAQ owns and operates two 915 MHz boundary layer radar wind profilers with radio acoustic sounding systems (RASS). One profiler is located at the Charlotte/Douglas International Airport, and the other is in Clayton approximately 20 km southeast of Raleigh. The boundary layer radar wind profilers are configured to sample winds at 60 m resolution up to 3000 m and at 100 m resolution up to 5500 m. Actual sampling heights are highly dependent on atmospheric conditions. The winds are continuously sampled and averaged into 25-minute observations every half hour. The RASS samples a vertical profile of virtual temperature for 5 minute every half hour up to 2000 m, but typically only to about 1000 m in height. The boundary layer radar profiler is useful in determining the vertical winds structure and mixed layer depth, while the RASS is helpful in determining the strength of low-level temperature inversions.

NCDAQ also evaluates two 3-D Eularian air quality models to assist in the forecasting process. NCDAQ has had the most experience with the Multiscale Air Quality SImulation Platform (MAQSIP) model run by Baron Advanced Atmospheric Systems. (BAMS 2004) The Penn State/NCAR MM5 model is run at 36 km and 12 km resolutions, then MAQSIP is coupled with the MM5. The MAQSIP/MM5 is run at 06 and 12 UTC at 36 and 12 km resolution. The other model used at NCDAQ is the NOAA Air Quality Forecast System (AQFS) (NOAA 2005). The NOAA AQFS is comprised of meteorological output from the North America Model (NAM), which is then fed into the CMAQ (Community Multiscale Air Quality) modeling system. NOAA AQFS is run at 06 and 12 UTC. Emissions inputs for both models are based on derivations of the 2000 National Emissions Inventory. In this paper we analyze the next day spatial ozone forecasts from the 1200 UTC cycle for both models. We will also compare ozone profiles within MAQSIP to profiles measured on the aircraft. Upper level ozone data was unavailable for NOAA AQFS.

3. Analysis

The most severe ozone event of 2005 was caused by an area of high pressure that remained over the southeast from July 24-27. Prior to the episode, a weak trough swung through the Mid-Atlantic States on July 23, triggering scattered thunderstorms across North Carolina and limiting 8-hour ozone to the lower Code Yellow range of 65 to 84 ppb (Fig. 5). Both the NOAA AQFS (Fig. 6a) and MAQSIP (Fig. 6b) forecasts for July 23 greatly over-predicted ozone, with widespread upper Code Yellow and isolated low Code Orange (85-104 ppb) in the metropolitan areas of NC. The high ozone within the models was caused by a missed precipitation forecast. Though the model predictions were too high, it gave an indication that ozone could reach Code Orange levels if clouds and precipitation were suppressed.

Early on July 24, the trough began to move offshore, and in its wake a stacked high pressure built into the southeast. Winds began to lighten, which reduced mixing and lead to a slight buildup of pollution in the boundary layer. Ozone in Charlotte rose to 80 ppb, approaching the Code Orange Action Day threshold of 85 ppb. Elsewhere across the state, ozone topped out between 55-72 ppb (Code Green to low Code Yellow) (Fig. 7). Since July 24 was a Sunday, the lower weekend levels of precursor emissions helped maintain ozone below 85 ppb.

The NOAA AQFS forecast for July 24 (Fig. 8a) was similar to the forecast for July 23, with widespread upper Code Yellow and spotty Code Orange, much higher than the observed ozone around the Code Green/Yellow threshold. The NAM (which feeds meteorology to CMAQ within NOAA AQFS) kept skies mostly clear, while observed cloud cover was near 50%. The lack of clouds within NAM caused CMAQ to produce too much ozone. The MAQSIP forecast for July 24 (Fig. 8b) was generally closer to observations, but still slightly high. The MM5 triggered some scattered afternoon convection, helping to suppress ozone formation.

On July 25, 8-hour ozone in both Charlotte and the Triangle reached the Code Orange range, with concentrations of 101 ppb and 90 ppb respectively (Fig. 9). Ozone in other areas of the state was somewhat lower, with Fayetteville in the middle Code Yellow, the Triad in the lower Code Yellow, and the western third of the state in the Code Green. The stacked high pressure had translated eastward into Georgia (Fig. 10), close enough to North Carolina to increase stagnation and cause a buildup in afternoon ozone. The Charlotte profiler data (Fig. 11) shows light and variable winds throughout the boundary layer from 12 UTC to 17 UTC, then a westerly flow of 5 knots or less the remainder of the afternoon. Forward trajectories released at 11 UTC (Fig. 12) indicate a slow northeasterly drift of ozone out of Charlotte. This trajectory would keep most of the plume south of the Triad, with perhaps some slight impacts to the Triangle and Fayetteville.

Evidence of a subsidence inversion, which would help keep ozone trapped within the boundary layer, can be seen on the Greensboro evening sounding (Fig. 13) between

800 and 850 mb. Tropical Storm Frances was tracking northeastward well off the Carolina coast, but may have been close enough to aid in subsidence over the southeastern US. The sounding was a bit unstable, with CAPE in excess of 1900 J kg^{-1} and a lifted index of -2.3, but there was enough of an inversion to keep the boundary layer mostly capped and prevent ozone from completely dispersing through the atmosphere. An ozone profile over Statesville, NC, located 45 miles north of Charlotte, during the afternoon of July 25 shows a slight buildup of ozone underneath the inversion (Fig. 14). However, concentrations were not excessively high above the inversion layer, suggesting little in the way of regional influences on the ozone within North Carolina. Ozone at the ridge tops remained in the lower Code Yellow or Code Green, supporting the premise that little in the way of ozone was transported into the Carolinas.

The models captured the 8-hour ozone quite well on July 25. The NOAA AQFS prediction (Fig. 15a) matched observations closely not only within North Carolina but also over the entire eastern seaboard. The NOAA AQFS correctly indicated that only the Charlotte area would have an exceedance. MAQSIP (Fig. 15b) was slightly low, indicating 8-hour ozone just below an exceedance around Charlotte. A vertical profile within the model at Statesville (Fig. 14) showed that MAQSIP generated too much ozone at the surface. Both models predicted too much ozone throughout the Triad.

On July 26, 8-hour ozone concentrations pushed well above 85 ppb (Fig. 16) as the stacked high pressure moved directly over the Carolinas (Fig. 17). Winds were very light, with winds below 5 knots throughout the boundary layer (Fig. 18). The nearly calm conditions led to good stagnation. The full sunshine, combined with the stagnation, pushed 8-hour ozone into the Code Red range (105-124 ppb) in Charlotte, with 1-hour concentrations peaking above 140 ppb. Ozone reached well into the Code Orange range around Raleigh and Fayetteville. The southernmost monitor in the Triad, located in Cooleemee, caught some of the high ozone from Charlotte and reached an 8-hour value of 84 ppm, just shy of Code Orange. The remainder of the Triad, as well the Asheville and Hickory areas, remained well below 85 ppb (Code Orange). In past years, rarely would a region reach the Code Red range while other regions, and especially the ridge tops, remained in the Code Green. Forward trajectories (Fig. 19) indicate that most of the ozone formed in Charlotte would be carried first toward the south, and then later toward the east. Thus, areas north and west of Charlotte would not experience the Charlotte ozone plume.

The atmosphere was not especially loaded for high ozone. The morning Greensboro, NC sounding (Fig. 20) shows no hint of the subsidence inversion that was present the prior evening. Morning aircraft spirals over Lancaster (Fig. 21) and Shelby (Fig. 22) measured ozone below 65 ppb from the surface to 9000 feet. The ozone formed the previous day had mixed thoroughly throughout the atmosphere, and no significant 'carry-over' ozone would be available to jump-start ozone. The lack of left-over ozone from the previous day makes the observed 8-hour ozone above 105 ppb all the more remarkable.

The evening sounding from Greensboro, NC (Fig. 23) indicated the atmosphere was well mixed to nearly 700 mb, with a very weak inversion at the top of the mixed layer. The sounding was fairly unstable, with CAPE of 2350 J kg^{-1} and a lifted index of -5.1. During an afternoon spiral over Concord, NC (Fig. 26) the UMd aircraft measured ozone between 110-120 ppb up to a height of 5500 feet, indicating prolific mixing.

Both models had reasonably good performance during the peak of the episode. NOAA AQFS (Fig. 27a) correctly predicted the Code Red around Charlotte, and the Code Orange values between 85 and 105 ppb on the south side of the Triangle. Ozone around Fayetteville is displaced a little north compared to observations, possibly because the sea breeze was too intense within the NAM. NOAA AQFS correctly predicted the spotty coverage of ozone, with Code Green at the coast and in the western mountains, but over-predicted ozone in the Triad. MAQSIP (Fig. 27b) predicted 8-hour ozone just above 85 ppb, or in the low Code Orange, around the major metropolitan areas. The ozone plumes seem to push northward out of the major metro areas, while actual plumes were directed more southerly, if they actually moved at all. Like the NOAA AQFS, predicted ozone in the Triad was too high. MAQSIP replicated the morning ozone profile fairly well over Lancaster (Fig. 21), and was just slightly high in the lowest 5000 feet around Shelby (Fig. 22). During the afternoon, the ozone profiles matched aircraft observations very well over Lancaster (Fig. 24) and Shelby (Fig. 25). MAQSIP predicted too little ozone over Concord (Fig. 26), and was about 1000 feet too shallow with the vertical extent of high ozone. Both models correctly indicated that ozone in excess of 85 ppb would be isolated to the major metropolitan areas.

Ozone declined slightly on July 27, but remained well within the Code Orange range (85-105 ppb) in Charlotte, the Triangle, and Fayetteville (Fig. 28). The stacked high pressure (Fig. 29) was just beginning to lose its grip over the southeast as a trough began to dig southward over the Great Lakes. Ozone in the Mountains and Hickory remained relatively low, due to the lack of an inversion above the surface. Ozone in the Triad also remained relatively low, as light westerly winds directed the Charlotte ozone plume due east (Fig. 30). Forward trajectories (Fig. 31) indicate ozone generated in Charlotte would drift slowly east-northeast. The GSO evening sounding (Fig. 32) is even better mixed than the previous day, with no hint of an inversion at the top of the boundary layer. CAPE was near 2400 J kg^{-1}, with lifted index below –5, indicating the potential for deep convective mixing. Aircraft data from Shelby, Lancaster, and Concord (Figs. 33, 34, and 35, respectively) on the morning of July 27 show no residual ozone above 65 ppb above 1500 feet, and therefore no significant regional ozone transport. Most of the ozone generated on the previous day had been dispersed throughout a rather deep mixed layer, and any ozone generated on July 27 was quickly mixed throughout the atmosphere. Given the efficient convective mixing, it is quite remarkable that ozone actually exceeded 85 ppm.

For July 27, both models predicted ozone above 105 ppb for Charlotte, but observed ozone was only 90 ppb. The NOAA AQFS (Fig. 36a) was generally close to observations in both concentration levels and coverage. However, the NOAA model predicted too much ozone in the Triad, and the area of ozone above 85 ppb near the Triangle and Fayetteville was positioned slightly north of observations. MAQSIP (Fig. 36b) indicated slightly wider coverage of ozone than what was observed, and had a similar over prediction in the Triad and a similar placement of the ozone around the Triangle and Fayetteville. A comparison of the morning ozone profiles (Figs. 33-35 shows that the MAQSIP kept too much residual ozone within the boundary layer. The residual ozone within the model quickly mixed down with daytime convective mixing, and led to an over-prediction of ozone in the Charlotte and Triad metropolitan regions.

The episode drew to a close on July 28 with ozone above 85 ppb confined to a couple of locations around Charlotte and Fayetteville (Fig. 37). The stacked high pressure responsible for the high ozone the 3 previous days had weakened and translated east by late evening of July 27. In the wake of the high, an upper level trough was moving east through Tennessee, while at the surface a weak cold front was pushing slowly through North Carolina (Fig. 38). After steadily moving though the northern $2/3^{rds}$ of the state, the front temporarily halted its forward progress across the southern portion of North Carolina during the afternoon essentially from a line from Charlotte eastward through Fayetteville. The pooling of pollutants just ahead of the front pushed ozone into the Code Orange in Charlotte and Fayetteville. As the upper trough translated further east, the front pushed south of North Carolina and evacuated the most polluted air out of the state. The upper trough also helped to instigate more shallow convection and cloud formation, shutting down significant ozone production and bringing an end to the ozone episode.

The model performance for July 28 degraded with the slow passage of the front across the state. The NOAA AQFS (Fig. 39a) dropped 8-hour ozone levels into the Code Green and Yellow across the state. Slight differences in the timing and movement of the front within the NAM seem to be responsible for the low predicted ozone. MAQSIP (Fig. 39b) was generally close with the magnitude of ozone, but was too far west with the spatial coverage. The forward progress of the front within the MM5 was too slow, keeping the front in the west-central portion of the state. Both models failed to capture the high ozone around the Fayetteville region, mainly due to the improper handling of the frontal boundary within the meteorological models.

The front pushed south of North Carolina on July 29, bringing a cleaner airmass to the state. An upper level trough was positioned overhead, which enhanced cloudiness and helped keep ozone in the Code Green (Fig. 40). The models captured the clean conditions reasonably well, with both models indicating 8-hour ozone in the Code Green and lower Code Yellow range (Fig. 41).

4. Discussion and Future Plans

The ozone episode of July 25-28 2005 was quite unique. Despite very high mixing heights, a weak subsidence inversion, and little regional ozone loading, 8-hour ozone topped out above 110 ppb in Charlotte, and between 85-98 ppb in Fayetteville and the Triangle. Hourly ozone peaked above 140 ppb a few miles northeast of Charlotte, with ozone above 110 ppb extending to an altitude of 5000 feet. Meanwhile, ozone remained below 65 ppb in the mountains, and below 85 ppb in the Triad and Hickory regions. On the July 26 and July 27, 8-hour ozone in Charlotte, the Triangle, and Fayetteville was well above 85 ppb, while 8-hour ozone in the Triad was 65-70 ppb. This difference in ozone between major metropolitan areas within North Carolina is almost unheard of in a stacked high pressure regime such as what occurred during this episode.

There are a few possible explanations why ozone in the Triad and the western third of the state remained so low. There was little in the way of regional transport of ozone, as seen from the low ozone at the ridge tops and the aircraft data. The lack of a strong subsidence inversion likely played a primary role in the lack of regional ozone loading. Another explanation was that the dominant wind direction was westerly to west-southwesterly. The prevailing winds kept the heart of the Charlotte ozone plume mostly south of the Triad, and south and east of Hickory and the mountains. In the past, the Charlotte "ozone plume" has played a role in many of the exceedance days in the Triad, Hickory, and the Mountains. Lastly, reductions in emissions in North Carolina and elsewhere in the country may finally be having an effect on ozone concentrations. An EPA Press release and report issued on August 18, 2005 suggested that NOx reductions, as part of the NOx SIP Call, contributed to the improved air quality across the Southeast.

Overall the models performed fairly well during this event. Both the NOAA AQFS and the MAQSIP models were premature with higher ozone at the beginning of the ozone event, but were generally quite close to observations during the episode itself. The poor model performance prior to the episode shows the importance of examining the meteorological models that feed the air quality models. The high predicted ozone on July 23 and July 24 was likely the result of too little convection and cloud cover in the ETA and the MM5. However, the models did show that the potential for ozone exceedances in North Carolina if skies were to remain mostly sunny.

In the future, we would like to perform modeling sensitivity studies to determine if emissions reductions may have led to lower ozone in this episode, as well as the rest of 2005. We propose to run CMAQ on episodes in 2005 using emissions from 2005, and comparing that to CMAQ runs using older 2002 emissions. In addition, sensitivity runs will be made for episodes in 2002 using emissions from 2002, and then comparing that to CMAQ runs using 2005 emissions. If the same systematic differences appear in both sets of model runs, then we can be fairly confident determining whether or not emissions reductions or meteorology had an effect on ozone concentrations in 2005.

5. References

BAMS, 2004 – Baron Advanced Meteorological Systems (BAMS) Multiscale Air Quality SImulation Platform (MAQSIP): http://www.baronams.com/products/maqsip/

NOAA, 2005 – The NOAA Air Quality Forecast System: http://www.weather.gov/aq/supplementalpages/aq-pdd.htm

SCO, 2005 - State Climate Office of North Carolina at NC State University: http://www.nc-climate.ncsu.edu/econet/

RAMMP, 2004 - The Regional Atmospheric Measurement, Modeling and Prediction Program: http://www.atmos.umd.edu/~RAMMPP/

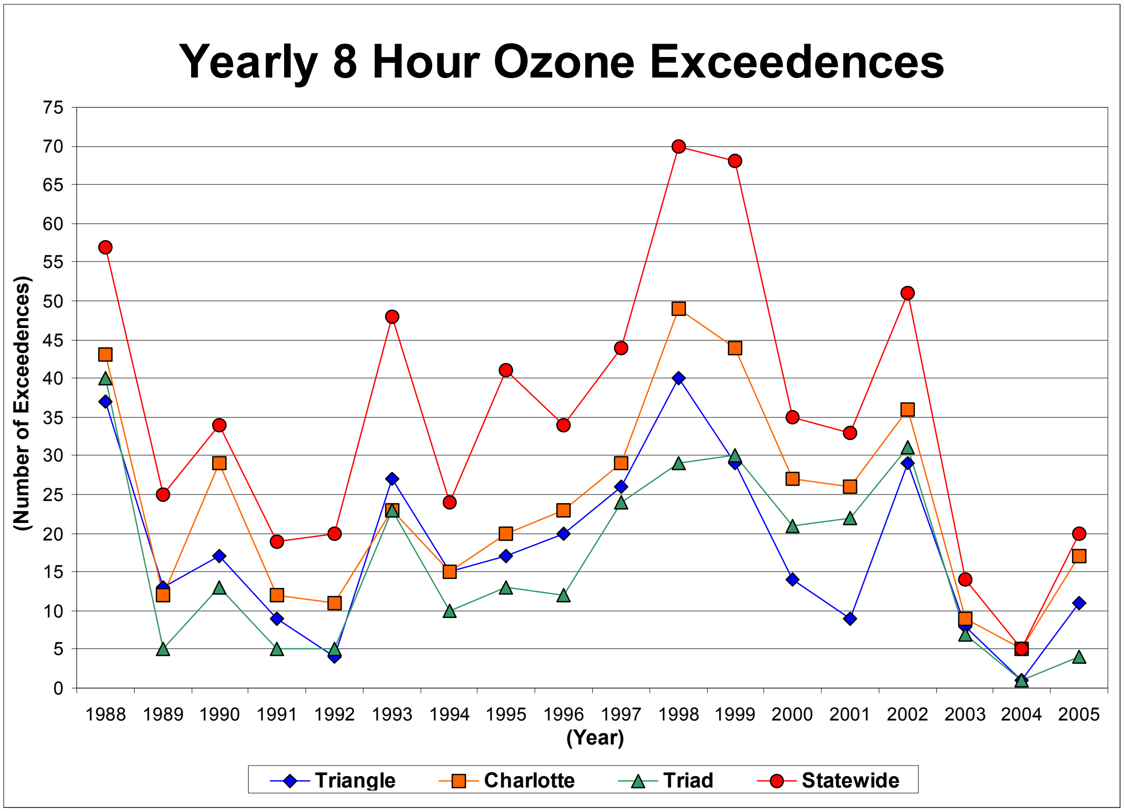

Figure 1. Total number of yearly 8-Hour ozone exceedance days for the Triangle, Charlotte, the Triad, and statewide from 1988 to 2005.

Peak 8-hour ozone concetrations (ppb) for each forecast region

Forecast Regions	23-Jul	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul	29-Jul
Asheville - Ridge Tops	71	64	59	58	54	53	51
Asheville - Valleys	62	55	59	60	55	43	39
Hickory	57	63	60	64	58	73	37
Charlotte	70	80	**101**	**111**	**90**	**86**	44
Triangle	65	72	**90**	**89**	**98**	76	57
Fayetteville	71	68	76	**98**	**94**	**95**	57
Triad	63	65	69	84	68	75	52
Statewide	71	80	**101**	**111**	**98**	**95**	58

Table 1. 8-hour ozone concentrations in each forecast region from July 23 to July 29.

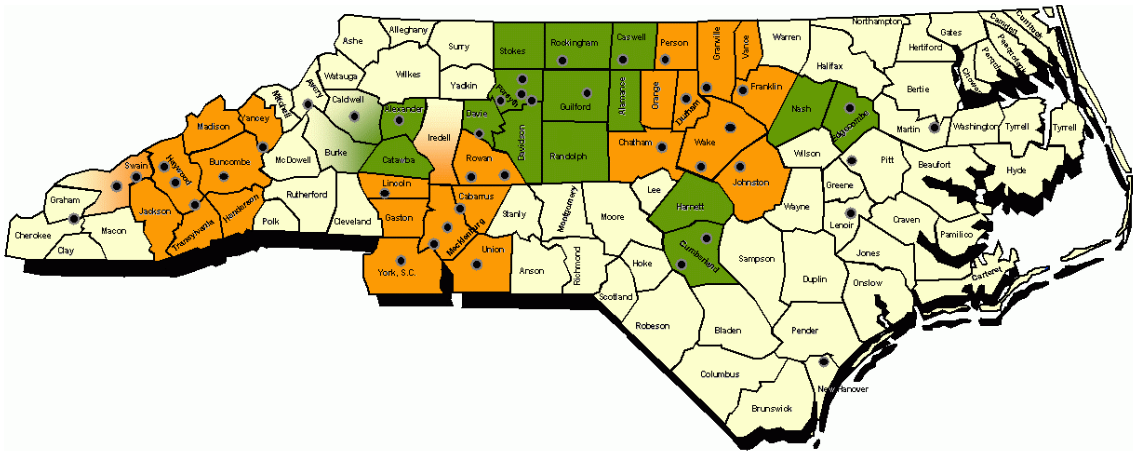

Figure 2. North Carolina's ozone network and various forecast areas.

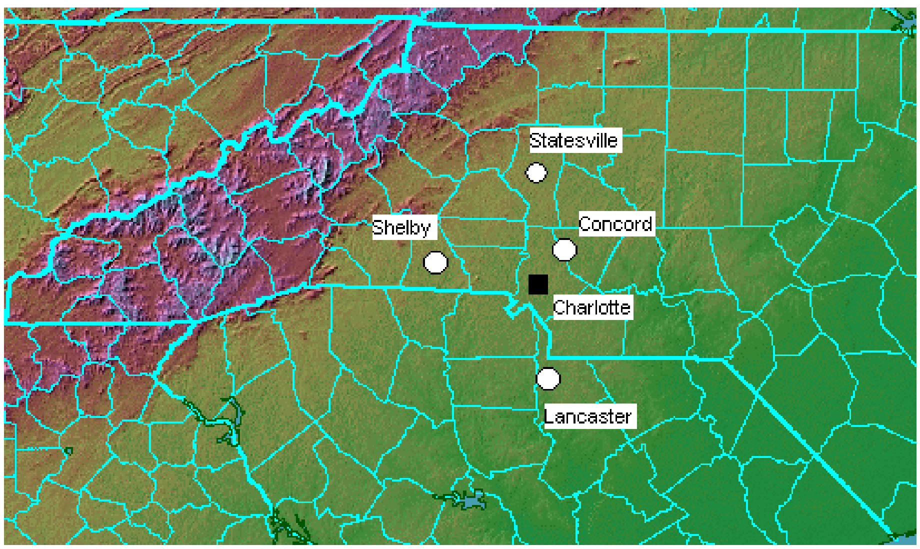

Figure 3. Locations of spirals performed by the University of Maryland Air Quality Research Aircraft.

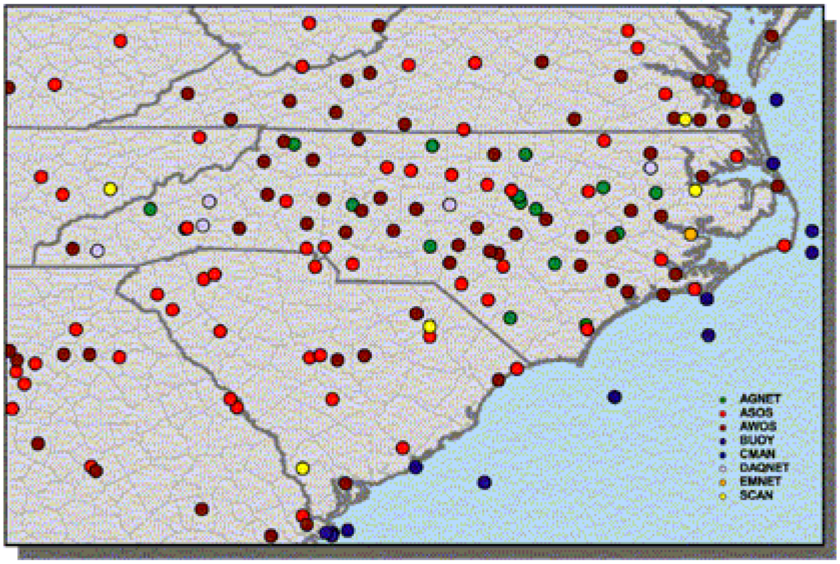

Figure 4. North Carolina State Climate Office ECONet.

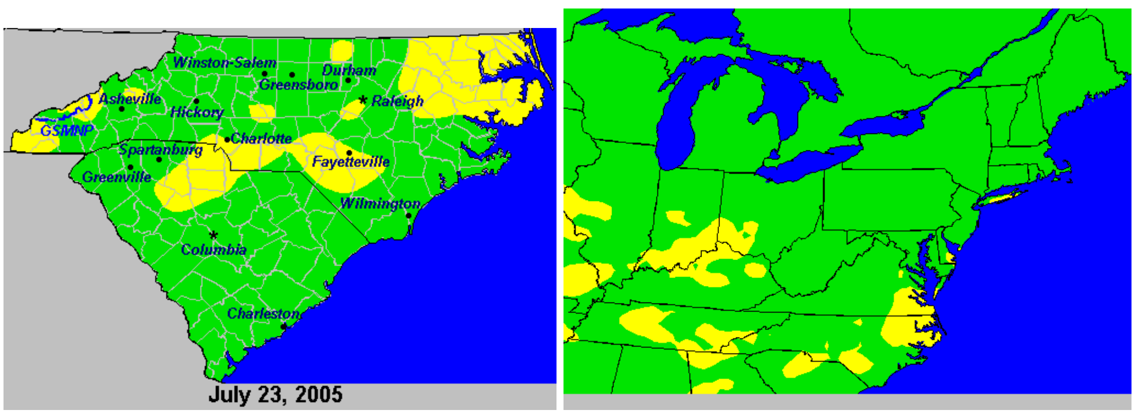

Figure 5. Observed 8-hour ozone for July 23, 2005 in (a) North Carolina and (b) the eastern US. Green shading is below 65 ppb, Yellow shading is 65-84 ppb, and Orange shading is 85-104 ppb.

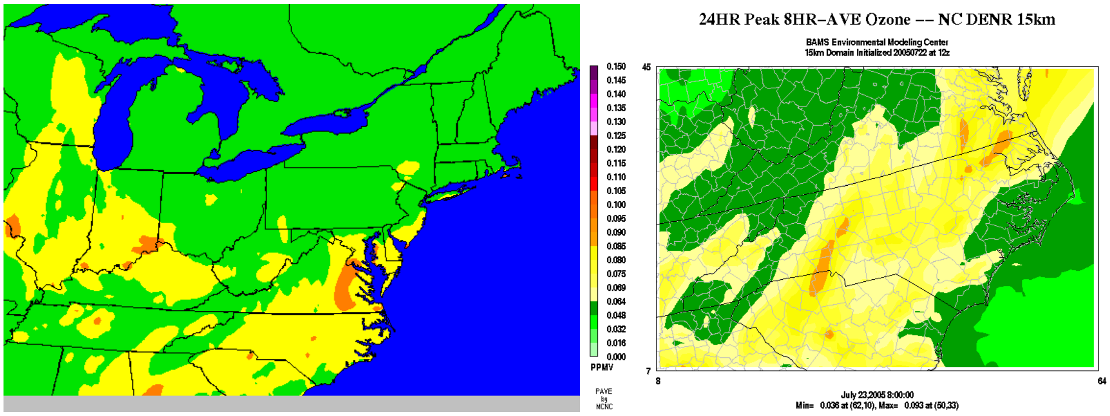

Figure 6. 8-hour predicted ozone for 7/23, initialized 7/22 12 UTC, for (a) NOAA AQFS and (b) MAQSIP.

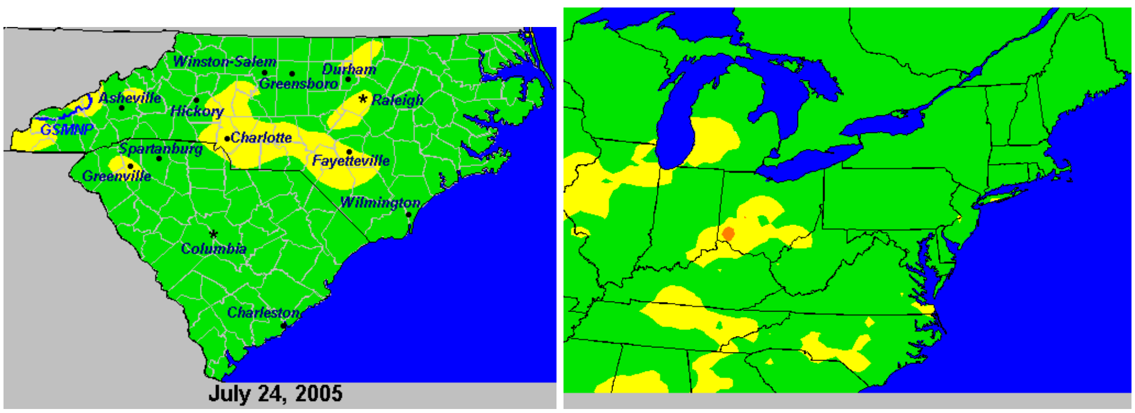

Figure 7. Observed 8-hour ozone for July 24, 2005 in (a) North Carolina and (b) the eastern US. Green shading is below 65 ppb, Yellow shading is 65-84 ppb, and Orange shading is 85-104 ppb.

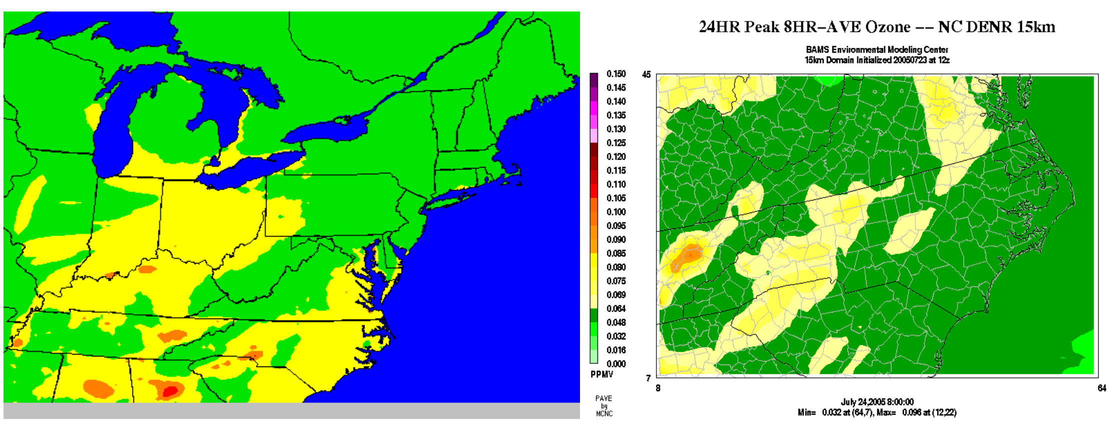

Figure 8. 8-hour predicted ozone for 7/24, initialized 7/23 12 UTC, for (a) NOAA AQFS and (b) MAQSIP.

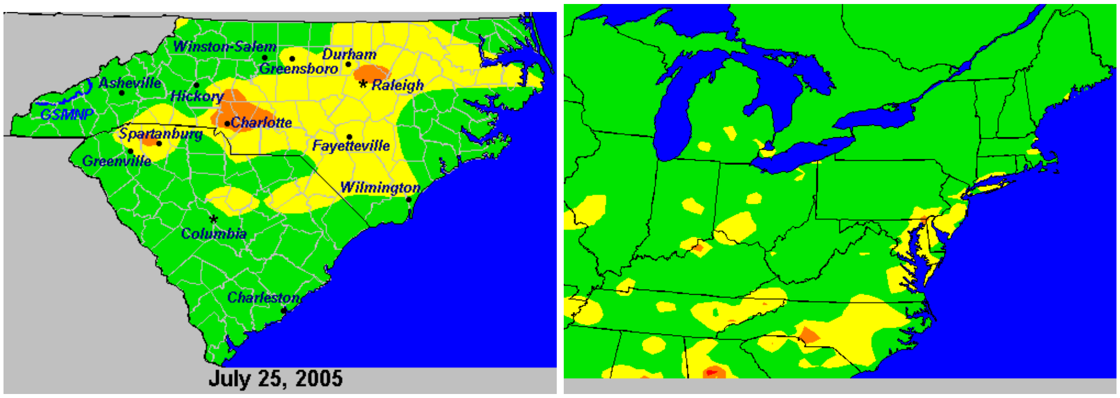

Figure 9. Observed 8-hour ozone for July 25, 2005 in (a) North Carolina and (b) the eastern US. Green shading is below 65 ppb, Yellow shading is 65-84 ppb, and Orange shading is 85-104 ppb.

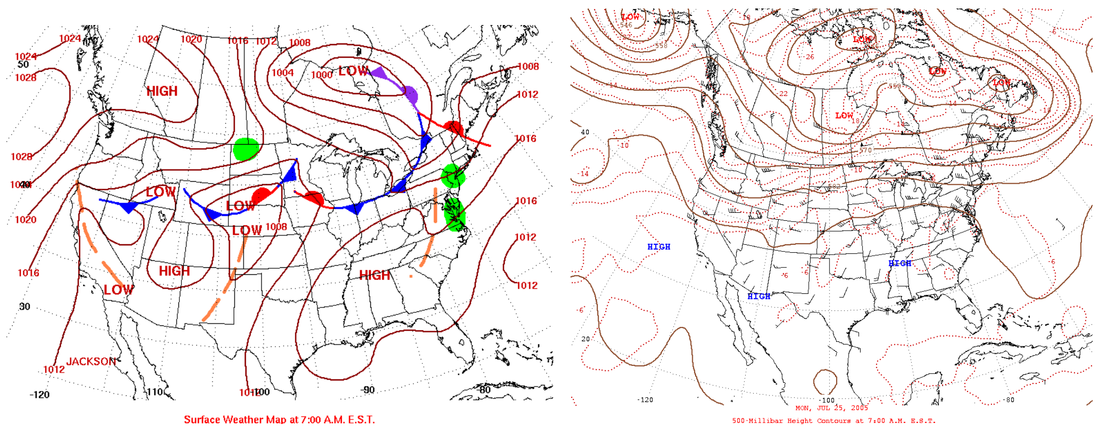

Figure 10. NOAA daily weather maps on July 25 12 UTC showing (a) surface analysis and (b) 500 mb analysis.

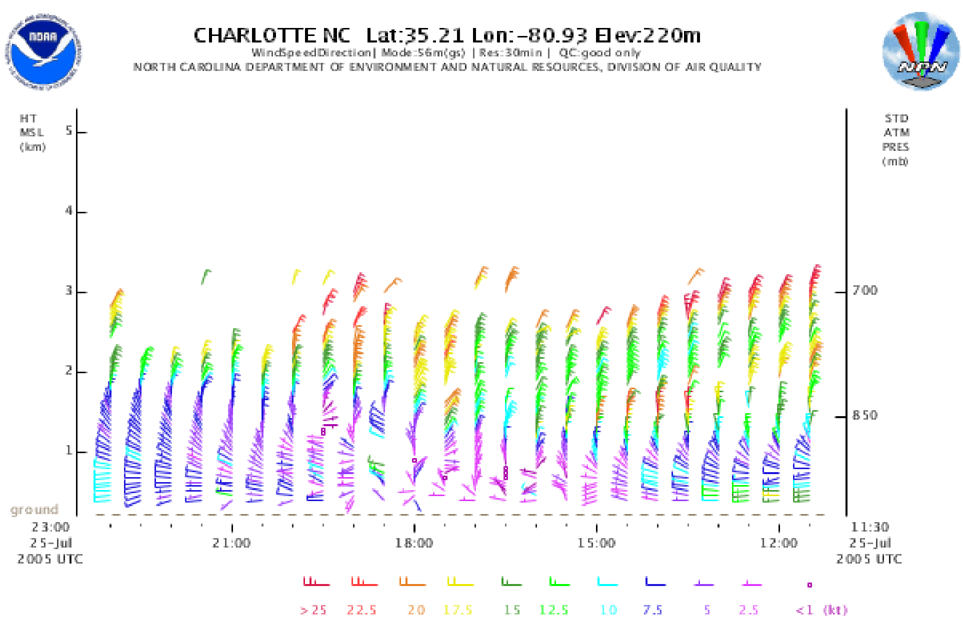

Figure 11. Winds from the Charlotte radar profiler on July 25 1130-2300 UTC.

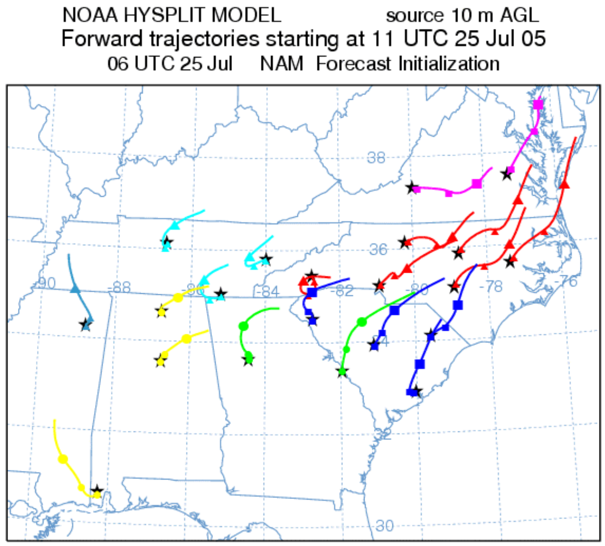

Figure 12. Forward trajectories starting at July 25 11 UTC from HYSPLIT, using NAM Initialized July 25 06 UTC

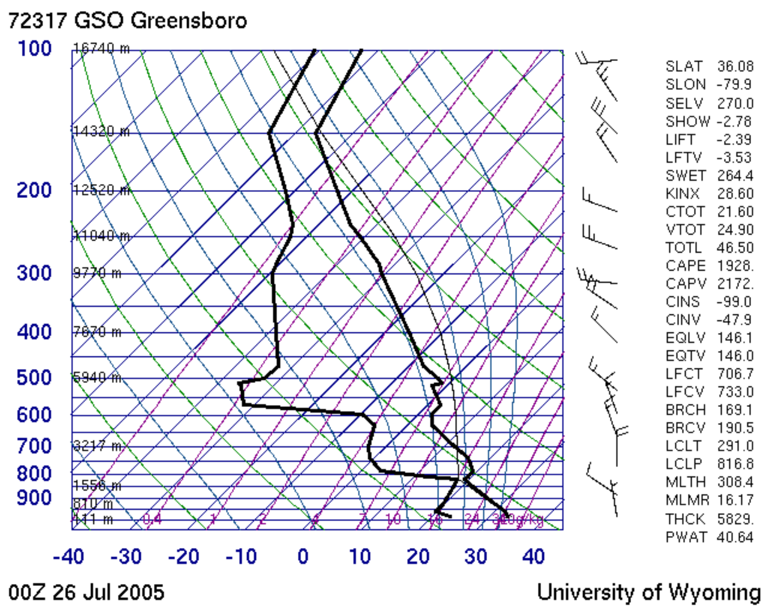

Figure 13. Greensboro sounding at July 26 00 UTC.

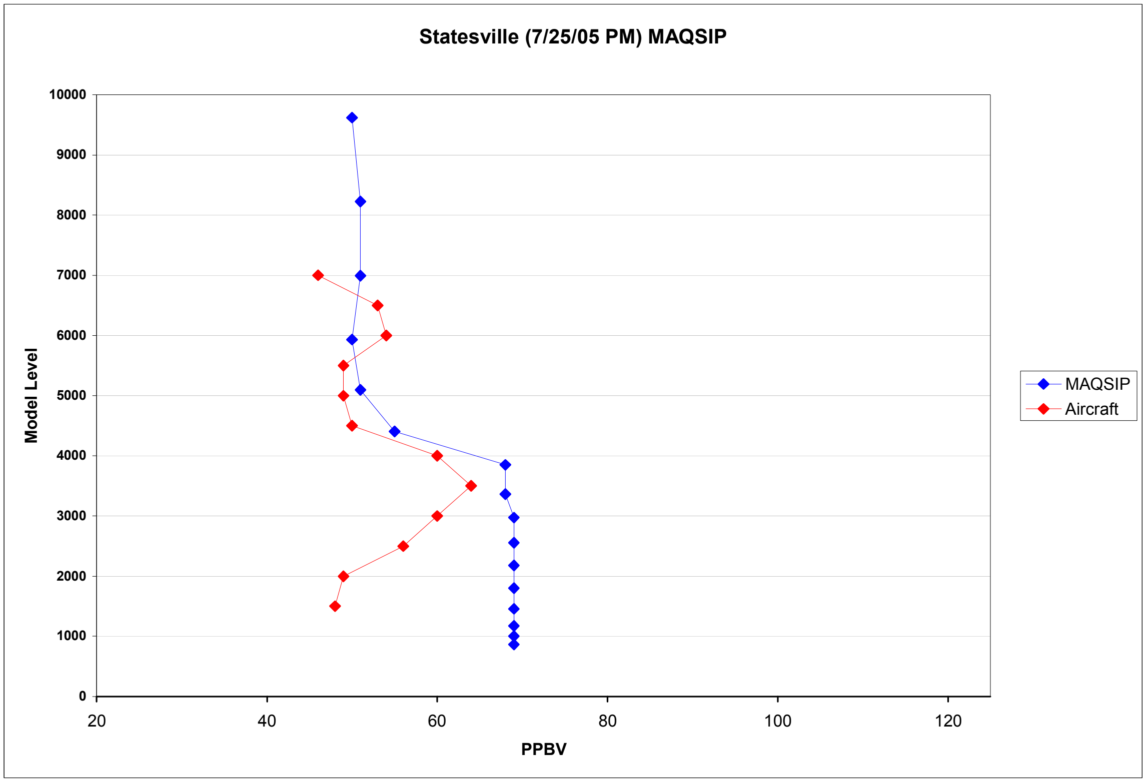

Figure 14. Ozone profiles from the UMD aircraft (red) and MAQSIP (blue) over Statesville, NC during the afternoon of July 25.

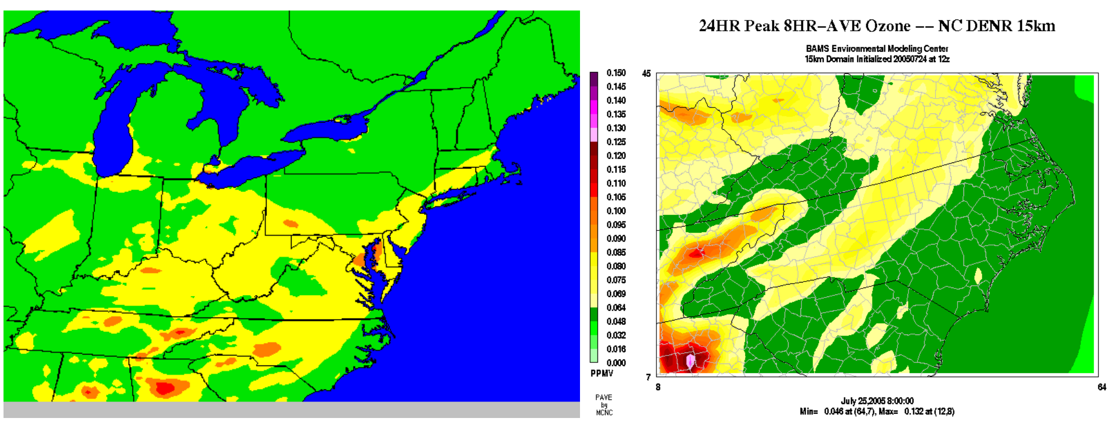

Figure 15. 8-hour predicted ozone for 7/25, initialized 7/24 12 UTC, for (a) NOAA AQFS and (b) MAQSIP.

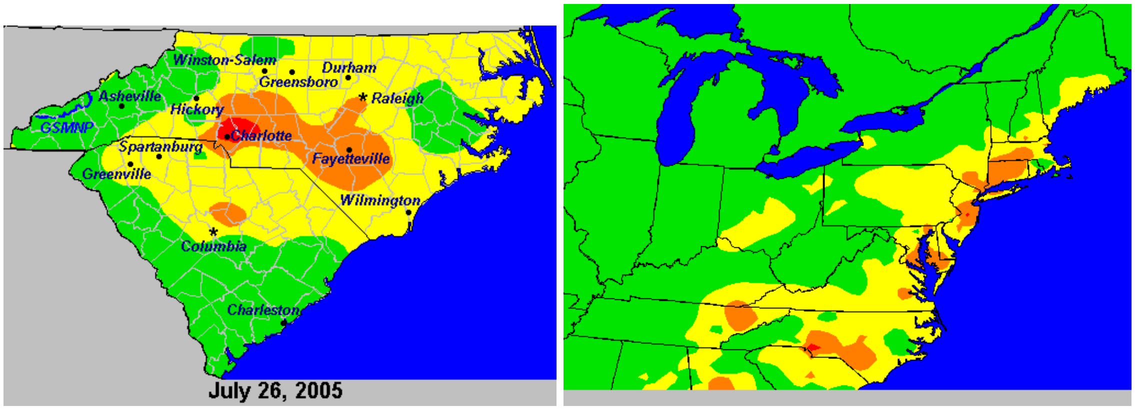

Figure 16. Observed 8-hour ozone for July 26, 2005 in (a) North Carolina and (b) the eastern US. Green shading is below 65 ppb, Yellow shading is 65-84 ppb, Orange shading is 85-104 ppb, and Red shading is 105-124 ppb.

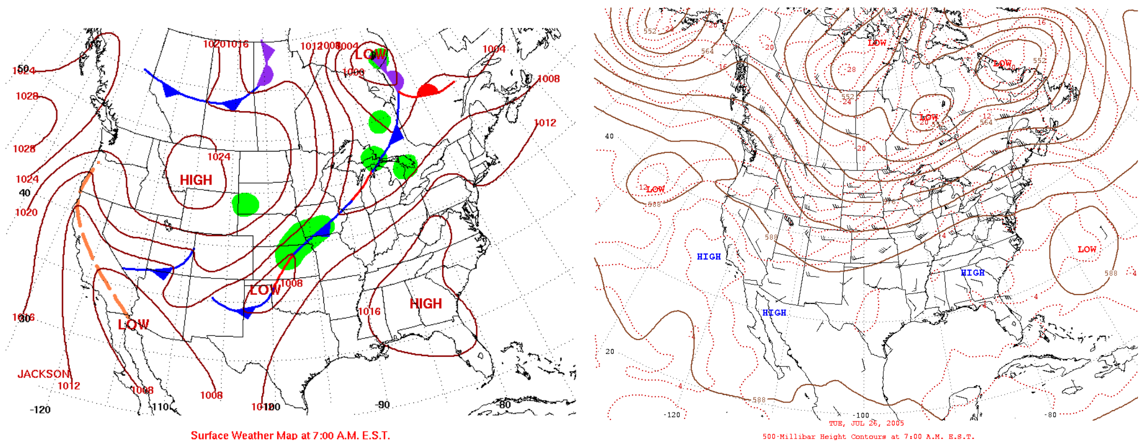

Figure 17. NOAA daily weather maps on July 26 12 UTC showing (a) surface analysis and (b) 500 mb analysis.

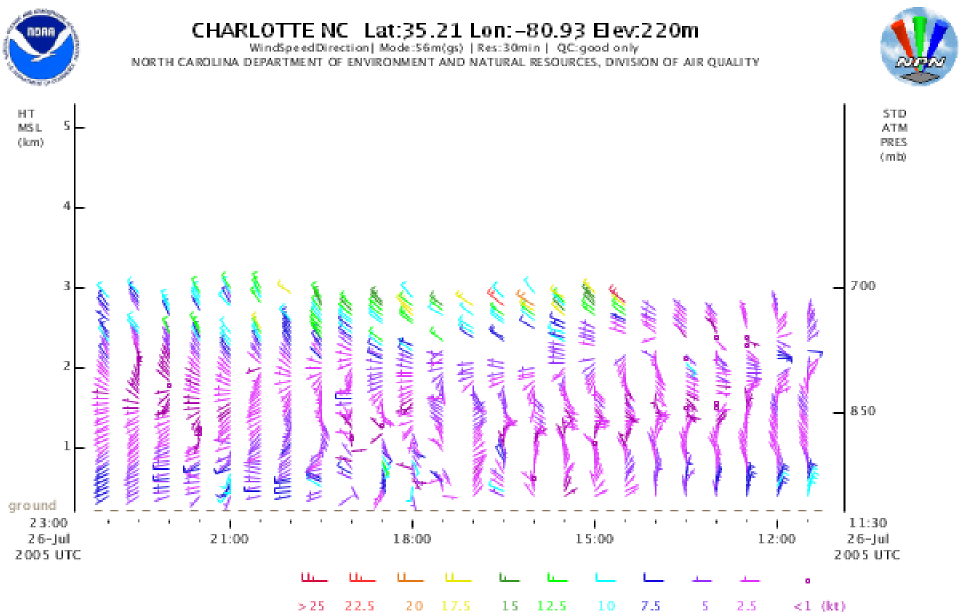

Figure 18. Winds from the Charlotte radar profiler on July 26 1130-2300 UTC.

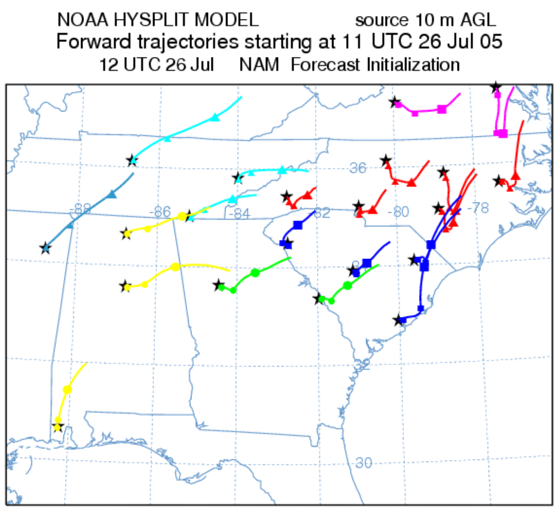

Figure 19. Forward trajectories starting at July 26 11 UTC from HYSPLIT, using NAM Initialized July 26 06 UTC

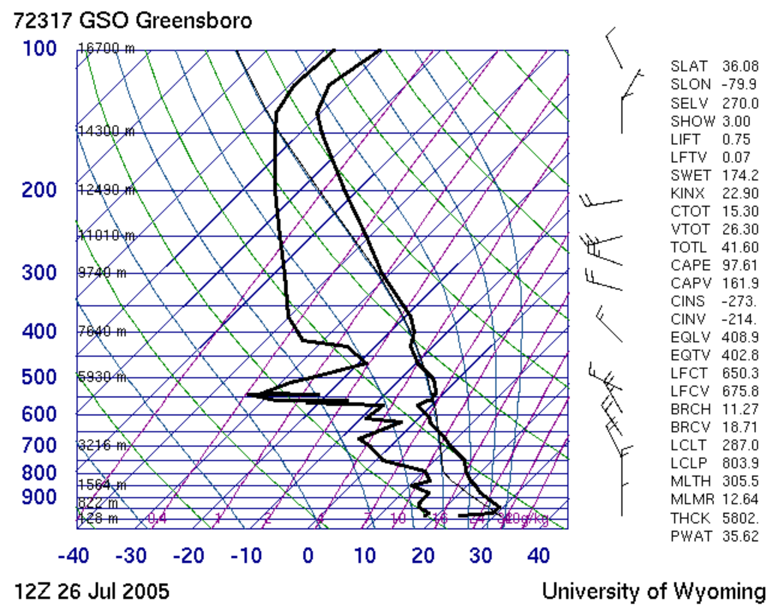

Figure 20. Greensboro sounding at July 26 12 UTC.

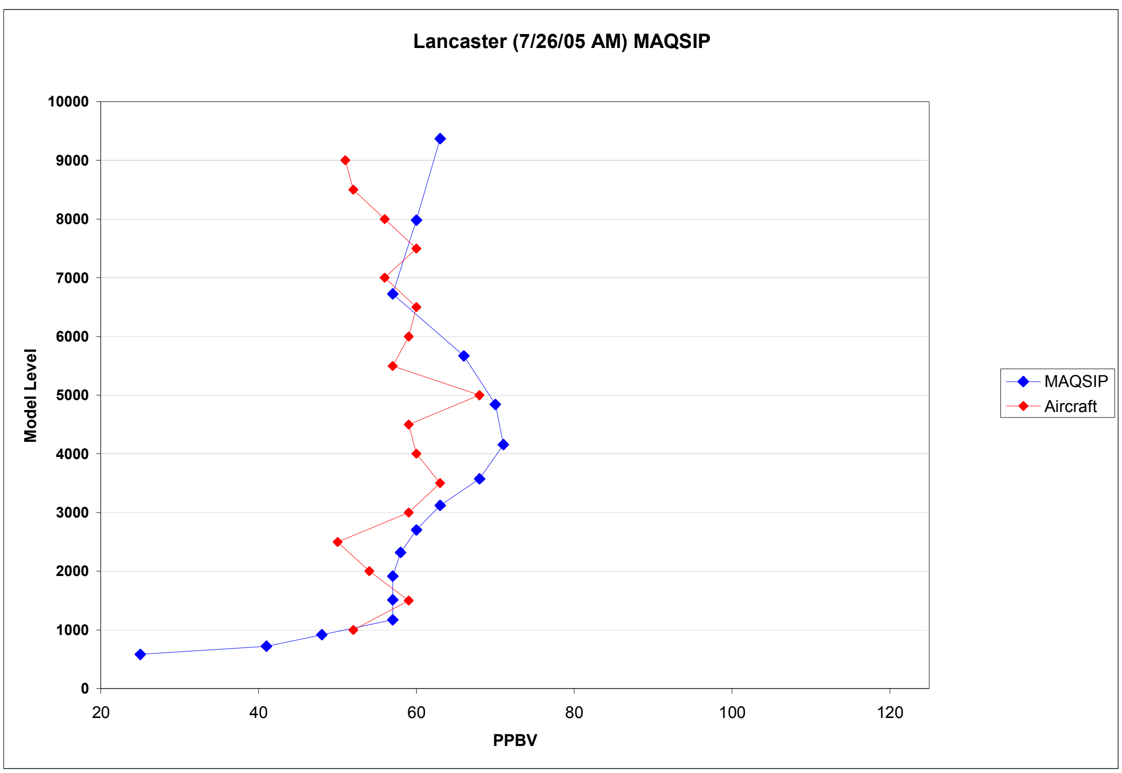

Figure 21. Ozone profiles from the UMD aircraft (red) and MAQSIP (blue) over Lancaster, NC during the morning of July 26.

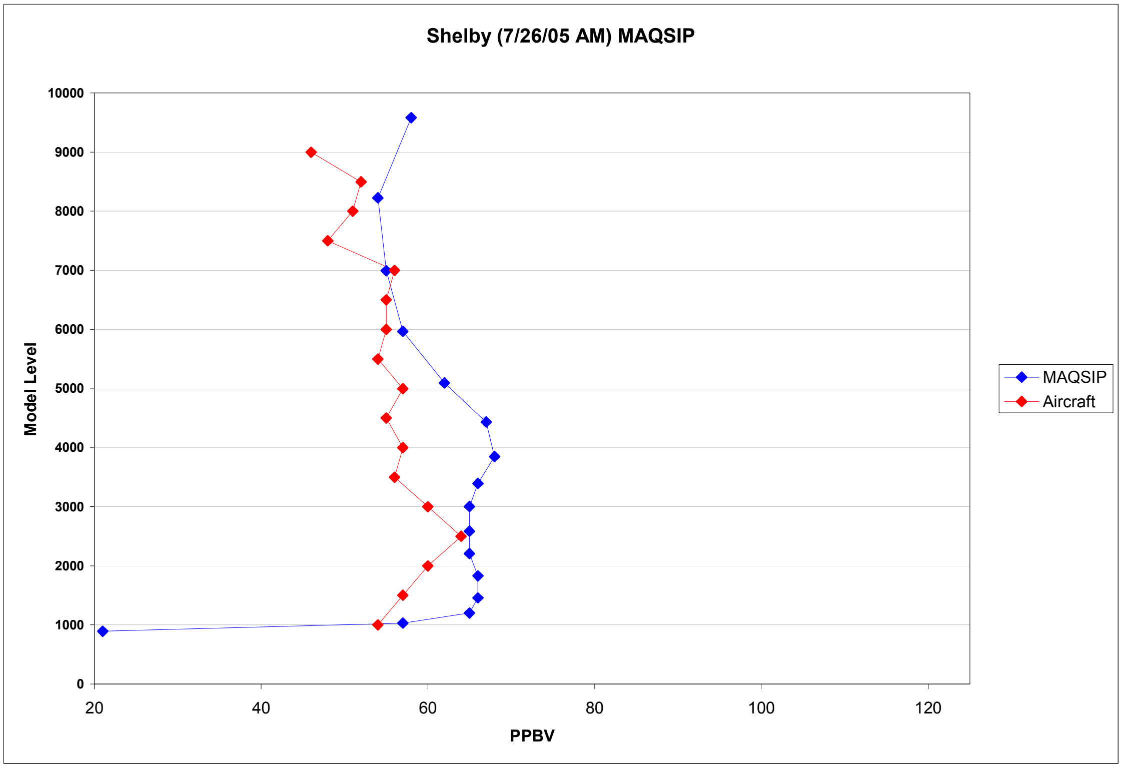

Figure 22. Ozone profiles from the UMD aircraft (red) and MAQSIP (blue) over Shelby, NC during the morning of July 26.

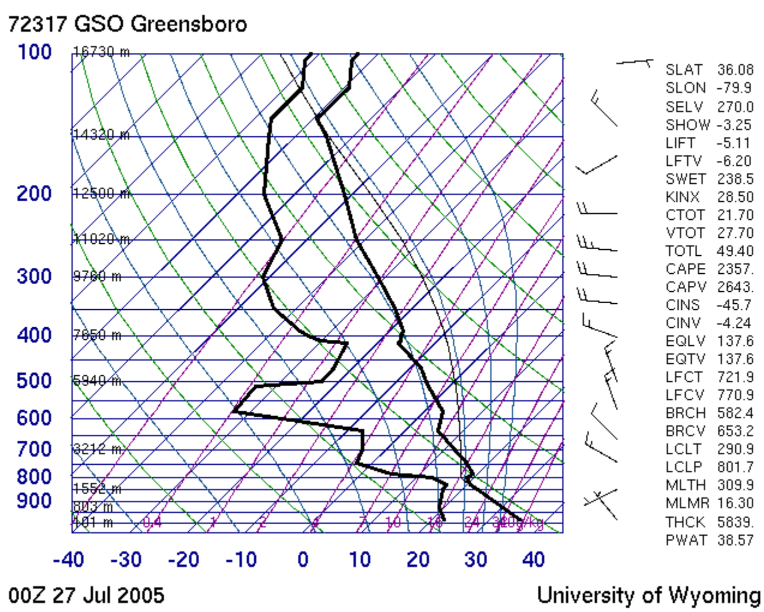

Figure 23. Greensboro sounding at July 27 00 UTC.

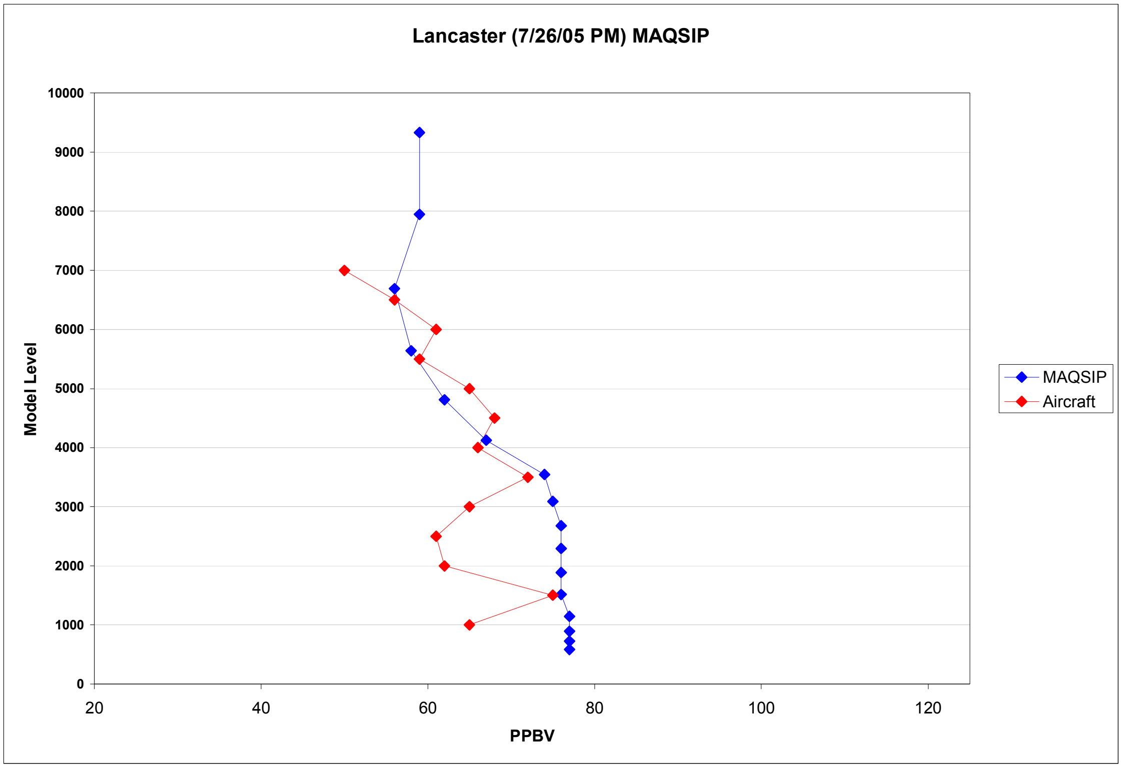

Figure 24. Ozone profiles from the UMD aircraft (red) and MAQSIP (blue) over Lancaster, NC during the afternoon of July 26.

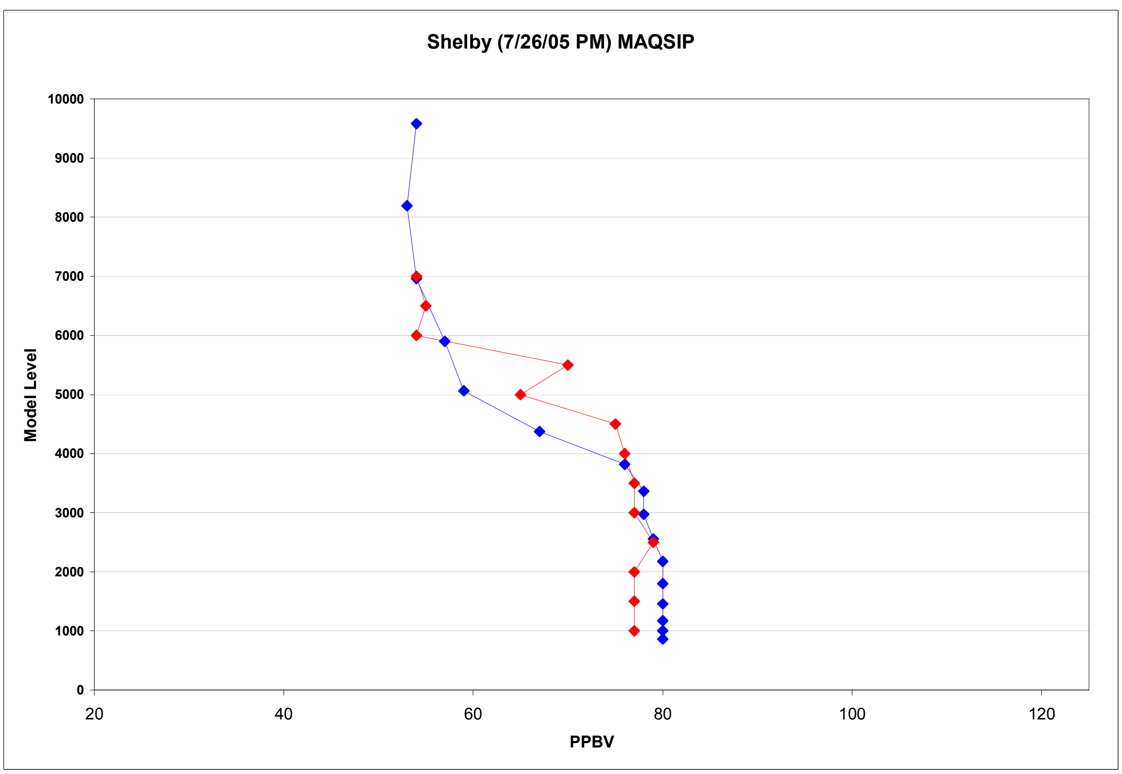

Figure 25 Ozone profiles from the UMD aircraft (red) and MAQSIP (blue) over Shelby, NC during the afternoon of July 26.

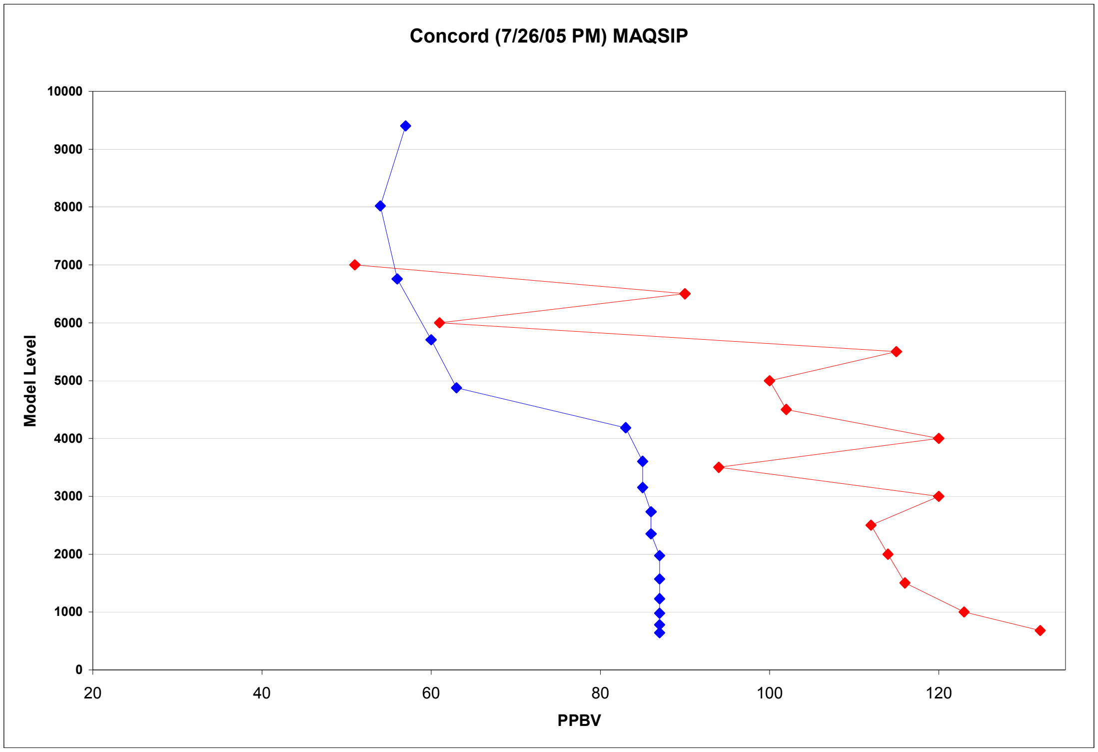

Figure 26. Ozone profiles from the UMD aircraft (red) and MAQSIP (blue) over Concord, NC during the afternoon of July 26.

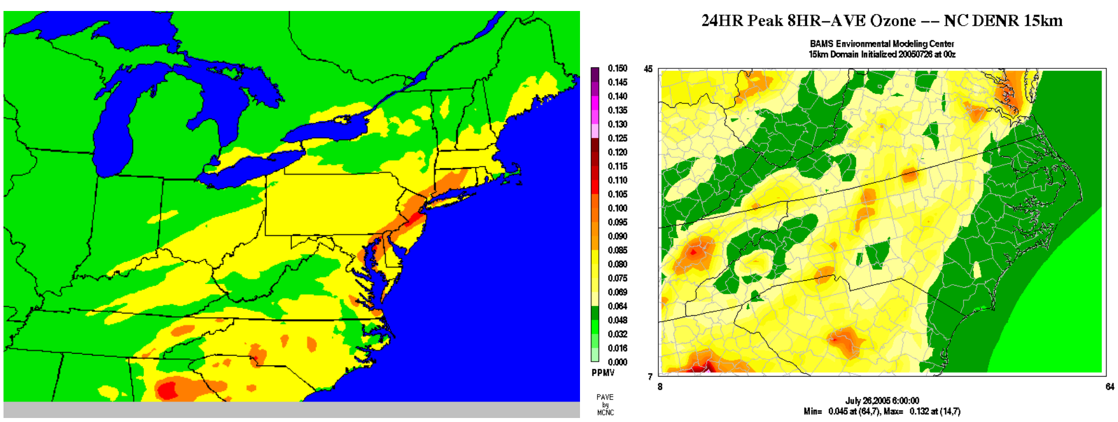

Figure 27. 8-hour predicted ozone for 7/26, initialized 7/25 12 UTC, for (a) NOAA AQFS and (b) MAQSIP.

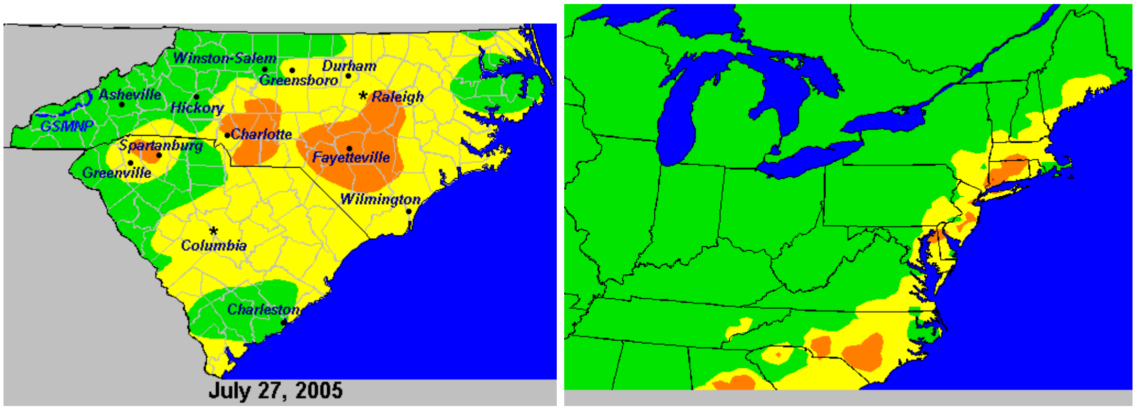

Figure 28. Observed 8-hour ozone for July 27, 2005 in (a) North Carolina and (b) the eastern US. Green shading is below 65 ppb, Yellow shading is 65-84 ppb, Orange shading is 85-104 ppb, and Red shading is 105-124 ppb.

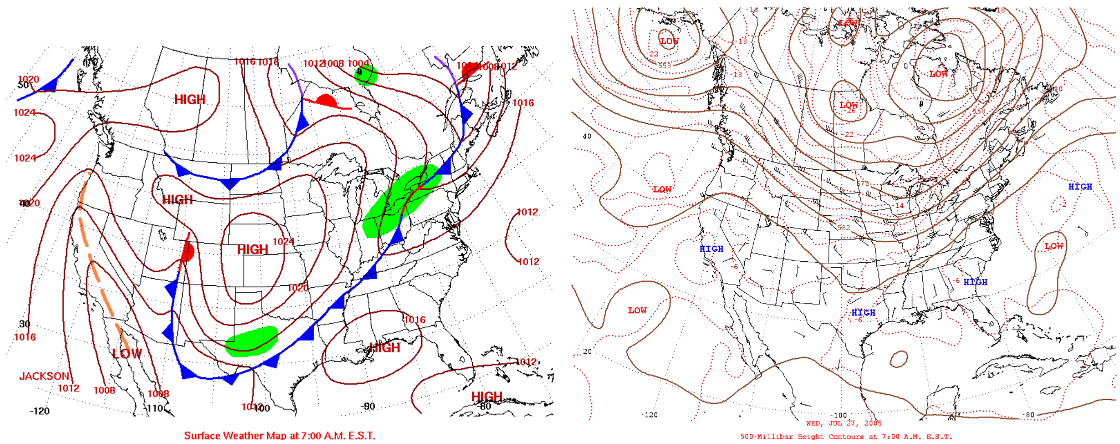

Figure 29. NOAA daily weather maps on July 27 12 UTC showing (a) surface analysis and (b) 500 mb analysis.

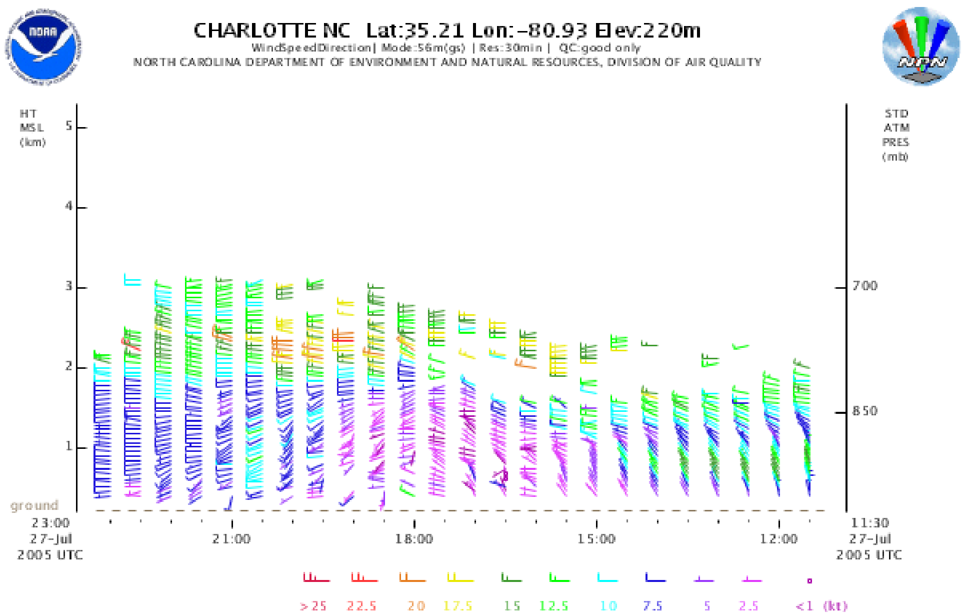

Figure 30. Winds from the Charlotte radar profiler on July 27 1130-2300 UTC.

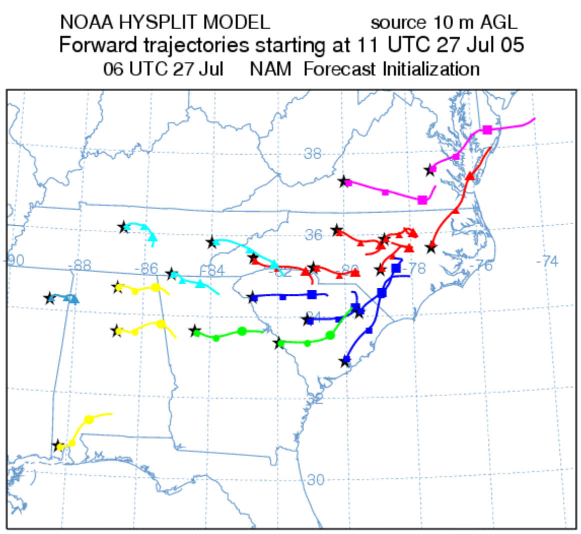

Figure 31. Forward trajectories starting at July 27 11 UTC from HYSPLIT, using NAM Initialized July 27 06 UTC

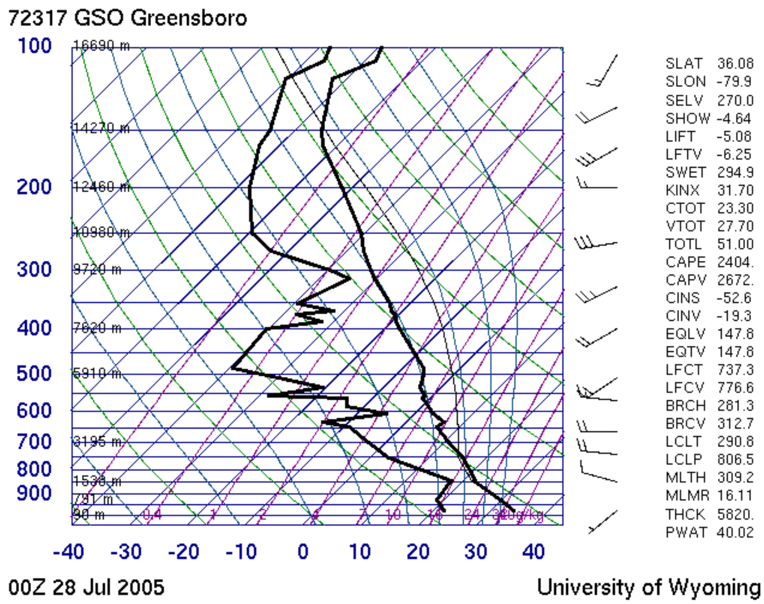

Figure 32. Greensboro sounding at July 28 00 UTC.

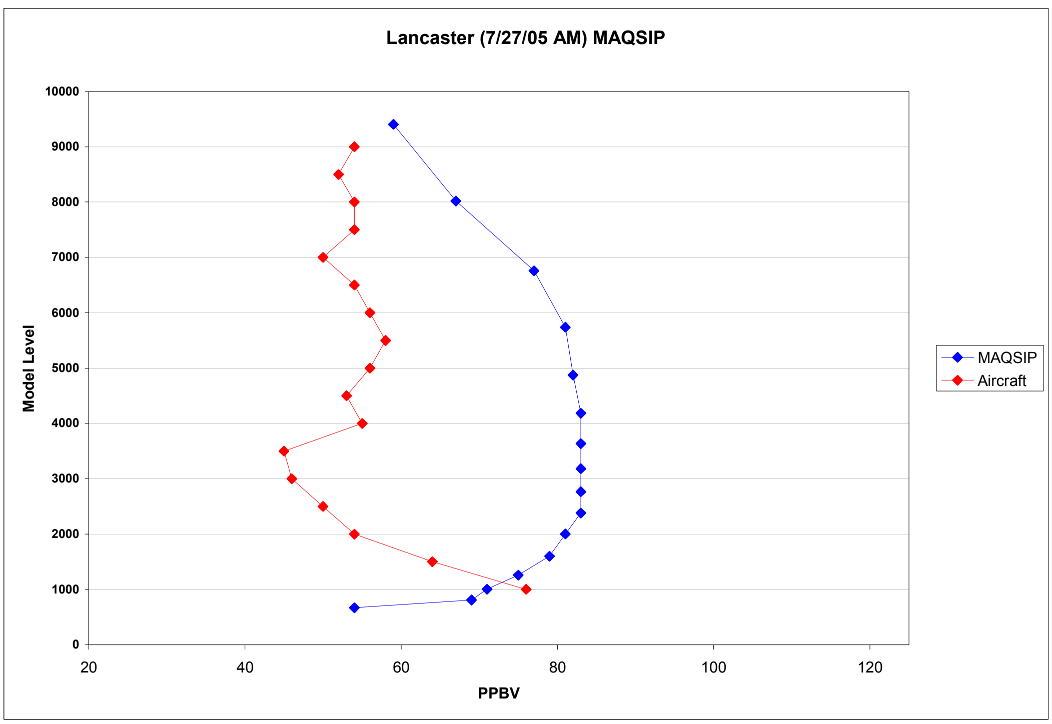

Figure 33. Ozone profiles from the UMD aircraft (red) and MAQSIP (blue) over Lancaster, NC during the morning of July 27.

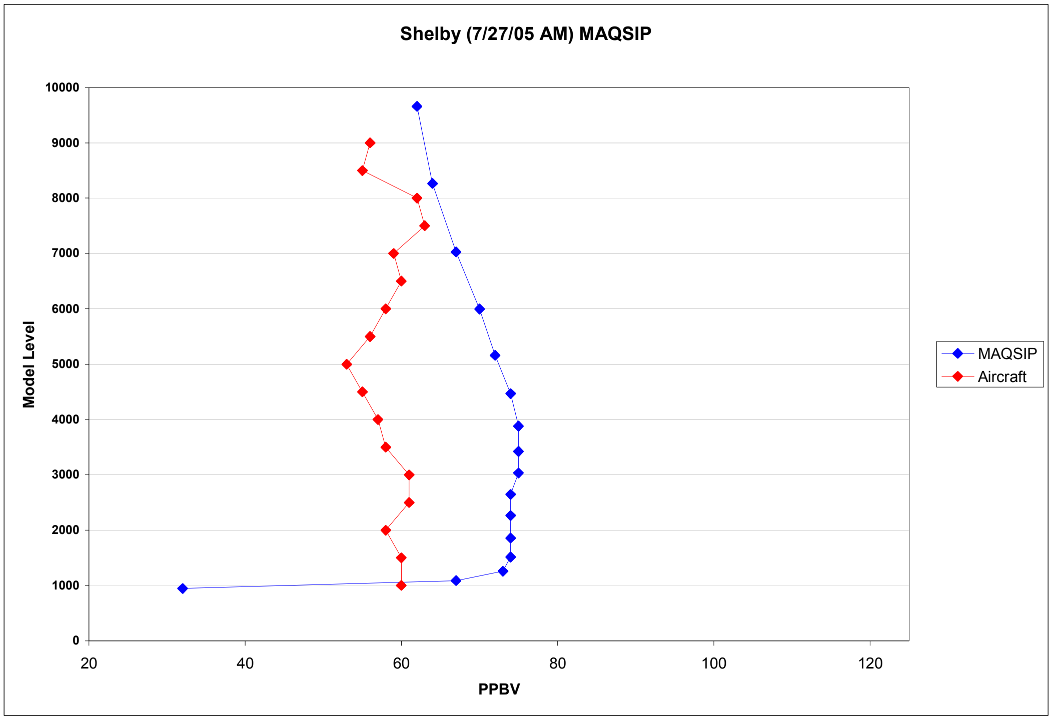

Figure 34. Ozone profiles from the UMD aircraft (red) and MAQSIP (blue) over Shelby, NC during the morning of July 27.

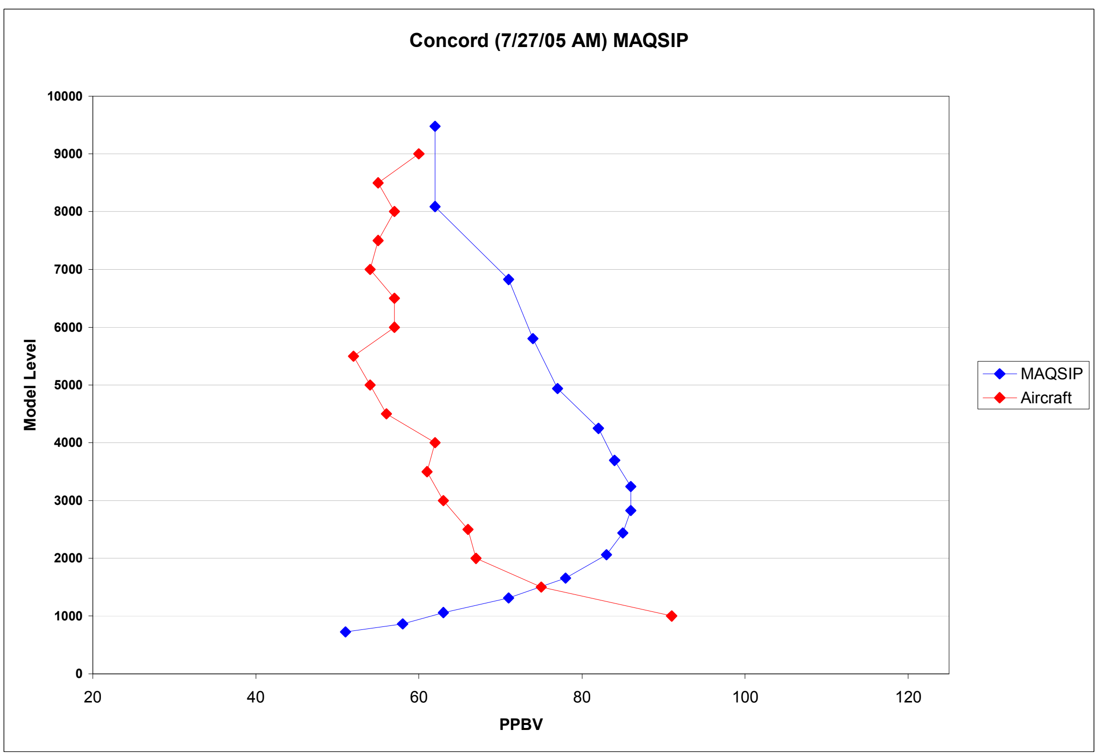

Figure 35. Ozone profiles from the UMD aircraft (red) and MAQSIP (blue) over Concord, NC during the morning of July 27.

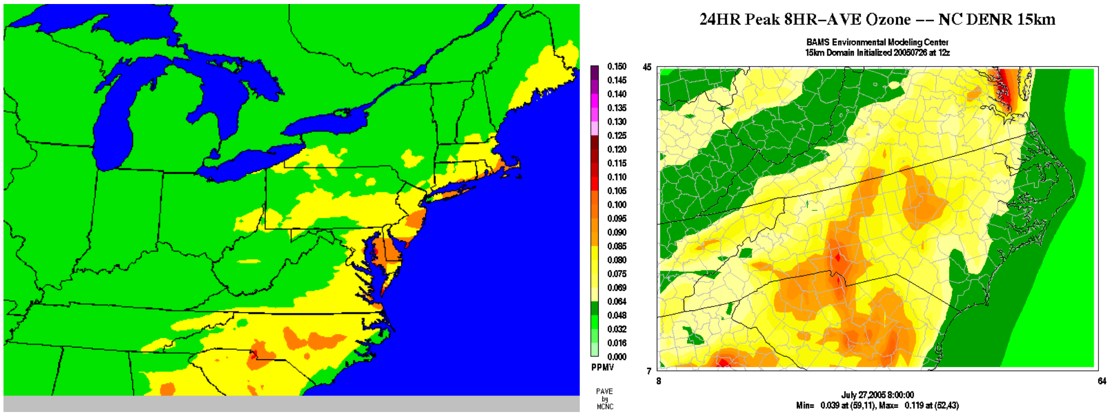

Figure 36. 8-hour predicted ozone for 7/27, initialized 7/26 12 UTC, for (a) NOAA AQFS and (b) MAQSIP.

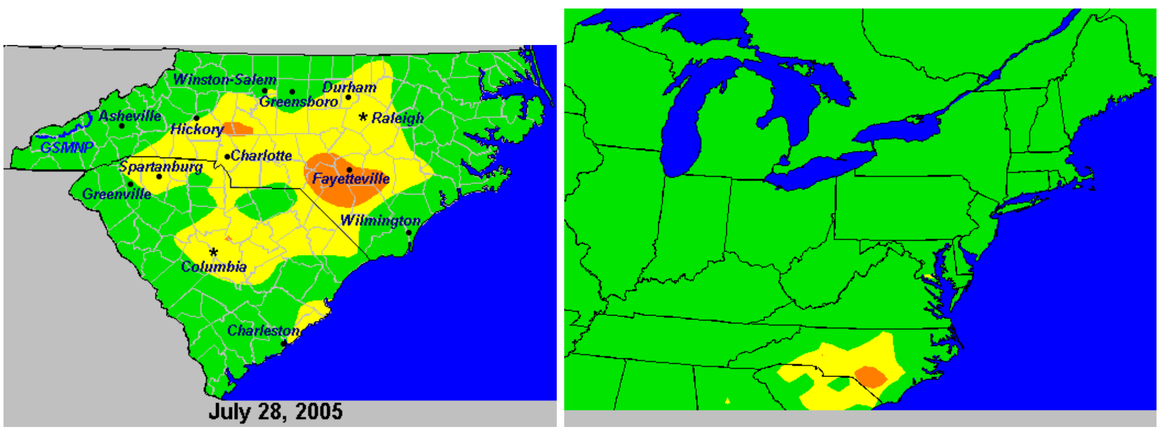

Figure 37. Observed 8-hour ozone for July 28, 2005 in (a) North Carolina and (b) the eastern US. Green shading is below 65 ppb, Yellow shading is 65-84 ppb, Orange shading is 85-104 ppb, and Red shading is 105-124 ppb.

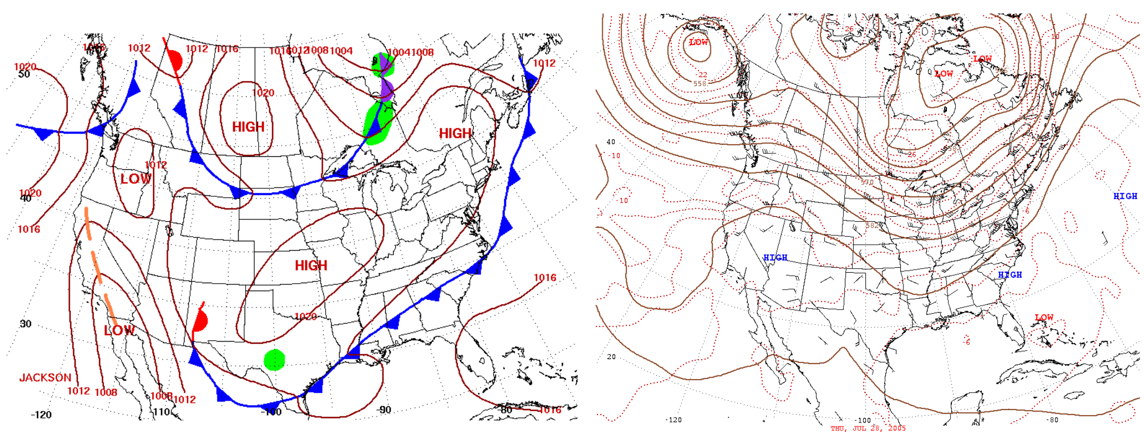

Figure 38. NOAA daily weather maps on July 28 12 UTC showing (a) surface analysis and (b) 500 mb analysis.

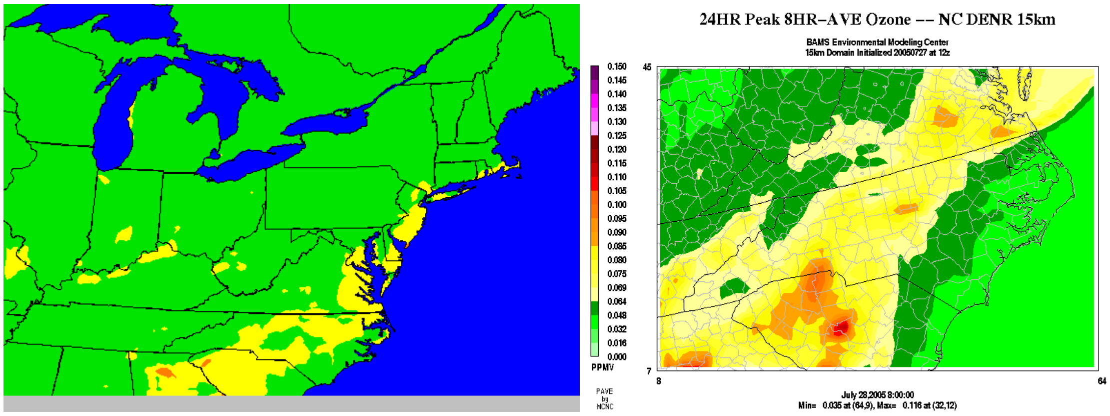

Figure 39. 8-hour predicted ozone for 7/28, initialized 7/27 12 UTC, for (a) NOAA AQFS and (b) MAQSIP.

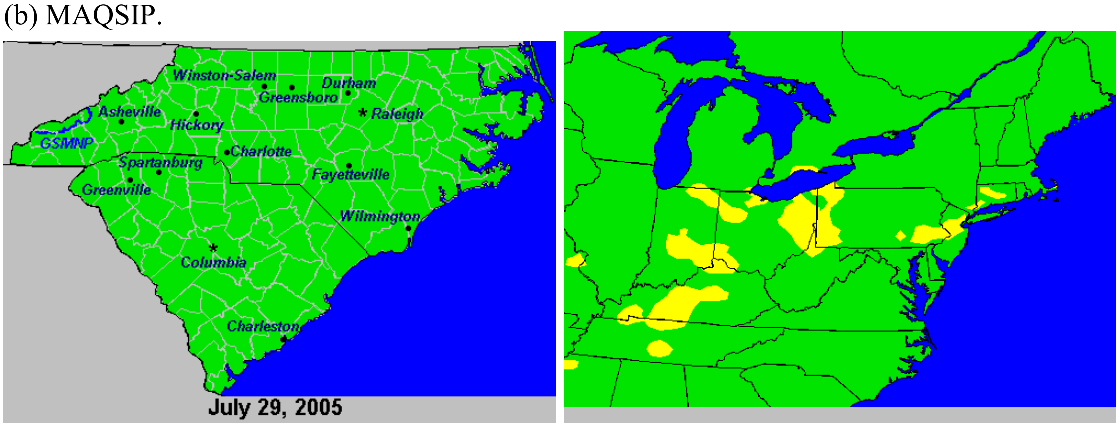

Figure 40. Observed 8-hour ozone for July 29, 2005 in (a) North Carolina and (b) the eastern US. Green shading is below 65 ppb, and Yellow shading is 65-84 ppb.

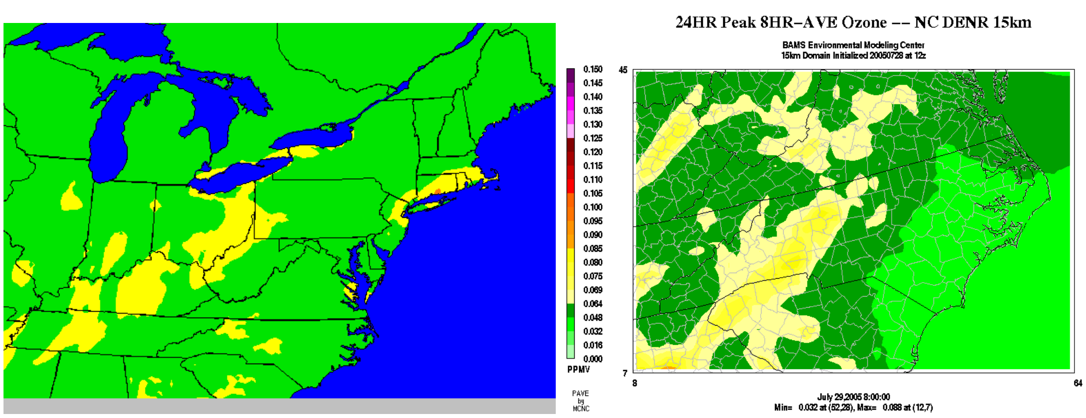

Figure 41. 8-hour predicted ozone for 7/29, initialized 7/28 12 UTC, for (a) NOAA AQFS and (b) MAQSIP.