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Implementation and Evaluation of a Continental US Air Quality Forecast System

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1. INTRODUCTION

Baron Advanced Meteorological Systems (BAMS) has implemented an air quality forecast system that predicts both particulate matter and ozone. The system includes the execution of two air quality models: 1) CMAQ (Community Multiscale Air Quality model) and 2) MAQSIP-RT (Multiscale Air Quality Simulation Platform – Real Time). This paper details the system setup and examines the performance of the models over the summer of 2005.

2. MODELING APPROACH

The meteorological model used in the system is the PSU/NCAR Mesoscale Model (MM5 version 3.6.3+, Grell et al., 1994). The MM5 modeling domain is shown in Figure 1. The model uses 31 vertical layers extending to 100 mb, and it is executed on a 45-km horizontal grid. MM5, like all of our other core models, is run on either/both a 20-processor SGI Altix or a 4-processor Altix. Here are the key physics options used for each 5-day run:

Soil: OSU land surface model
PBL: MRF (modified)
Rad: Rapid Radiative Transfer Model (RRTM)
Cld: Kain-Fritsch 2 cumulus parameterization
Microphysics: Reisner 1 (mixed phase)
Initialization: GFS

The modeling system is executed twice daily, at 06 UTC and 18 UTC. We chose those initial times in order to produce timely air quality forecasts, especially for our state clients who need the results by early afternoon local time. The meteorological model is executed with MCPL, an I/O API output module for MM5.

After MM5 finishes, we execute the SMOKE (Sparse Matrix Operator Kernel Emissions) system in order to provide the emissions inputs for the air quality model. The emissions are generated first for MAQSIP, and then a couple of postprocessors convert the data into the format expected by CMAQ.

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The emissions are generated on the air quality domain (figure 2), which is considerably smaller than the MM5 modeling domain. A few significant enhancements were made to the emissions system in late August, 2005. The first upgrade involved an improvement to the BEIS3 processor that effectively reduces biogenic isoprene emissions by approximately 30%. The second involves the insertion of fire emissions into the system using simple assumptions regarding the evolution of observed fires on the day the model initializes. Finally, the third upgrade is the inclusion of a simple dust model. It became apparent after a few days that the dust emissions were overdone, so we reduced those emissions by a factor of ten to keep particulate matter concentrations reasonable.

After SMOKE completes, all of the data necessary to drive MAQSIP-RT are available. However, MCIP2.2 still needs to be executed to produce meteorological fields that can drive CMAQ 1.4+. We typically execute CMAQ on the 4-processor Altix using MPP, while MAQSIP is executed in shared memory mode using up to 18 processors on the 20-processor Altix. We also execute MAQSIP for large 15-km domains, but that will not be discussed in this paper. Note that in neither model do we apply vertical "collapsing" of model layers, so we use the full 31 layers.

3. EVALUATION PRODUCTS

Most of the evaluation products we generate are client-based and are therefore of limited interest to the general user. These are the product families:

Species: PM2.5, 1H-O3, 8H-O3
Varying time: 24H, 1H
Plot types: Time series, scatter, stat tables
Areas: AL, AR, LA, NC, OK, TN, TX

For the sake of these analyses, the daily products were defined to be from 06UTC-06UTC. This is subtly different from the official definition of a "day", which is based on local time. The products are also segregated by forecast day/cycle accumulated over a month time scale, so that we can evaluate all of our 2-day 06Z forecasts, for example, in a simple time series plot. A couple of examples of these types of plots are shown in figures 3-4. Note that for ozone CMAQ is slightly low biased (figure 3), and PM2.5 is even more low biased in the Charlotte, NC area for July 2005.

4. SPATIAL EXAMPLES

An exhaustive evaluation of CMAQ/MAQSIP-RT over the summer will be performed at a later date. For this paper we will employ a qualitative analysis. This is accomplished by selecting certain “interesting” days (in terms of observed air quality) and comparing the model forecast(s) with the AIRNOW observed air quality index (AQI) maps.

4.1 *PM2.5 analysis*

Figure 5 shows a significant particulate matter (PM2.5) episode in the Midwest on June 27, 2005. There are widespread reports of code orange AQI, with at least one report of a code red. The 2-day CMAQ forecast for this day (model initialized at 06Z July 26, 2005) correlates well with the observations, but the magnitude of the pollution is significantly underestimated. This is rather typical of the model in general. Part of the problem could be that the resolution is too coarse to resolve the particulate matter, but it seems more likely that the persistent underestimation is caused by some modeling imperfection.

A southeastern PM2.5 event occurs on July 25, 2005 (figure 6). The 3-day CMAQ prediction once again does a credible job in terms of estimating where the maximum PM2.5 will occur, but again the model appears to be about ½ an AQI category too low.

PM2.5 concentrations are generally low across the entire US on August 22 (figure 7). Note that even at relatively low PM2.5 levels the model still shows a low bias. The 4-day forecast continues to show some skill in terms of predicting the locations of maximum pollution. Note, however, that the widespread code yellow observations in California are totally missed.

Figure 8 shows the same result for September 13, 2005 in California. Note, however, the outstanding predictions in the eastern US, and this is a 5-day forecast! Presumably the fire/dust emissions which were added to the system before this case (but after the earlier examples) have significantly helped with the persistent low bias.

Figure 9 shows a significant PM2.5 event in California that the model again mostly misses in the 2-day forecast. Since the forecast over the rest of the country looks reasonable, it appears that there might be some emissions problems in our southern California data base.

4.2 *Ozone (8H) analysis*

Figure 10 shows the 4-day forecasts for CMAQ and MAQSIP-RT for June 24, 2005. This day represents a significant ozone outbreak in the Great Lakes area and over much of the eastern US. Neither CMAQ nor MAQSIP-RT does a great job, but they both show some skill embedded within an overall low bias. MAQSIP-RT appears to outperform CMAQ for this day.

Figure 11 shows the 2-day forecasts for June 26, 2005, a continuation of the ozone episode shown above. For this day CMAQ continues its general underprediction, while MAQSIP-RT appears to be high biased. This result is typical of most of the ozone season. The BEIS3 emissions adjustment (referenced above) that was implemented in late August should lower forecasted maximum O3 in both models, so the high bias in MAQSIP-RT might be somewhat ameliorated in future years. The low bias in CMAQ, however, will probably become even more of an issue.

Some ozone AQI reports of code orange are evident on July 28, 2005 (figure 12). Both CMAQ and MAQSIP-RT suggested possible pollution problems in the southeast five days in advance, but MAQSIP-RT shows a high bias. Interestingly enough, neither model did a credible job predicting the widespread high ozone evident in California. Again this suggests a possible emissions problem for that area in our modeling system.

4. Summary and Conclusions

- Generally speaking, skill has been shown in both CMAQ and MAQSIP-RT in predicting pollution up to five days into the future.
- CMAQ shows a general low bias in forecasting PM2.5. The low bias may have been partially corrected by the inclusion of fire/dust emissions which entered the system in late August, 2005.
- MAQSIP-RT tends to overestimate ozone, while CMAQ tends to underestimate ozone. A BEIS3 emissions upgrade should cause lower ozone forecasts in both models for future episodes.

- California forecasts tend to be routinely low biased by a significant amount. This is most likely an emissions problem.

ACKNOWLEDGEMENTS

Numerous BAMS colleagues have contributed to the modeling presented in this report. I want to thank Carlie Coats and Jerry Condrey for their assistance in getting the core models compiled/executed on the Altix platform. Ted Smith deserves a huge amount of credit for his part in designing the forecasting system. I thank Jeff Vukovich for his emissions work, and also John McHenry for his scientific recommendations.

REFERENCE

Grell, G. A., J. Dudhia, and D. R. Stauffer, 1994: A description of the fifth-generation Penn State/NCAR Mesoscale Model (MM5). NCAR Tech. Note, NCAR/TN-398+STR, 122 pp.

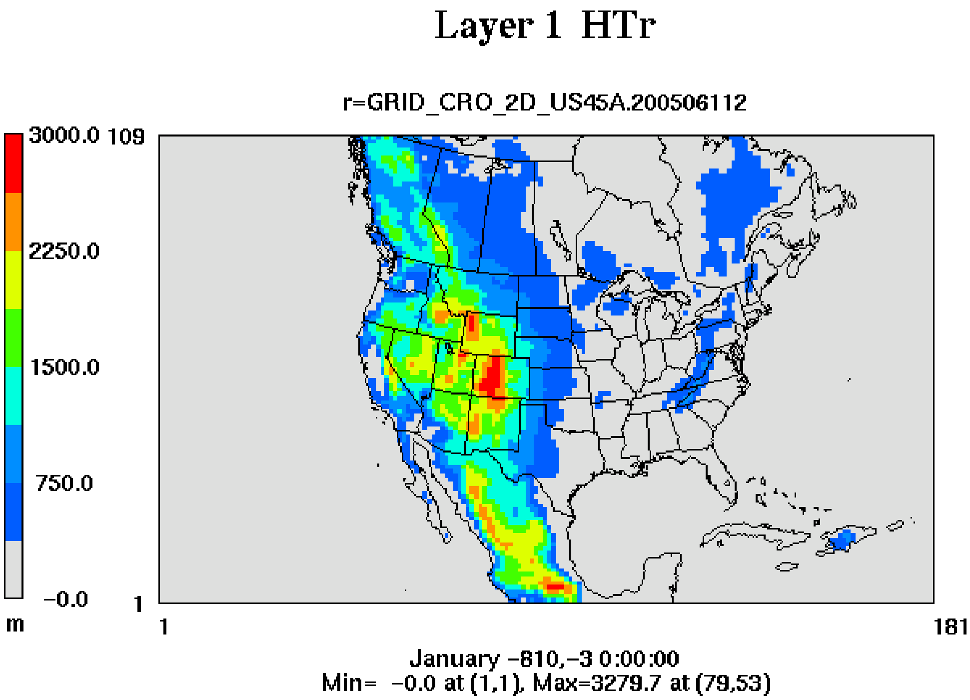


Figure 1. MM5 45-km modeling domain and terrain heights

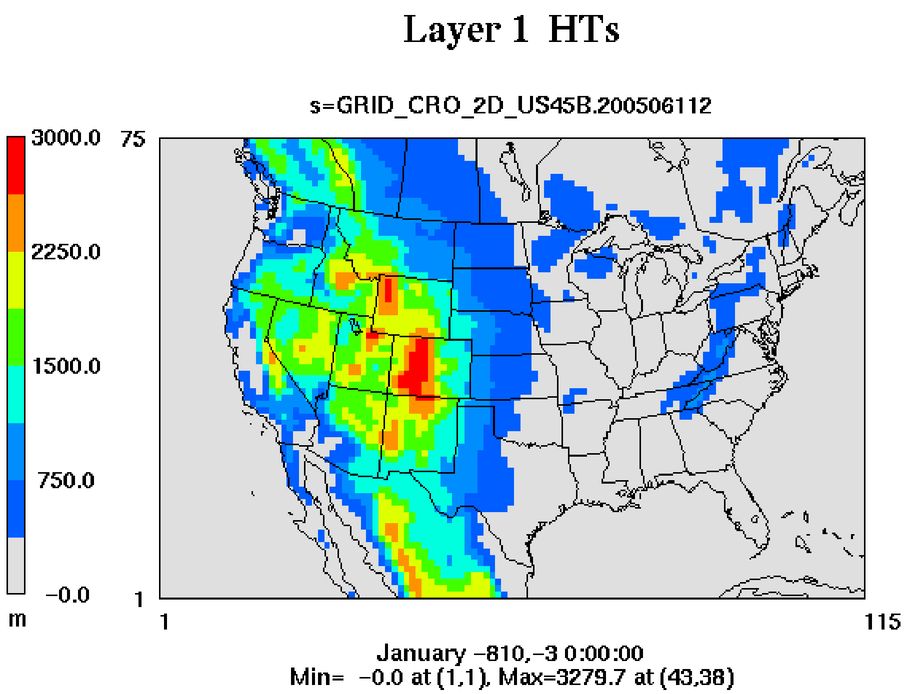


Figure 2. 45-km CMAQ/MAQSIP-RT modeling domain and terrain heights.

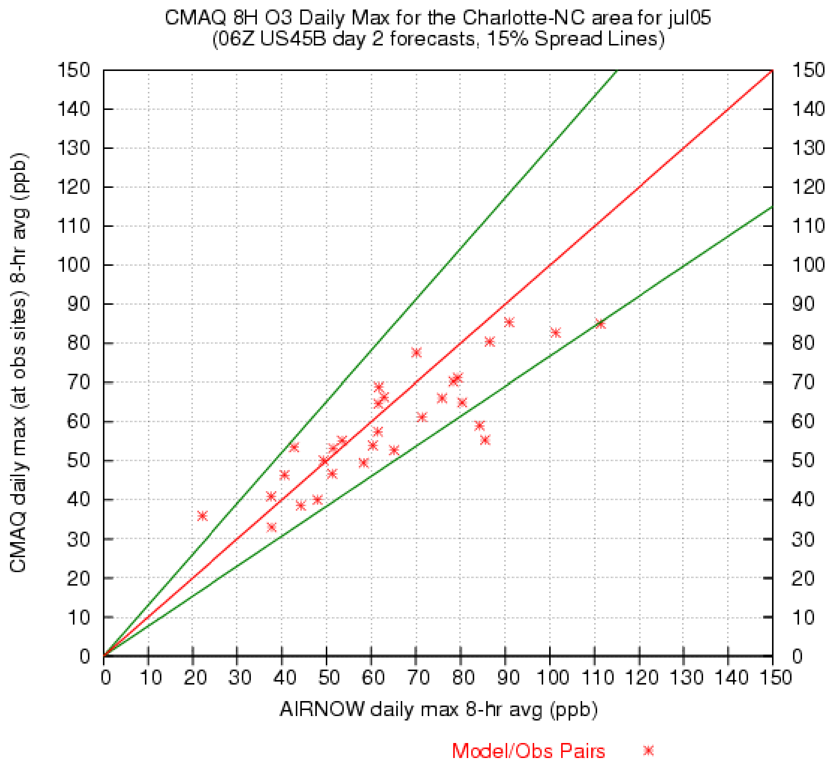


Figure 3. CMAQ 8H O3 daily max scatter plot in the Charlotte, NC area for all 06Z 2-day forecasts in July '05

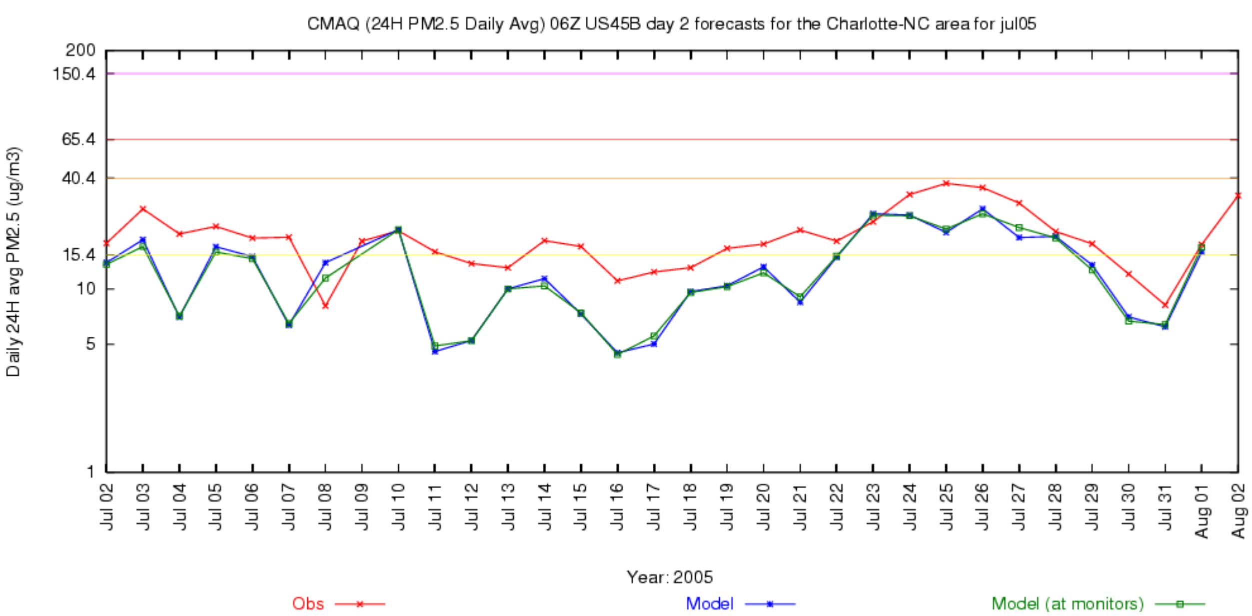


Figure 4. Like figure 3, except for daily max 24H PM2.5 time series.

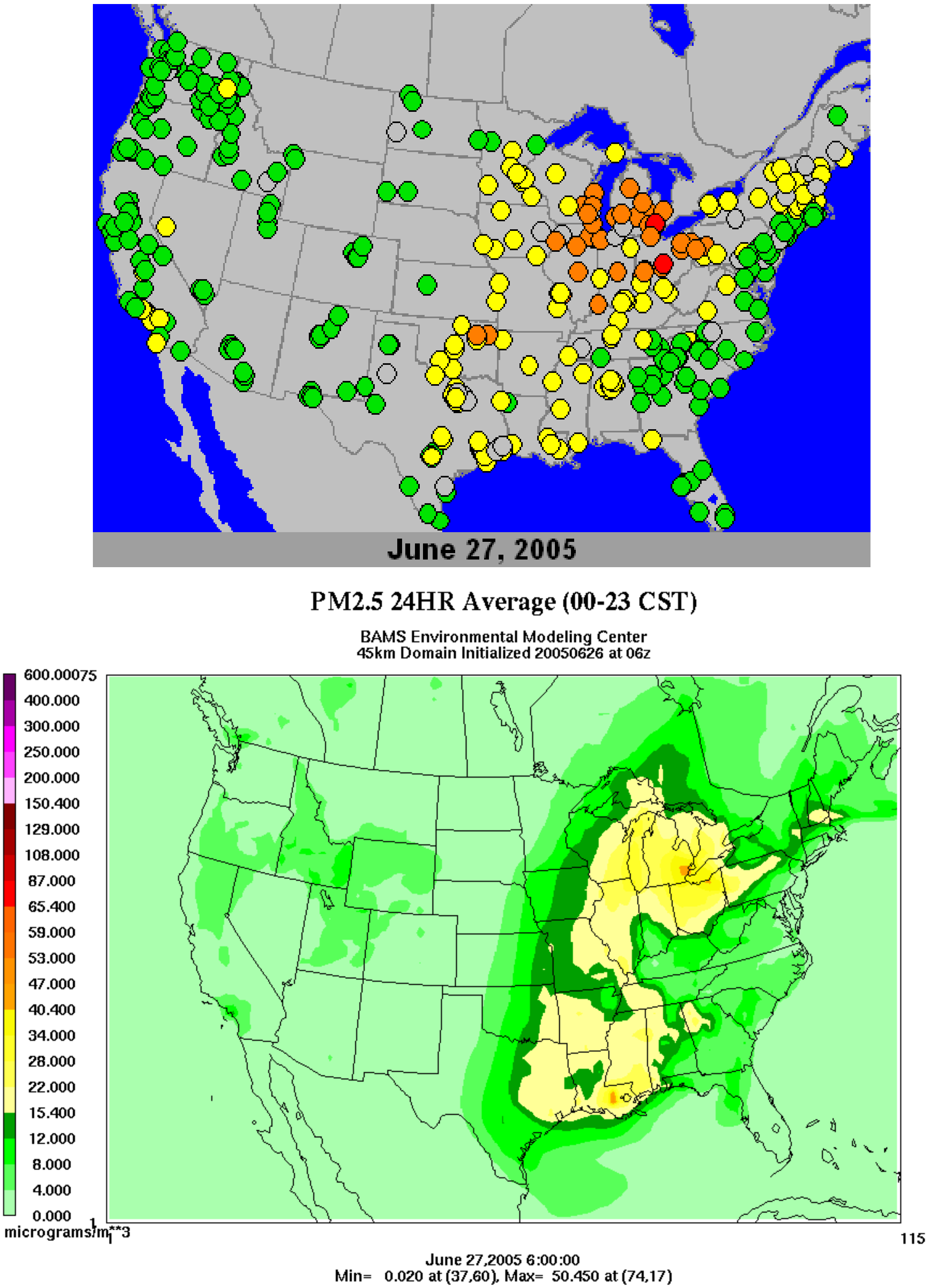
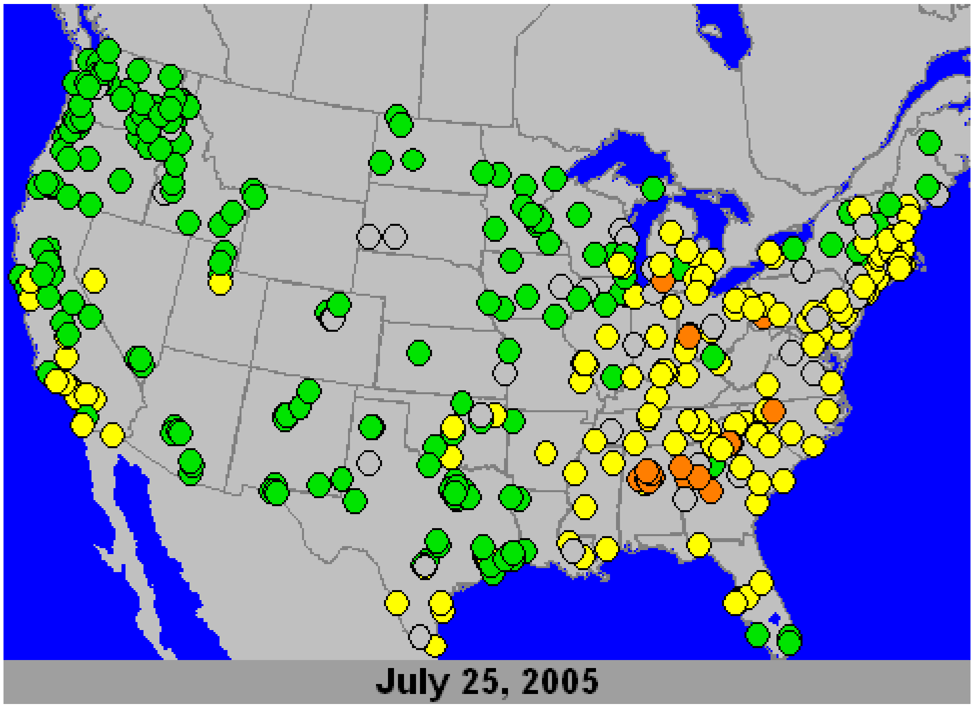


Figure 5. AIRNOW maximum PM2.5 AQI/CMAQ 2-day forecast AQI for June 27, 2005.



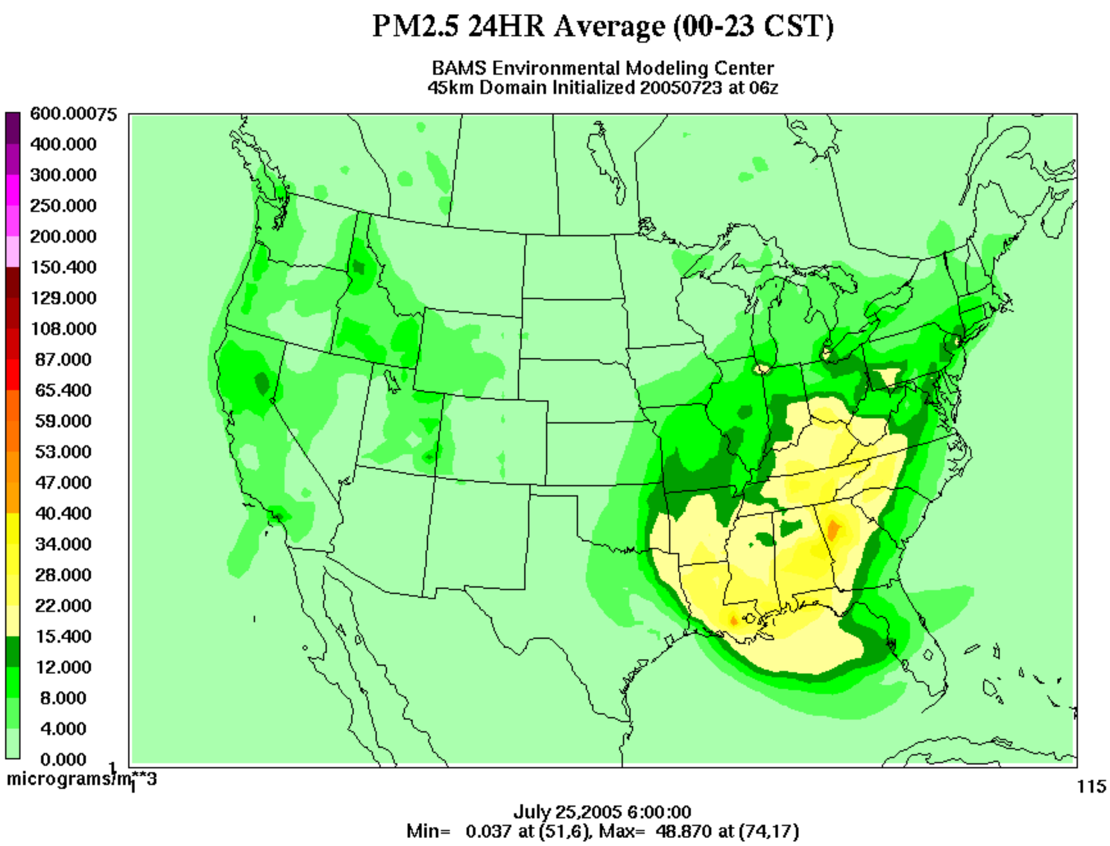
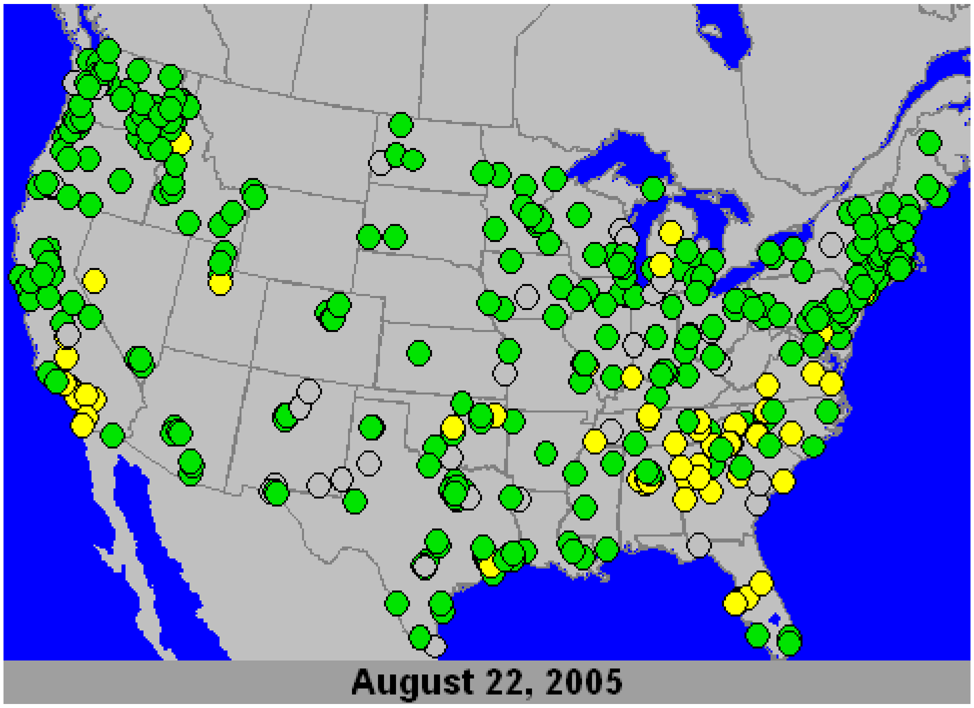


Figure 6. AIRNOW maximum PM2.5 AQI/CMAQ 3-day forecast AQI for July 25, 2005.



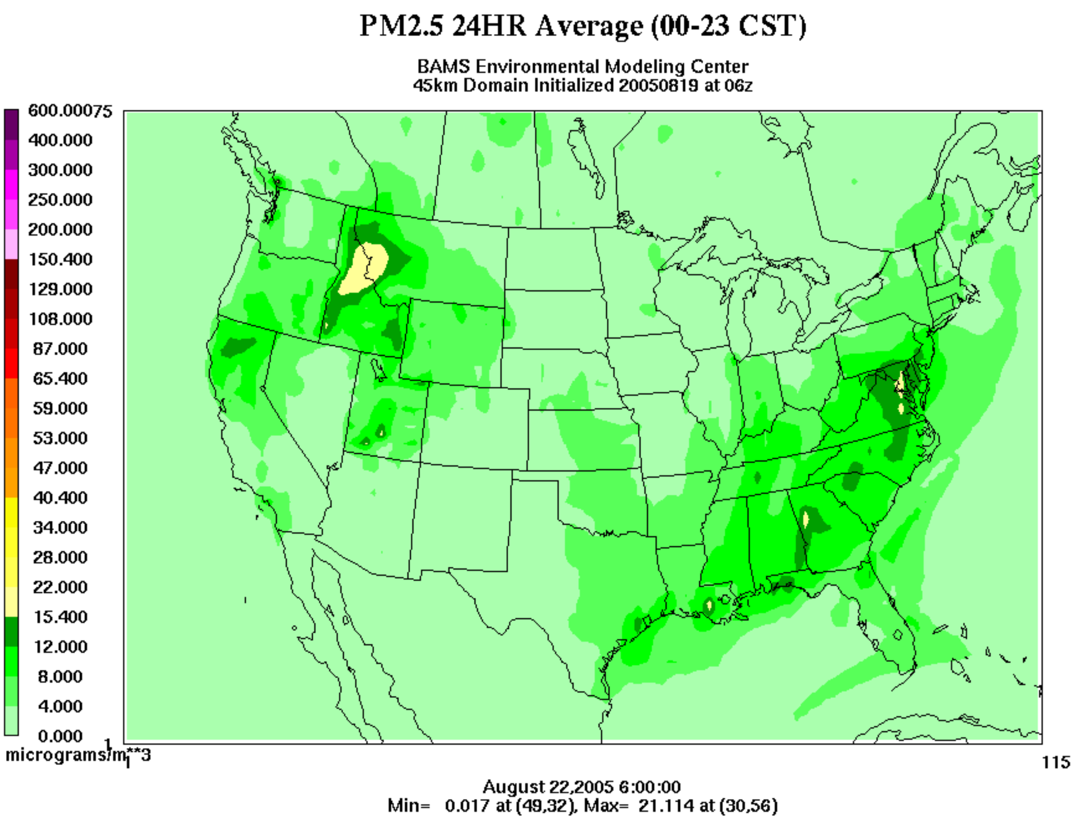


Figure 7. AIRNOW maximum PM2.5 AQI/CMAQ 4-day forecast AQI for August 22, 2005.

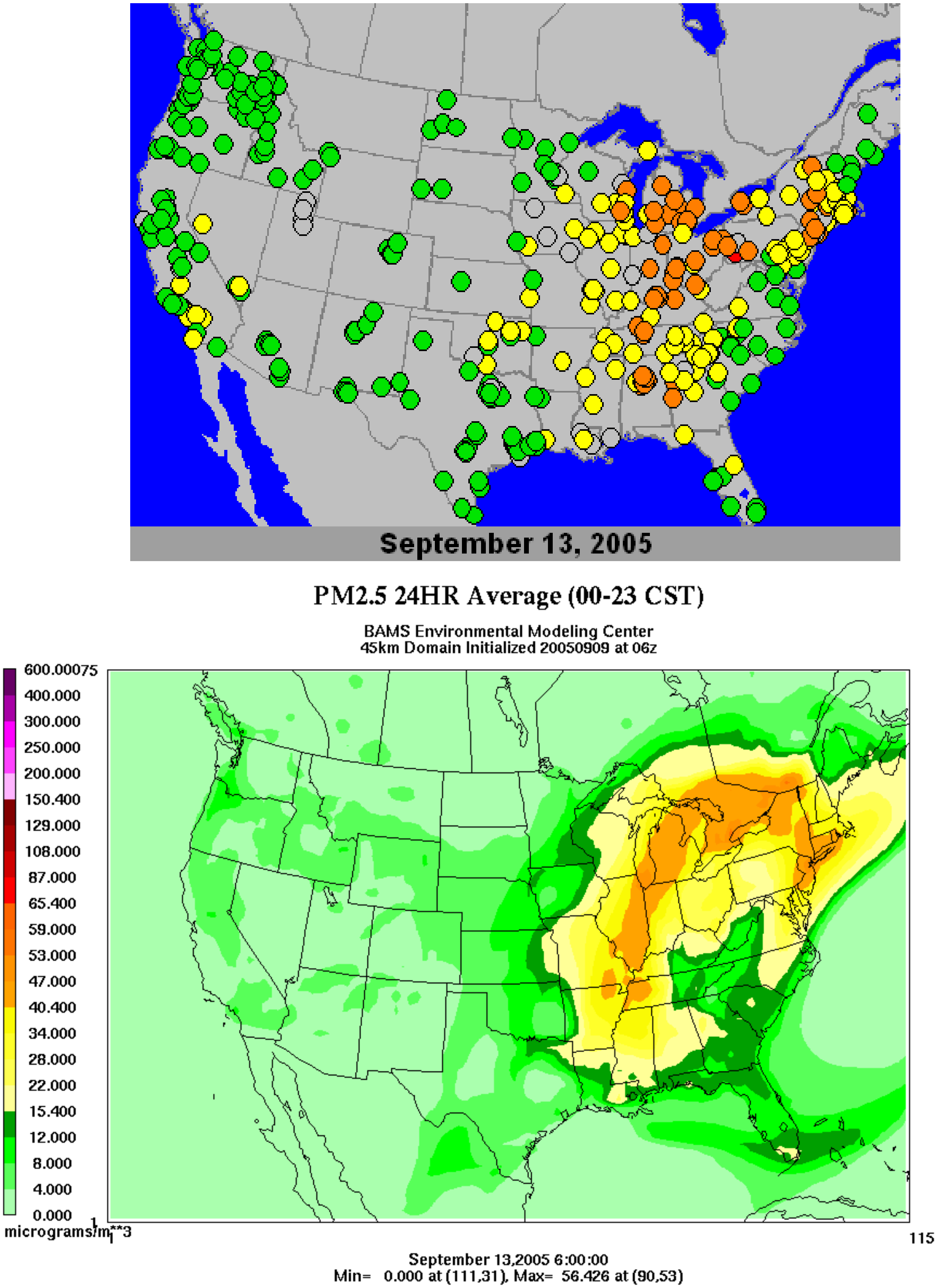


Figure 8. AIRNOW maximum PM2.5 AQI/CMAQ 5-day forecast AQI for September 13, 2005.

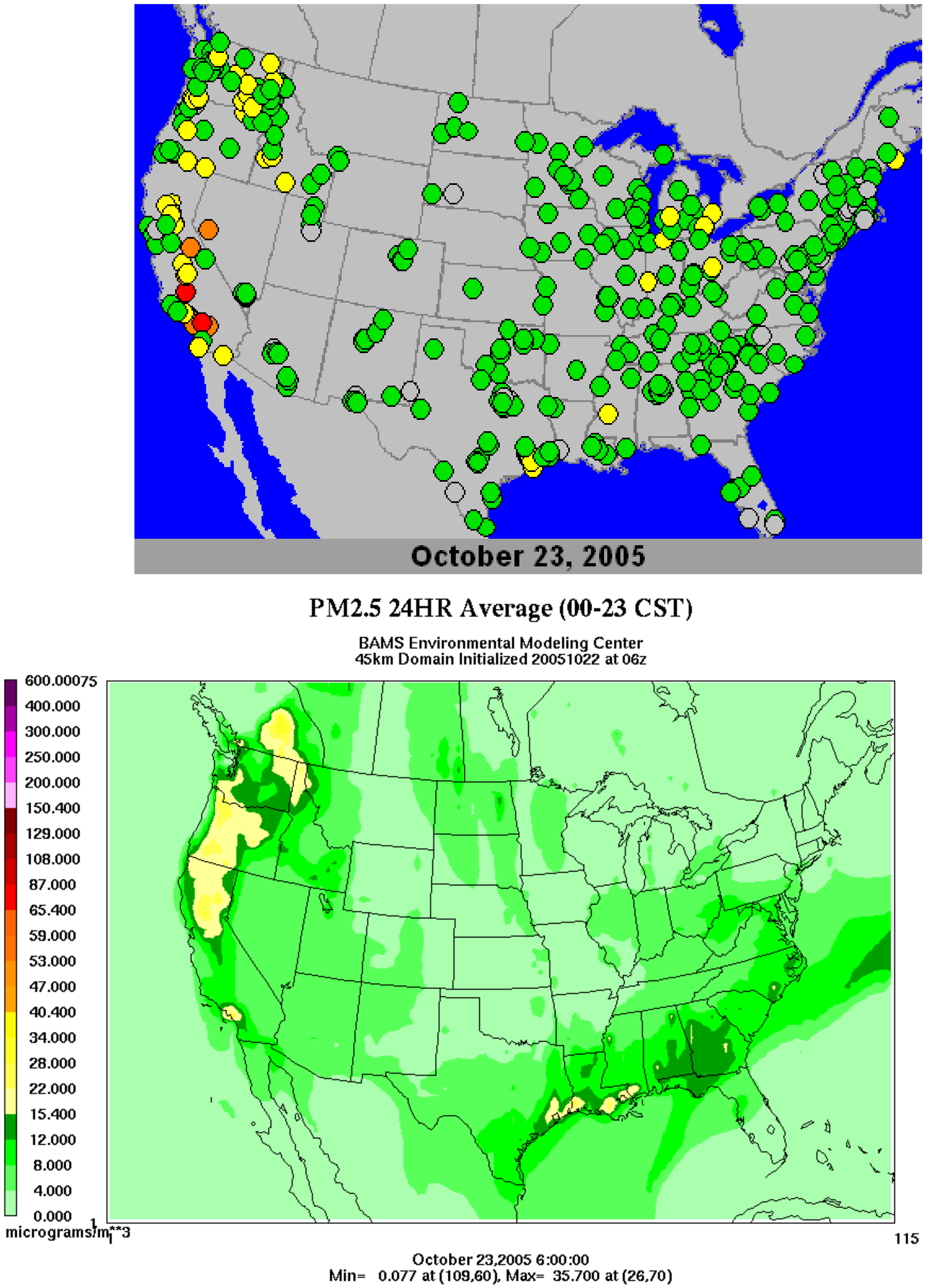
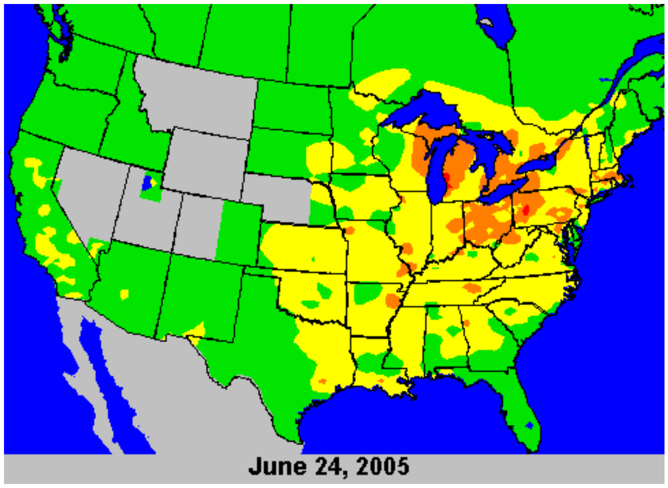
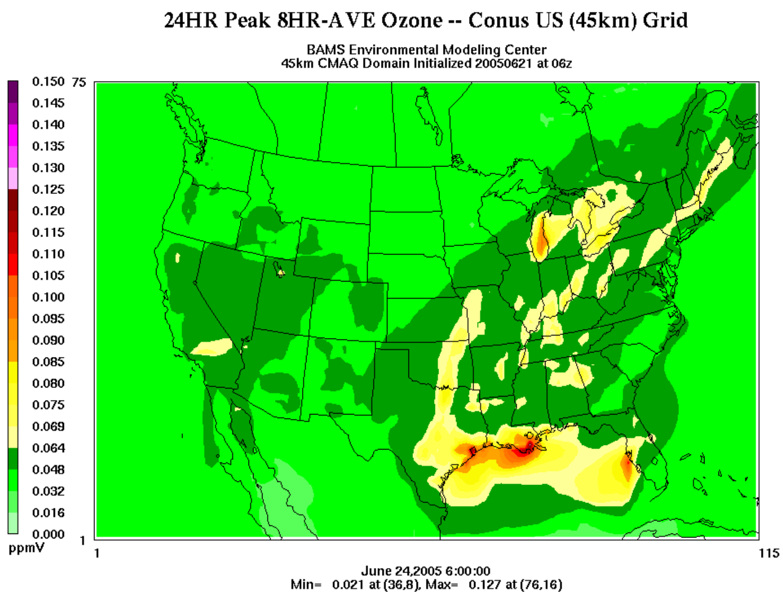


Figure 9. AIRNOW maximum PM2.5 AQI/CMAQ 2-day forecast AQI for October 23, 2005.





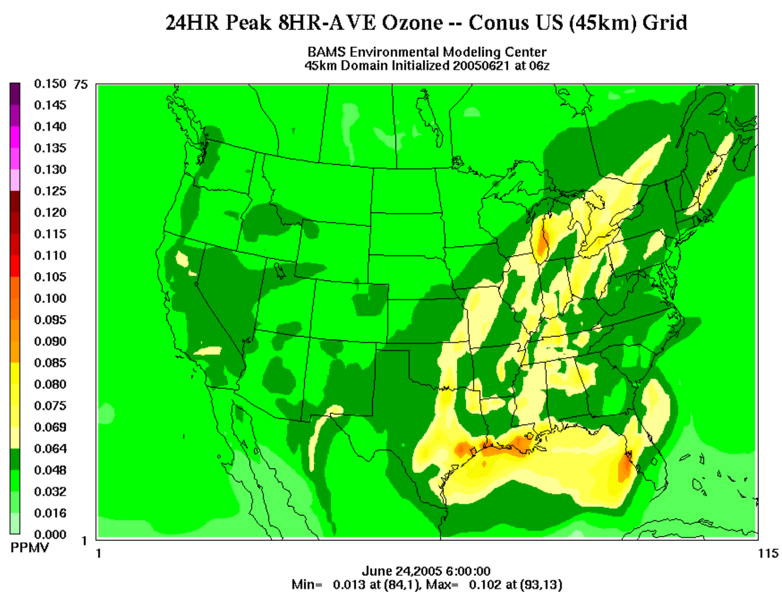


Figure 10. Maximum 8H O_3 AQI from AIRNOW and CMAQ/MAQSIP 4-day forecast AQI for June 24, 2005.

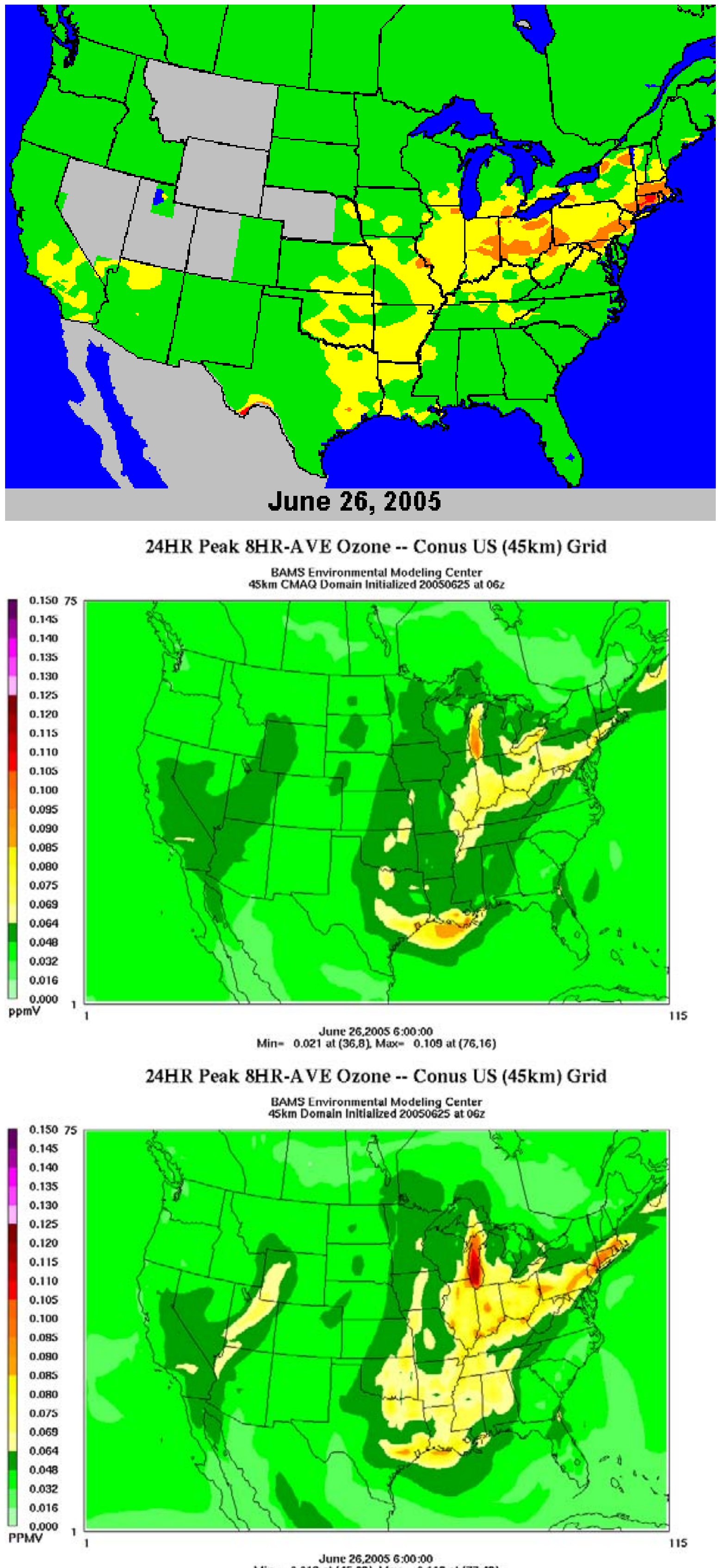


Figure 11. Maximum 8H O_3 AQI from AIRNOW and CMAQ/MAQSIP 2-day forecast AQI for June 26, 2005.

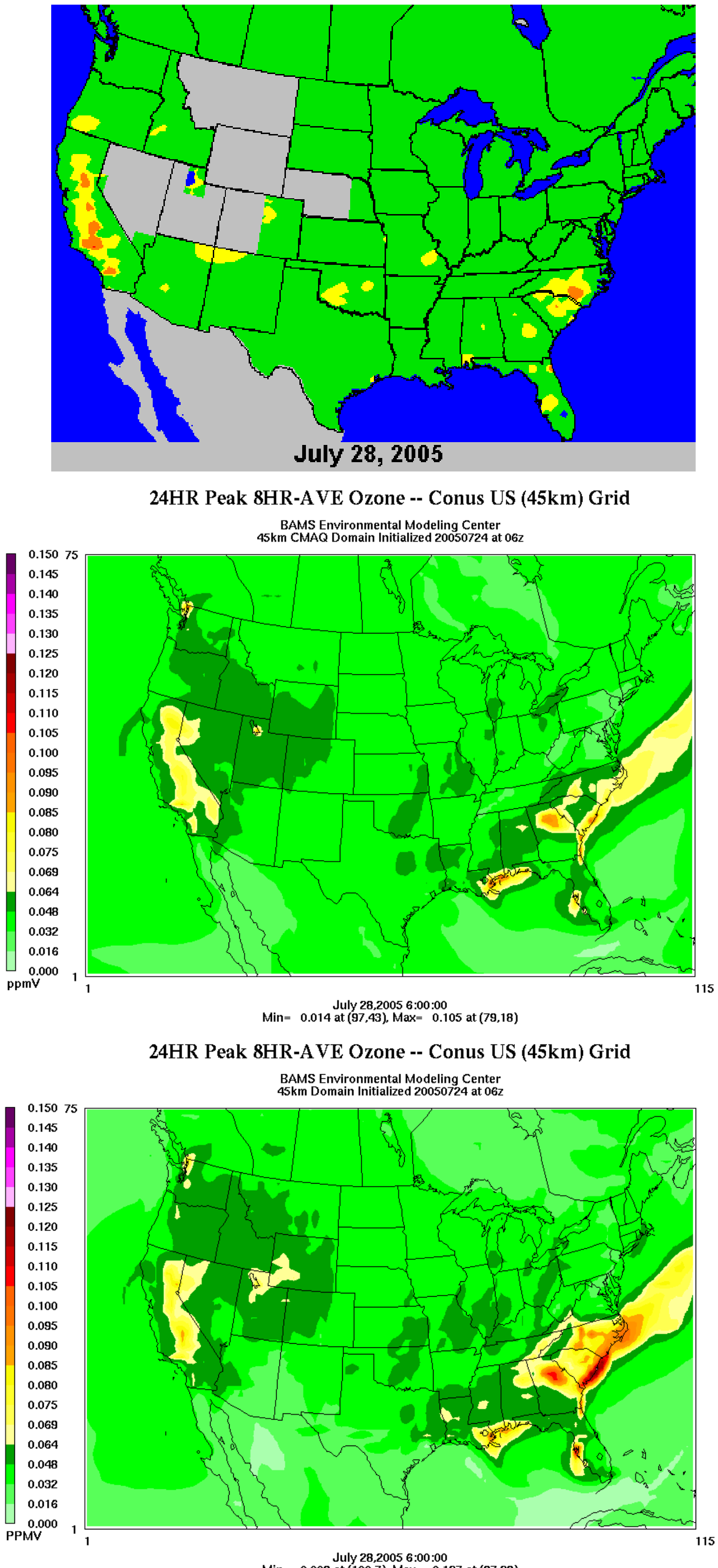


Figure 12. Maximum 8H O_3 AQI from AIRNOW and CMAQ/MAQSIP 5-day forecast AQI for July 28, 2005.