NOAA ARL Monthly Activity Report

November 2003

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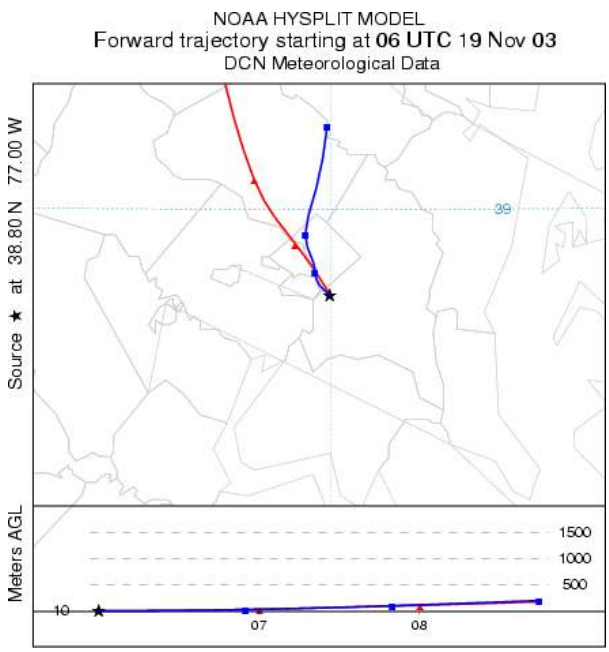
Contents

Highlights

1. DCNet and HYSPLIT Developments. As a step towards improving urban-area dispersion forecasting, programs have been developed to produce higher resolution meteorological data sets. In particular, local observational data can be blended into existing gridded data files to permit simulations to easily transition from observed local data (the hindcast) to the mesocale, regional, or global forecast. A future application (not yet incorporated) will be to customize relatively coarse grid data to be more representative of finer spatial scales by incorporating high resolution topography and land-use data.

The first program derives 3D turbulent velocity variances (u'^2, v'^2, w'^2). These new fields are then added as additional records to each level of the data file. A second program performs a bilinear spatial interpolation to

create new grid points between those of the existing grid. The new grid spacing should be comparable to the spacing of any observational data that will be subsequently blended into the data file.



A third program interpolates the input data file to a finer temporal frequency to match the temporal frequency of the observations. A fourth program in the sequence edits the meteorological data file based upon observations such as wind direction, speed, and turbulence. Observations are matched with the gridded data interpolated to the same location and then the gridded data are adjusted in direction and speed to match the observations.

The series of programs is not intended to be a replacement for data assimilation, but a quick way to adjust the initial transport direction to match local observations near the computational starting point. An example calculation is shown in the accompanying illustration. The 12 km ETA fields and the DCNet tower data were interpolated into a 2-km 15 minute resolution data grid. A three-hour duration HYSPLIT trajectory using only the ETA fields is shown in red and the same calculation using the blended DCNet data is shown in blue. Initial directions are almost identical, except that the ETA transport is almost twice as fast. roland.draxler@noaa.gov

2. Tracer Studies in New York City and Washington, DC. Discussions have been held with personnel from DHS regarding an atmospheric tracer study to be conducted next calendar year in Manhattan. A subsequent study is planned for Washington, DC. FRD has been asked to help write the experimental plan, and is waiting for a white paper from DHS that discusses the overall goals of the Manhattan study before we begin designing the experiment. (kirk.clawson@noaa.gov and Bruce Hicks)

Silver Spring

3. New Turbulence Parameterizations for HYSPLIT. The HYSPLIT dispersion subroutines have been restructured to use the turbulent velocity variance (m^2/s^2) to compute dispersion rather than a diffusion coefficient (m/s^2). The equations used for dispersion did not change, just the computational order. The change was required to support an option to use the ETA or RAMS model's TKE (turbulent kinetic energy) field to compute dispersion instead of HYSPLIT's boundary layer (BL) parameterizations. The code was also modified to permit the direct input of the velocity variance as another record in the meteorological data input file. New relationships for the boundary layer velocity variances as a function of u*, w*, and z_i, applicable for short-range dispersion simulations, have been researched by long-time Hysplit collaborator Dale Hess (BoM, AU), and should be incorporated into the code by the time this document is in print. This will permit the decomposition of the TKE into its vertical and horizontal components to be a function of the BL properties. roland.draxler@noaa.gov

4. Jim Angell 80th Birthday Symposium. On November 4, 2003, more than 50 colleagues and friends gathered at the NOAA Science Center in Silver Spring, Maryland, for a one-day symposium reviewing and honoring Jim's career achievements and celebrating his 80th birthday (which was November 2). A series of eight presentations highlighted Jim's contributions to atmospheric research, including major advances in global temperature and ozone monitoring and research, discovery and characterization of quasi-biennial oscillation, and identification of volcanic, solar, and El Nino-Southern Oscillation signals in the global climate system. The evening featured

a birthday dinner celebration, where participants recited poems they had composed in Jim's honor. More information about Jim Angell and the Angell Symposium, including photos, some presentations, the poems, and Jim's publications list, is online at www.arl.noaa.gov/ss/climate/AngellSymposium.html. An article summarizing the event is in preparation. dian.seidel@noaa.gov

Boulder

5. SURFRAD/ISIS. A considerable amount of time was spent moving all computing code associated with SURFRAD and ISIS data processing and research to a secure Linux computer. This involved checking, changing, and improving, as appropriate, hundreds of programs associated with all aspects of these networks, including daily processing, plotting, web processing, research, averaging, etc. All of the code was made more general, so that future moves such as this will be easier.

SRRB's three standard pyrgeometers, that are used to transfer calibrations to SURFRAD monitoring pyrgeometers before and after the annual instrument exchanges, were sent to the National Renewable Energy Laboratory (NREL) in Golden, Colorado for calibration using the new "NREL blackbody System" (NBBS), which was developed for NREL by Eppley Laboratory, Inc. The NBBS is described in the Journal of Atmospheric and Solar-Terrestrial Physics, 64, 2002, 1623-1629. This marks a departure from past protocol where the three SRRB standard pyrgeometers were sent annually to the World Radiation Center in Davos, Switzerland for calibration. Having these calibrations performed by NREL will save the SURFRAD program about $3000 annually. john.a.augustine@noaa.gov

6. Summary of EPA UV Audits. The Central UV Calibration Facility (CUCF) performs calibration audits for the EPA UV Monitoring Program managed by the University of Georgia, National UV Monitoring Center (NUVMC). The EPA UV Monitoring program has 21 sites located across the United States. The CUCF performs calibration audits on Mark IV Brewer UV spectroradiometers at approximately one third of the sites per year during the Fall. This year the CUCF visited Olympic WA, Glacier National Park MT, Research Triangle Park (RTP) NC, Shenandoah National Park VA, Boulder, CO, Sequoia National Park CA, and Volcanoes National Park Hawaii.

Calibrations are performed with 2-3 CUCF calibrated horizontal 100W lamps to check for consistency between lamps. Responsivity from different lamps agreed within 2%. The variation is explained primarily by the changing external temperature during the different scans. The responsivities are then compared to previous audits by the CUCF. Changes in the responsivity occur in two separate spectral regions, 290-325 nm and 325-363 nm. Approximate changes in the responsivity between the two audits (calibration dates are given in parentheses, Julian date and year) are given for the two spectral regions.

Olympic: -5% and -6% (316 1999 and 245 2003)
Glacier: +3% and +3% (270 2000 and 265 2003)
RTP: +150% and +150% (289 2001 and 283 2003)
Shenandoah: -15% and -10% (300 1999 and 295 2003)
Boulder: +35% and +15% (157 2001 and 275 2003)
Sequoia: -3% and -3% (329 2002 and 307 2003)
Hawaii: +7% and +8% (339 1999 and 338 2003)

Changes in the responsivity are due to many factors, including but not limited to mechanical changes and upgrades to the instrument during the period, temperature effects on the responsivity, and degradation of instrument components. patrick.disterhoft@noaa.gov, kathy.o.lantz@noaa.gov.

Research Triangle Park

7. Community Multiscale Air Quality (CMAQ) Modeling System. Following the release of the Community Multiscale Air Quality (CMAQ) model this fall (version 4.3), work was initiated on several sensitivity tests to prepare for the upcoming annual simulation. Tests include using different vertical layer structures, incorporating the plume-in-grid treatment with aerosols, and application of a NO_x/SO_x control strategy. Sensitivity runs will be performed on selected 2-week time-periods from the 2001-2002 annual meteorological data set. Results of this study will provide guidance for in-house modeling and to develop guidelines of layer structures for CMAQ simulations. (Shawn Roselle, 919 541 7699)

Division scientists completed the first part of a major sensitivity analysis of the photochemistry of CMAQ. One area of concern is the choice of vertical mixing algorithms (part of the physics) because they alter the species concentration mixing histories and, hence, the photochemical processing. Results of the sensitivity analysis show that while the physics sensitivities had a noticeable effect on the simulation of the base year ozone, the physics sensitivities had only a very small, to insignificant, effect on the simulation of the relative response of O_3 to a precursor emissions reduction. The control strategy O_3 relative change predictions of the CMAQ sensitivity versions were not significantly different from the control strategy relative change predictions from the default CMAQ. An important observation that continues to be substantiated is that the base year O_3 changes due to a sensitivity are likely not to be correlated with the differences in the relative control strategy response caused by the sensitivity. Based on this analysis, a recommendation for CMAQ users is that they stay close to the CMAQ default value and not be unduly influenced or concerned by the nighttime performance for O_3 in base year simulations. These results were presented at the CMAQ Users Group's CMAS Meeting in October. A paper on this sensitivity analysis is in review. (Robin Dennis, 919 541 2870)

A version of the Community Multiscale Air Quality (CMAQ) model, which includes explicit tracking of primary carbonaceous particulate matter emitted from distinct source categories, was tested successfully on the continental United States domain and is now operational. Tests verified that the model calculations yield carbonaceous aerosol concentrations that, when summed over all sources, are nearly equivalent to the results obtained from the publicly released version of the CMAQ model. The source apportionment model has been applied for the June 15-August 1, 1999, period, resulting in spatially and temporally resolved estimates of contributions of each major particulate matter emission source category to the atmospheric carbonaceous aerosol budget. Model results will be evaluated against source-specific organic compound measurements collected at eight monitoring sites in the southeastern United States. (Prakash Bhave, 919 541 2194)

8. Scientist to Scientist Workshop at Sandia National Laboratory. On November 12 and 13, 2003, scientists from the Atmospheric Sciences Modeling Division (ASMD), met with scientists at Sandia National Laboratory, Albuquerque, New Mexico, to lay foundations for collaborative pilot studies. Three area of collaboration were discussed: Microarray Technology and Science, Remote Sensing Technologies and Science, and Air Quality Modeling. Scientists from ASMD were involved in the Air Quality discussions that focused on improving the computational performance of the Community Multiscale Air Quality (CMAQ) model. Sandia computational scientists reported on progress to date that included detailed analysis of CMAQ performance, modifications to I/O that improve parallel performance, improved cache usage in vertical diffusion, and initial testing of a new highly efficient and accurate advection scheme. Plans were made for the coming year to continue optimization of the CMAQ code concentrating on serial performance that will improve computational speed on any platform. It is estimated that combined performance improvements developed at Sandia and in ASMD will result in a high performance CMAQ code that will simulate 1 year for continental United States in less that 10 days on a moderately sized Linux system of 16 cpu's. (Jonathan Pleim, 919 541 1336)

9. Community Multiscale Air Quality - Mercury Model. Efforts continued toward the organization of an intercomparison study of atmospheric mercury models with specific interest in the origins of mercury depositing over North America. For the study to be conducted within existing program budgets, it was decided that all

models in the study should use the 2001 Mesoscale Model Version 5 (MM5) meteorological data set already developed by OAQPS. It was agreed that the study should investigate why the various models yield different results, not just how different they are. It was also agreed that Atmospheric and Environmental Research, Inc., (AER) be invited to participate with the Trace Element Analysis Model. Other models to be run include the Comprehensive Air-quality Model with extensions (CAMx) developed by Environ, Inc., and the Regional Modeling System for Aerosols and Deposition (REMSAD). It was also decided that the study should investigate the use of additional global scale models beyond the Global/Regional Atmospheric Heavy Metals (GRAHM) model developed by Environment Canada. There was some scepticism expressed about the 1999 mercury emission inventory with regard to the speciation estimates and total mercury fluxes for certain source types. It was agreed that the study will likely find various "surprises" in the new emission inventories. It has already been discovered that mobile sources have once again been omitted from the mercury inventory. (O. Russell Bullock, 919 541 1349)

10. Anthropogenic Secondary Organic Aerosols - Model Intercomparison. In August, members of the Air Quality Modeling Group in EPA's Office of Air Quality Planning and Standards (OAQPS) presented a comparison of air pollutant concentrations predicted with two different air quality models, the Regional Modeling System for Aerosols and Deposition (REMSAD) and the Community Multiscale Air Quality (CMAQ) model. REMSAD is developed by Systems Applications, Inc. (SAI) and has been used extensively by OAQPS in the regulatory decision-making process. The most significant discrepancy between the REMSAD and CMAQ results, as identified by the OAQPS group, is in the summertime anthropogenic secondary organic aerosol (SOA) concentrations. REMSAD simulations of the July 1996 period yield anthropogenic SOA concentrations that exceed the corresponding CMAQ results by more than a factor of 10. Members of the CMAQ model development team were asked to identify the root cause(s) of this discrepancy. The CMAQ model results are in reasonable agreement with anthropogenic SOA concentrations reported by others in the peer-reviewed literature, so our investigation focused on the REMSAD source code and chemical mechanism. Several hypotheses for explaining the differences were posed and subsequently tested. Ultimately, it was found that the source identity of volatile organic compounds (VOC) is not tracked adequately in the REMSAD gas-phase chemical mechanism. In that mechanism, certain reaction products of biogenic VOCs are indistinguishable from compounds of anthropogenic origin. After the source identity is lost, these biogenic VOC reaction products proceed to form secondary organic aerosols, all of which are assumed to be of anthropogenic origin. This problem is not encountered in the chemical mechanisms used in the CMAQ model because the most important gas-phase precursors of anthropogenic SOA (*e.g.*, toluene, xylene) are tracked explicitly. Recommendations for correcting the REMSAD model formulation were provided to SAI. This work was conducted in collaboration with OAQPS and the National Exposure Research Laboratory's Human Exposure and Atmospheric Sciences Division. (Prakash Bhave, 919 541 2194)

11. Community Modeling and Analysis System Center. During November 2003, Dr. William Benjey continued serving as Project Officer for the Community Modeling and Analysis System (CMAS) center at the University of North Carolina at Chapel Hill's Carolina Environmental Program. CMAS facilitates the advancement the Models-3/Community Multiscale Air Quality (CMAQ) user community and collaboration in model improvements, training, and support. Plans were advanced during November to establish a community-access web site for other (non-EPA) developers of Models-3/CMAQ products. Specifically, code for CMAQ, the Sparse Matrix Operator Kernel Emission (SMOKE) modeling system, and the Package for the Analysis and Visualization of Environmental Data (PAVE) visualization tool will likely be placed on the Source Forge web site. This will allow other developers to check code in and out of the site so that they can make and test improvements. The code on Source Forge will be unofficial and will not affect the approved code version issued through CMAS. Once contributed changes and additions are tested, they may be issued as part of the official code release in the future. For example, one possible earlier contribution may be the MADRID aerosol version of CMAQ. CMAS also continued plans to conduct an independent peer review of the science within the Models-3/CMAQ model. Reviewers were selected and provided materials during November. The review is scheduled to be held in Research Triangle Park, North Carolina, during December 17-18, 2003. (Bill Benjey, 919 541 0821)

12. Sub-Canopy Model Evaluation. Results from the evaluation of the Meyers-Paw U sub-canopy deposition model with the Purchase 2002 field study data suggest that the model does quite well in predicting the deposition of ozone in the upper- and mid-canopy levels, but underpredicts the deposition in the lowest levels of the canopy near the ground. The increase in deposition over what is predicted may be due to a number of factors: more stomatal activity in the lower stems, higher than expected deposition to the soil, lower than expected mixing, or titration by soil NO. Ongoing analysis from the Purchase 2003 field study, will shed some light on this. (Peter Finkelstein, 919 541 4553)

13. Air Toxics Modeling. Emission processing for the 2001 National Air Toxics Assessment (NATA) annual simulations are more than 50% complete. Test files for the December 2000 ramp-up period have been successfully created and were used to test the initial toxics version of CMAQ. Emission processing for the year 2001 is expected to be completed within the next month. (George Pouliot, 919 541 5475)

14. Spatial Modeling. Work is ongoing to develop and implement statistical models for spatially correlated data, particularly data that come from disparate sources. Statistical methods under investigation include data assimilation techniques, Bayesian hierarchical models, and non-stationary covariance modeling techniques. Work with spatially correlated data supports efforts in model evaluation, the NO_x initiative, CIRAQ, and other projects. (Jenise Swall, 919 541 7655)

15. Air-Quality Forecasting Initiative. The pre-processor to the Community Multiscale Air Quality (CMAQ) model for air-quality forecasting (PREMAQ) was modified to process the vertical eddy diffusivity field directly from the Eta model to improve coupling between Eta and CMAQ. In addition, ozone analyses from NCEP's Global Forecast System (GFS) have also been added to PREMAQ to test time-varying chemical boundary conditions. Both updates to PREMAQ will be evaluated over the next month with the goal of improving the air-quality forecasting system for the Summer 2004 test period. (Tanya Otte, 919 541 7533)

Retrospective mobile source emission estimates for the summer of 2003 have been created. An initial analysis indicates that estimated NO_x emissions from mobile sources increased by10% since the previous summer, across the Northeast 12-km domain. Future work involves the estimation of emissions for a retrospective period using the same techniques. (George Pouliot, 919 541 5475)

16. Fugitive Dust Emissions. A prototype for a new module in the Sparse Matrix Operator Kernel Emission (SMOKE) modeling system that estimates emissions of fugitive dust sources from unpaved roads has been developed. Initially, the methodology currently used for the 1999 National Emissions Inventory (NEI) version 2 and later emission inventories has been incorporated into the module as part of SMOKE rather than outside of the emission processing. Currently, fugitive dust from unpaved roads is treated as an area source with no episodic meteorological dependence. Vehicle Miles Traveled (VMT) information from unpaved roads is multiplied by an emission factor dependent on rainfall data and silt content to estimate an annual emissions estimate. The annual emission estimate is used in SMOKE to create a gridded hourly value based on a spatial surrogate and temporal profile. The new module incorporates the emission factor estimate directly in SMOKE by treating fugitive dust from an unpaved road as a mobile source. VMT data is used as an input to SMOKE. The new module matches the VMT inventory data at the county level with the unpaved road silt content information and creates a SMOKE-compatible emission factor file that can be integrated with other SMOKE components. Future enhancements to the emission estimate can be made easily by incorporating meteorological information into the module directly to make episodic estimates of fugitive dust from unpaved roads. (George Pouliot, 919 541 5475)

17. Universities Research Award. Undergraduate students in the Department of Statistics, North Carolina State University, Raleigh, won the Universities Research Award for their work analyzing emissions and ambient monitoring data related to Houston's ozone problem. The students will each receive a $500 award next semester to continue work on this project. Their poster and presentation were entitled, *Solving the Houston Air Quality*

Emission Inventory Discrepancy. They have also expanded their methodology and applied it to the Atlanta situation. (David Mobley, 919 541 4676)

Idaho Falls

18. Extreme Turbulence Sphere. FRD has continued to look at modifications to the ET probe's design that will reduce or eliminate fouling of the pressure ports by rain water. The simplest approach being investigated is to enlarge the ports and to slope all the plastic tubing upward towards the top of the sphere. This reduces the effects of capillary action and allows gravity to aid in keeping the tubing clear. One of the existing spheres was modified by replacing the original 0.0625 inch ID tubing with 0.25 inch ID tubing. The advantages of this approach are that it requires no additional power and it does not require any changes to the electronics or software. ATDD is pursuing an alternate approach that uses an air pump to actively backflush the ports. Neither approach has yet been tested under realistic hurricane conditions, so it is unclear how well they will reduce the water fouling problem. It is possible that ET probes of both designs will be deployed during the next hurricane season. richard.eckman@noaa.gov

19. JOINT URBAN 2003. We are continuing to work towards the completion and release of the two SF_6 tracer data sets collected during the Joint Urban 2003 project, i.e., the continuous analyzers and the bag samplers. The data from the continuous analyzers have been completely reviewed and all areas that require special flags have been identified. A number of errors were discovered and corrected during this process. The last hurdle remaining is acquiring good positions (i.e. longitude, latitude) for the analyzers during the various intensive observation periods (IOPs). The continuous analyzers were mounted in minivans that were parked in different locations during the IOPs. By examining operator log books and Operations Center notes, we identified approximately 40 locations where the sampling vans were parked during the experiment. The GPS positions acquired at each of these locations were then examined. By eliminating positions without enough satellites or with too high error values, we obtained reasonable GPS positions could be obtained for about half of the locations. The remaining 20 locations were documented as completely as possible with written descriptions and photographs, and then sent to the University of Oklahoma. Personnel at OU will then determine positions from the GIS database developed for Joint Urban 2003.

Some previous tests indicated that bags filled after the sampler is exposed to high levels of tracer show slightly elevated concentrations even though all tracer has been flushed out of the area. This last test used the same sampling methods used during Joint Urban 2003 and demonstrated that bags exposed to high levels of SF_6 contain approximately 0.08% of the highest concentration the sampler was exposed to. We are currently reviewing data from the experiment to determine if this was a problem. roger.carter@noaa.gov and debbie.lacroix@noaa.gov

20. CBLAST-Low. Work continues on data analysis from the 2001 field campaign. A paper outlining a comparison between buoy-measured winds and LongEZ-measured winds is in preparation. This paper highlights the methodology developed and refined by ATDD and FRD scientists to derived winds from the LongEZ measurement system. Several methods for correcting winds to 10 m neutral conditions, parameterizations used in the TogaCoare Alogrithm, and spatial averaging techniques are all explored in this paper. Tami Grimett, jeff.french@noaa.gov

21. CBLAST-High. Two abstracts were submitted for the AMS 26th Conference on Hurricanes and Tropical Meteorology to be held in Miami in May. The first paper focuses on the development and evolution of the BAT probe from an instrument mounted on light aircraft operating in fair weather conditions to one robust enough to fly through hurricanes. Several iterations from the original design were necessary to produce an instrument capable of operating under such conditions. The second paper focuses on measurements in Hurricanes Fabian and Isabel. In these two storms, ARL scientists and the NOAA P-3 crew acquired for the first time ever estimates of boundary layer fluxes in hurricanes. A third paper, which ARL scientists are listed as co-authors, will focus

on estimates of heat and momentum flux calculated using data from the BAT probe compared with a bulk scheme using data from drop sondes. jeff.french@noaa.gov

22. Light Aircraft Research Program. A government contractor, Conklin and DeDecker, has begun an A-76 study into the feasibility for contracting SERA operations for ARL. A cost analysis for the SERA program was prepared and is being supplied to Conklin and DeDecker for use in the A-76. The outcome of this study, expected in early January, will determine the future of the SERA program within ARL. Phil Hall, OMAO officer currently assigned to AOC, is working with Jeff French to determine the requirements and associated costs for engineering and testing modifications to a SERA. AOC is responsible for the safety of any aircraft within the NOAA fleet. Although the SERA would be operated by ARL, AOC will work closely with ARL scientists and administrators to assure a safe and useful operation. jeff.french@noaa.gov

23. INEEL Mesoscale Modeling. A number of upgrades and improvements have been made to the MM5 forecast system being run at FRD. NCEP has for some time provided the 12 km Eta model output in a tiled format, but until recently this output was missing important variables necessary for initializing MM5. This problem has been fixed by NCEP, so the FRD simulations are now being initialized solely from the 12 km tiled output. One benefit of this change is that the total number of Megabytes being downloaded from NCEP has dropped considerably, so the download time is now just a few minutes. Early on, the download time was a considerable fraction of the total time required to run the MM5 simulations. Another change is that the newest versions of the MM5 programs have been installed. These newer versions seem to provide much improved estimates of near-surface winds and temperature than the older versions.

Steps are also being taken to use 4D data assimilation with frequent updates. A new configuration of MM5 is being tested which assimilates the INEEL Mesonet data every 15 minutes, and also uses any satellite-derived winds and temperatures available within the model domain. Eventually, this configuration may also assimilate University of Utah MesoWest data and commercial aircraft (ACARS) data. Overall, these changes should significantly improve the skill of the INEEL MM5 forecasts. richard.eckman@noaa.gov

Las Vegas

24. Cloud-to-Ground (CG) Lightning Study. Research focus was on analysis of the distribution of positive flash intensity versus terrain elevation. For the eight, warm-season data base, only 3% of the total flashes with intensities ≥5.0 Ka deposited positive charge to the ground. The average positive flash intensity was 13.3 Ka with approximately 80% of these flashes occurring between 3500 ft and 6500 ft Mean Sea Level (MSL). With a mean flash intensity of 13.3 Ka, the positive flashes were slightly more energetic than the negative flashes with a mean of 9.6 Ka. Approximately 25% of the positive flashes, having intensities of 15 to 19 Ka, were focused between 4500 and 6000 ft MSL**.** By contrast, 27% of the negative flashes, having intensities of 5 to 9 Ka where located between 5000 and 6500 ft MSL. (Darryl Randerson, 702 295 1231, Jim Sanders, 702 295 2348, and Doug Soule', 702 295 1266)

25. NOAA Cooperative Institute for Atmospheric and Terrestrial Applications (CIASTA). Mesoscale Modeling: NV-RAMS ran to completion on the University of Nevada-Las Vegas computer system 29 of 30 days (a 97% completion factor). Data are continuing to be renamed and saved daily, and backed up to CD monthly (4 CDs). (Walt Schalk, 702 295 1262)

26. MEDA Maximum Temperature Predictions. The MEDA maximum temperature predictions for November showed generally good agreement with the actual high temperatures during the month. The temperatures during November were below normal with departures as much as -6°F with the overall being near -4°F. The predictions showed a bias error of +1.2°F and an absolute error 3.7°F. These errors fall in line with most of the previous months. The bias fits in with the overall month being below normal. (Doug Soule', 702 295 1266)