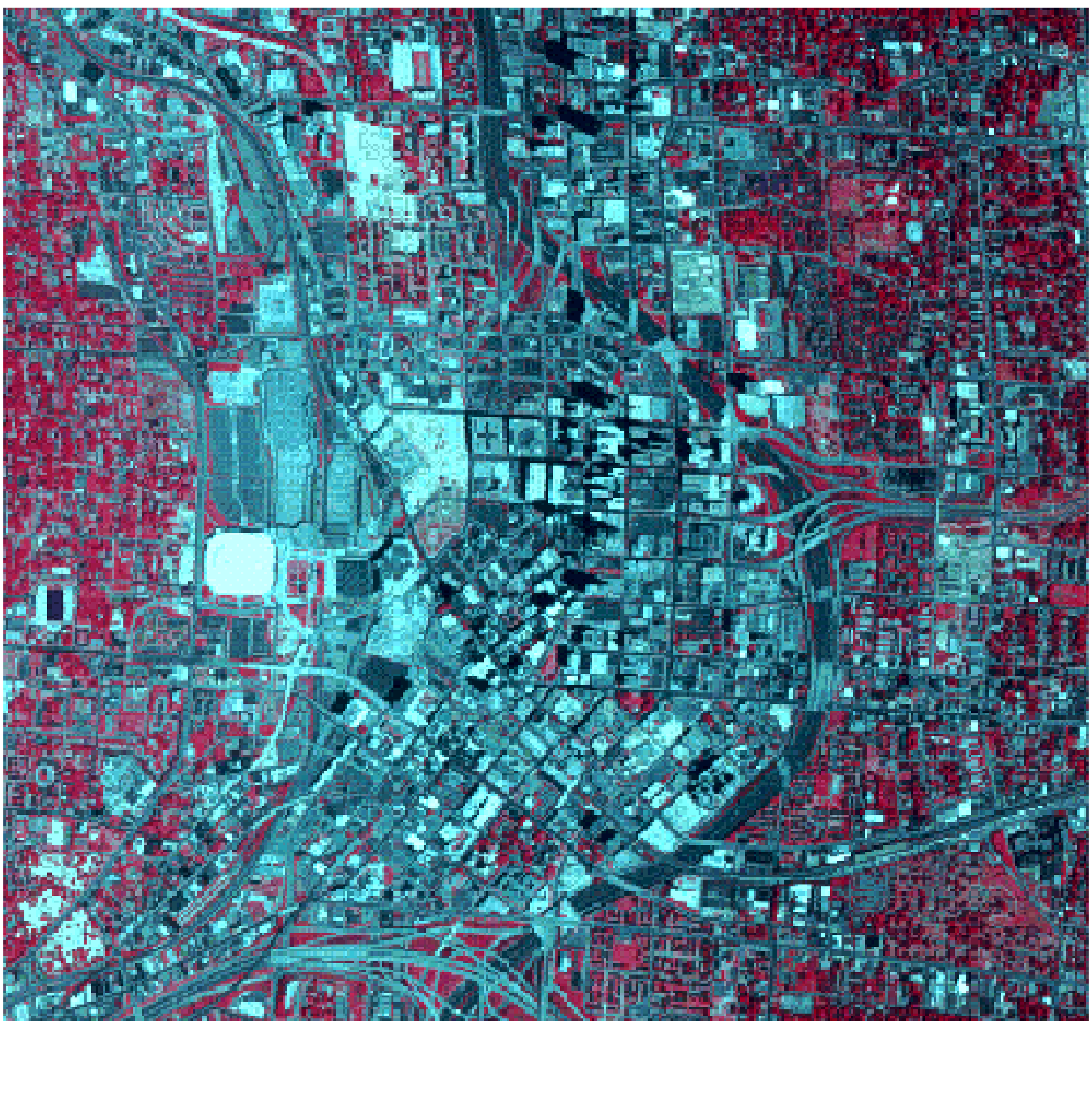
EOS IDS PROJECT
FY97 YEAR-END REPORT

"A Remote Sensing-Based Study of Past and Future Land Use Change Impacts on Climate and Air Quality of the Atlanta, Georgia Metropolitan Region"

Project ATLANTA (ATlanta Land use ANalysis: Temperature and Air quality)

December 31, 1997



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1. Background

Project ATLANTA (ATlanta Land-use ANalysis: Temperature and Air-quality) as a newly-funded NASA EOS Interdisciplinary Science (IDS) investigation in 1996, seeks to observe, measure, model, and analyze how the rapid growth of the Atlanta, Georgia metropolitan area since the early 1970's has impacted the region's climate and air quality. The primary objectives for this research effort are: 1) To investigate and model the relationship between Atlanta urban growth, land cover change, and the development of the urban heat island phenomenon through time at nested spatial scales from local to regional; 2) To investigate and model the relationship between Atlanta urban growth and land cover change on air quality through time at nested spatial scales from local to regional; and 3) To model the overall effects of urban development on surface energy budget characteristics across the Atlanta urban landscape through time at nested spatial scales from local to regional. Our key goal is to derive a better scientific understanding of how land cover changes associated with urbanization in the Atlanta area, principally in transforming forest lands to urban land covers through time, has, and will, effect local and regional climate, surface energy flux, and air quality characteristics. Allied with this goal is the prospect that the results from this research can be applied by urban planners, environmental managers and other decision-makers, for determining how urbanization has impacted the climate and overall environment of the Atlanta area. It is our intent to make the results available from this investigation to help facilitate measures that can be applied to mitigate climatological or air quality degradation, or to design alternate measures to sustain or improve the overall urban environment in the future.

2. Atlanta Urban Growth and Effects on Climate and Air Quality

In the last half of the 20th century, Atlanta, Georgia has risen as the premier commercial, industrial, and transportation urban area of the southeastern United States. The rapid growth of the Atlanta area, particularly within the last 25 years, has made Atlanta one of the fastest growing metropolitan areas in the United States. The population of the Atlanta metropolitan area increased 27% between 1970 and 1980, and 33% between 1980-1990 (Research Atlanta, Inc., 1993). Concomitant with this high rate of population growth, has been an explosive growth in retail, industrial, commercial, and transportation services within the Atlanta region. This has resulted in tremendous land cover change dynamics within the metropolitan region, wherein urbanization has consumed vast acreages of land adjacent to the city proper and has pushed the rural/urban fringe farther and farther away from the original Atlanta urban core. An enormous transition of land from forest and agriculture to urban land uses has occurred in the Atlanta area in the last 25 years, along with subsequent changes in the land-atmosphere energy balance relationships.

Air quality has degenerated over the Atlanta area, particularly in regard to elevations in ozone and emissions of volatile organic compounds (VOCs), as indicated by results from the Southern Oxidants Study (SOS) which has focused a major effort on measuring and quantifying the air quality over the

Atlanta metropolitan region. SOS modeling simulations for Atlanta using U.S. Environmental Protection Agency (EPA) State Implementation Plan guidelines suggest that a 90% decrease in nitrogen oxide emissions, one of the key elements in ozone production, will be required to bring Atlanta into attainment with the present ozone standard (SOS, 1995).

3. Project ATLANTA Science Approach

The scientific approach we are using in relating land cover changes with modifications in the local and regional climate and in air quality, is predicated on the analysis of remote sensing data in conjunction with *in situ* data (e.g., meteorological measurements) that are employed to initialize local and regional-level numerical models of land-atmosphere interactions. Remote sensing data form the basis for quantifying how land covers have changed within the Atlanta metropolitan area through time from the mid-1970's, when Atlanta's dramatic growth began in earnest, to the present. These remotely sensed data will be used to provide input to numerical models that relate land cover change through time with surface energy flux and meteorological parameters to derive temporal models of how land cover changes have impacted both the climatology and the air quality over the Atlanta region. Current remote sensing data (i.e., data obtained during 1997) will be used to calibrate the models and as baseline data for extending the models to predict how prospective future land cover changes will effect the local and regional climate and air quality over the Atlanta-north Georgia region. Additionally, remote sensing data will be used as an indirect modeling method to describe urbanization and deforestation parameters that can be used to assess, as well as predict, the effects of land use changes on the local microclimate.

In concert with the remote sensing-based analysis and modeling of land cover changes is an extensive numerically-based modeling effort to better understand the cause-and-effect relationships between urbanization and trends in climatology and air quality. Sophisticated numerical meteorological models can complement extensive field monitoring projects and help improve our understanding of these relationships and the evolution of the urban climate on a location-specific basis. Measured data alone cannot resolve the relationships between the many causes of urban heat islands/urban climates and observations. For example, measured data cannot directly attribute a certain fraction of temperature rise to a certain modification in land use patterns, change in energy consumption, or release of anthropogenic heat into the atmosphere. These are aspects that numerical modeling can help resolve. Similarly, monitored air quality data cannot be used to establish a direct cause-and-effect relationship between emission sources, activities, or urbanization and observed air quality (e.g., smog). In this sense, photochemical models can be used in testing the sensitivity of ozone concentrations to changes in various land-use components, emission modifications and control, or other strategies. Thus, we are incorporating an assessment of land cover/land use change as measured from remote sensing data, with temporal numerical modeling simulations to better understand the effects that the growth of Atlanta has had on local and regional climate characteristics and air quality.

4. Science and Applications Tasks

The science tasks associated with Project ATLANTA are being executed via a number of separate, but highly interlinked, tasks. Figure 1[♦] presents a flow diagram for research tasks within the overall investigation. Two science team meetings which brought together all personnel involved on this project, have been held since funding was received in January, 1997 to support the investigators on Project ATLANTA. One team meeting was held at the Global Hydrology and Climate Center in Huntsville, Alabama on April 11-12, 1997. This first meeting served as a fulcrum for initiating research activities and for discussing strategies to successfully achieve the project's objectives and goals. A second Project ATLANTA team meeting was held in Atlanta, Georgia on December 15-16, 1997. This second meeting focused on having team members provide updates on research progress, to discuss the challenges that were being encountered in executing their respective research tasks, to discuss publication, communication, and dissemination of the results from Project ATLANTA research, and to discuss how to best interlink the project's science objectives as applied to the needs of the user community. A Project ATLANTA Web page has been established at:

http://wwwghcc.msfc.nasa.gov/atlanta/.

This home page will provide updates of the project's progress and research findings. An overview of the work progress that has been accomplished for Project ATLANTA during FY97 is presented below by major research task, along with a description of the science tasks planned to be accomplished during FY98.

4.1 Land Use/Land Cover Change Mapping for the Atlanta Area (Task Leader: C.P. Lo, University of Georgia)

Land use/cover maps of the Atlanta Metropolitan Region for the years 1973, 1979, 1983, 1988, and 1992 have been produced using center-shifted Landsat MSS data. From these maps, land use/cover and land use/cover change statistics have been generated.

FY97 Science Task Highlights: Land Use/Cover Changes in the Atlanta Metropolitan Region, 1973-1992

(1) For the whole Atlanta satellite image area: By examining the land use/cover maps of 1973, 1979, 1983, 1988, and 1992 (Figures 2-6), a time sequence of the spatial spread of both high-density urban use and low-density residential use from the center of the city of Atlanta along highways is clearly visible. This spatial spread seemed to slow down somewhat between 1988 and 1992. As a result, both forest land and grassland/cropland have decreased in absolute area. Between 1973 and 1992, forest land and grassland/cropland have declined by 18.4% and 21.8% respectively, while high-density urban use and low-density residential use have increased by 188.5% and 58.5% respectively. For each year, the percentage of forest land has decreased from 62.64% of the whole scene in 1973 to 51.09% in 1992. The same trend can be seen in grassland/cropland from 9.10% in 1973 to 7.12% in 1992. On the other hand, high-density urban use has increased from 1.96% in 1973 to 5.67% in 1992. Similarly, low

[♦] All figures are presented at the end of the text.

density residential use has increased from 20.29% in 1973 to 32.14% in 1992. These changes are borne out in Figure 7 and Table 1[δ].

The location-specific change pattern maps (Figures 8 to 11) illustrate where and what types of land use/cover have been involved in the change between two years. One should be cautioned, however, that because the land use/cover maps are 87% or so accurate, some "changes" could be the results of misclassification. Having taken into account of these errors, one can see that a lot of forest land has been involved in these changes. It should be noted that "cultivated/exposed land" was also involved in the change because it included a lot of land in transition at the time of satellite data acquisition.

(2) For Atlanta Regional Commission Counties only: The boundaries of the counties in Atlanta that constitute Atlanta Regional Commission (ARC) have been marked on the land use/cover maps of Figures 2 to 6. By doing so, the complete metropolitan area of Atlanta is covered, which is smaller in areal extent than the whole satellite scene. All the comments made in (1) above for the whole scene will apply, except that the land use change has been more intense if only the ARC is considered. Figure 12 and Table 2 show land use change by class for the ARC area from 1973 to 1992. The trends are very similar to those shown in Table 1 and Figure 7. Between 1973 and 1992, forest land and grassland/cropland have declined by 24.1% and 38.1% respectively while high- density urban use and low-density residential use have increased by 207.76% and 61.1% respectively. In percentage terms for the ARC area, forest land has declined from 60.33% in 1973 to 45.77% in 1992 Similarly, grassland/cropland has declined from 7.71% in 1973 to 4.77% in 1992. In both cases, the decline was much greater for the ARC area than the whole satellite image area, indicating that much of the loss occurred inside the ARC area. On the contrary, high-density urban use has increased from 2.90% in 1973 to 8.94% in 1992, and low-density residential use has increased from 23.27% in 1973 to 37.49% in 1992. The higher percentages for the ARC area than the whole satellite image area also suggests that the increases occurred mostly inside the ARC area.

FY98 Science Task Plans:

The focus for this science task in FY98 will be to complete the following:

1) Extract NDVI values from Landsat MSS data for 1973, 1979, 1983, 1988, and 1992, and examine the significance of NDVI changes;
2) Map the most recent land use/cover of the Atlanta metropolitan region by using Landsat Thematic Mapper (TM) data acquired in 1997 to coincide with collection of high spatial resolution multispectral airborne data collected over Atlanta (see Section 4.2 below);
3) Map the land use/cover of the Atlanta metropolitan region using high spatial resolution airborne multispectral scanner data obtained on May 11, 1997 (see Section 4.2 below);

[δ] All tables are presented at the end of the text.

4) Interpret color infrared aerial photographs acquired at the same time with the high spatial resolution multispectral aircraft data obtained over Atlanta on May 11, 1997 (see Section 4.2 below). [These data will provide ground truth for verifying accuracy of the land use/cover maps produced from Landsat TM and the high spatial resolution multispectral aircraft data];
5) Extract surface temperatures from Landsat TM data and the high spatial resolution multispectral aircraft data; and
6) Extract NDVI from Landsat TM data and the high spatial resolution multispectral aircraft data of the Atlanta metropolitan region.

4.2 Analysis of Urban Surface Energy Fluxes from High Spatial Resolution Multispectral Thermal IR Data (Task Leaders: J. Luvall & D. Quattrochi, NASA, GHCC)

To augment the quantitative measurements of land cover change and land surface thermal characteristics derived from satellite data (i.e, Landsat MSS and TM data for assessment of land cover change; Landsat TM thermal, and AVHRR and GOES data for land surface thermal characteristics), we are employing high spatial resolution airborne multispectral thermal data to provide detailed measurements of thermal energy fluxes that occur for specific surfaces (e.g., pavements, buildings) across the Atlanta urban landscape, and the changes in thermal energy response for these surfaces between day and night. This information is critical to resolving the underlying surface responses that lead to development of local and regional-scale urban climate processes, such as the urban heat island phenomenon and related characteristics (Quattrochi and Ridd, 1994, 1998). These aircraft data will also be used to develop a functional classification of the thermal attributes of the Atlanta metropolitan area to better understand the energy budget linkages between the urban surface and the boundary layer atmosphere.

FY97 Science Task Highlights: ATLAS and MAS Data Collection Over Atlanta

ATLAS Data Collection

High spatial resolution multispectral thermal infrared airborne data were acquired over Atlanta using the Advanced Thermal and Land Applications Sensor (ATLAS), which is flown onboard a Lear 23 jet aircraft operated by the NASA Stennis Space Center. The ATLAS is a 15-channel multispectral scanner that basically incorporates the bandwidths of the Landsat TM (along with several additional channels) and 6 thermal IR channels similar to that available on the airborne Thermal Infrared Multispectral Scanner (TIMS) sensor. Of particular importance to the Atlanta study is the multispectral thermal IR capability of the ATLAS instrument. ATLAS thermal IR data, collected at a very high spatial resolution, have been used to study urban surface energy responses in a previous study over the Huntsville, Alabama metropolitan area with excellent results (Lo et al., 1997). A description of the ATLAS sensor, along with sensor system specifications can be found in Quattrochi and Luvall, 1997 and Lo et al., 1997.

ATLAS data were collected over a 48 x 48 km^2 area, centered on the Atlanta Central Business District (CBD) on May 11 and 12, 1997. ATLAS data were collected at a 10m pixel spatial resolution during the daytime, between approximately 11:00 a.m. and 3:00 p.m. local time (Eastern Daylight Time) to capture the highest incidence of solar radiation across the city landscape around solar noon. ATLAS 10m data were also obtained the following morning (May 12) between 2:00-4:00 a.m. local time (Eastern Daylight Time) to measure the Atlanta urban surface during the coolest time of the diurnal energy cycle.

Sky conditions at the time of the daytime overflights were mostly clear with some cirrus clouds present. The Lear jet aircraft flew at an altitude of 5,063m above mean terrain to achieve a 10m pixel resolution which was well below the cirrus clouds. Cirrus clouds covered the entire Atlanta metropolitan area during the night flights. The presence of cirrus cloud cover at night did, to some extent, dampen the cooling effect of thermal energy release to a clear sky, but air temperatures were still sufficiently cool to provide ample difference with daytime heating. Maximum air temperatures during the daytime overflights were approximately 25^{o}C, while air temperature during the nighttime flights was around 10^{o}C. Sample surface temperatures for tree-shaded grass, tree canopy, and asphalt in full sunlight recorded with a hand-held infrared thermometer (8-14 λm) during the afternoon were 28^{o}C, 21^{o}C, and 50^{o}C, respectively. Daytime temperatures for a commercial building roof comprised of rock/membrane coating ranged from 49^{o}C to 52^{o}C. This illustrates that although air temperatures were cooler than optimal for development of the urban heat island effect, there was still significant heating by artificial urban surfaces to permit good contrast with nighttime cooling.

Figure 13 illustrates daytime thermal (channel 13 - 9.60-10.2 λm) ATLAS data collected over the Atlanta CBD area. Figure 14 provides an example of ATLAS data (channel 13) acquired during the night over the Atlanta CBD. Both images are oriented with north at the top. Excluding the effects of the highly variable emissivities of urban building materials, an empirical observation of the images presented in Figures 13 and 14 illustrates the wide range of thermal energy responses present across the Atlanta city landscape, as well as the detail that can be discerned from the 10m data. The Georgia Dome, an enclosed football stadium, appears as the large square-shaped structure due west of the Atlanta city center. Interstate highways 75/85 which traverse in a north-south direction around the city center, are seen as a dark "ribbon" on the day data (Figure 13) just to the east of downtown Atlanta. Just south of the city center, is the junction of Interstate Highways 75/85 and 20. Shadows from tall buildings located in the Atlanta city center can also be observed on the daytime data. In Figure 13, the intense thermal energy responses from buildings, pavements and other surfaces typical of the urban landscape, as well as the heterogeneous distribution of these responses, stand in significant contrast to the relative "flatness" of Atlanta thermal landscape at night (Figure 14). Also, the damping effect that the urban forest has on upwelling thermal energy responses is evident, particularly in the upper right side of the daytime image where residential tree canopy is extensive. In Figure 14, there is still evidence, even in the very early morning, of elevated thermal energy responses from buildings and other surfaces in the Atlanta CBD and from streets and highways. It appears that thermal energy responses for vegetation across the image are relatively uniform at night, regardless of vegetative type (e.g., grass, trees).

MAS/AVIRIS Data Collection

In addition to the collection of ATLAS data, MODIS Airborne Simulator (MAS) and Airborne Visible Infrared Imaging Spectrometer (AVIRIS) data were collected over the Atlanta metropolitan area on August 6, 1997. Although these data are important for augmenting the information obtained from the ATLAS data, the MAS data are key to developing a working understanding of how MODIS can be used for measuring urban surface energy fluxes. Although MAS data collection was the primary purpose for the ER2 overflight in August, AVIRIS data collected concurrently with the MAS data are useful for deriving a hyperspectral characterization of land covers across the Atlanta metropolitan area.

Meteorological conditions were not optimal during the MAS/AVIRIS overflight of Atlanta on August 6. Although clear weather was predicted over Atlanta for August 6, convective cumulus clouds, typical of the summertime meteorological regime in the southeastern U.S., began to form just as MAS/AVIRIS data collection began at approximately 12:00 noon EDT. The cumulus clouds continued to build throughout the duration of the ER2 overflight. Despite the presence of clouds, quick-look browse images of the MAS data illustrate that data collected during the early part of the overflight are usable. Figure 15 is an example of the MAS quick-look data provided by the Ames Research Center that shows the ER2 flight track flown directly over the Atlanta metropolitan area.

FY98 Science Task Plans:

The focus for this science task in FY98 will be to complete the following:

1. Complete atmospheric correction of ATLAS thermal IR data;
2. Derive calibrated at-sensor thermal IR radiance values from ATLAS data;
3. Derive calibrated at-sensor radiance values for ATLAS visible, reflective and near IR data;
4. Use ATLAS data to derive thermal IR measurements of land surface energy fluxes for day and night for the Atlanta metropolitan area for input to land use change, and meteorological and air quality modeling tasks (see Sections 4.1 and 4.4); and
5. In conjunction with the land use change tasks described in Section 4.1, derive NDVI analysis of the Atlanta metropolitan area using ATLAS data.

4.3 Linking the Remote Sensing Data with Temporal Changes in Urban Land Cover and Observed Climatic Data (Task Leaders: K. Gallo, NOAA/NESDIS & R. Gillies, Utah State University)

This research tasks consists of four interlinked science elements: 1) To detect land use/land cover changes that are meteorologically or climatically significant across the Atlanta metropolitan area using retrospective Landsat MSS and TM data; (2) to derive NDVI estimates of changes in greenness for the Atlanta area through time using Landsat-

MSS and -TM, and AVHRR data; 3) To derive an historical description of urbanization (i.e., associated land use change) for Atlanta using the available archived satellite data (e.g., AVHRR) from 1985 to date (1997) on an annual basis, and to estimate the amount of soil moisture, and vegetative cover that has been modified as a result of the urbanization process; and 4) To relate model output changes derived using the "Triangle" Method to changes in land use/land cover through time as determined from retrospective AVHRR data. The first year has primarily been devoted to data acquisition and preprocessing. Three Landsat MSS scenes were acquired from the EROS Data Center (EDC) and forwarded to C.P. Lo at the University of Georgia for development of a preliminary land use/land cover map. We have successfully made arrangements with EDC to receive the AVHRR data that is included in their biweekly composites produced for the conterminous USA. We have identified climate stations that will be used in an intensive analysis of the urban/rural environment around the Atlanta region. R. Gillies has developed a copy of the program to compute fractional vegetation cover and the near-surface soil water content. We have successfully used the program on composite data, however, we need to verify the output using a single- date image.

FY97 Science Task Highlights: Land Use/Land Cover Change Detection from Landsat MSS, TM, and AVHRR Data

The emphasis of this task is to utilize the developed MSS- and TM-based land use classes in comparison with the AVHRR analysis. The TM- and MSS-based land use classes will be mapped to 25 and 100m projections, respectively, that can be overlayed onto the AVHRR data (1,000m). NDVI and surface temperature (Tsfc) data derived for the AVHRR data can then be stratified by classes as determined by the MSS and TM data. The NDVI and Tsfc will then be examined for trends over time as related to the changes in land use. We have obtained three Landsat-MSS scenes from EDC and forwarded these to C.P. Lo at the University of Georgia. We will begin the above comparisons in the next year as the land use/land cover images are available.

FY97 Science Task Highlights: Extraction of NDVI from Landsat and AVHRR Data

NDVI values will be computed for the AVHRR images acquired for the Atlanta region. The NDVI will be based on post-launch calibrated Ch1 and Ch2 data and processed at the EROS Data Center. The images will be geographically co-registered so that comparisons can be made over time related to changes in the NDVI. Additionally, Tsfc will be computed from the AVHRR data and similarly analyzed.

We have biweekly composite products produced by EDC for the 1989 through 1995 time period (CD-ROMs). We expect to receive the 1996 CD’s shortly. We have also made arrangements with EDC to have the daily data, that is used in preparation of the CD’s, archived on tape and sent to us for analysis. Thus far we have received data for the 30 May through 3 July 1997 interval (e.g. Figure 16). This data set, however, includes only data acquired by NOAA-14. We have identified several scenes of NOAA-12 data which appear to have clear conditions over the Atlanta region. We plan to order these scenes and the retrospective scenes of AVHRR data in a mass purchase within the next few months. Once in-house, data extraction will begin.

FY97 Science Task Highlights: Estimation of Soil Moisture and Vegetative Cover by the "Triangle" Method

Although the "Triangle" Method model has shown good results for estimation of regional patterns of surface moisture availability (M_o) and fractional vegetation (F_r) in the presence of spatially variable vegetation cover (Gillies and Carlson, 1994, 1995; Owen, 1995), a significant improvement can be made to the model by relating model output to changes in urban land use/land cover over time. The major climate changes that are influenced by changes in urban land covers are increased summer maximum and minimum temperatures, decreased wind, and increased runoff.

We have identified approximately a dozen weather observation stations within a 50 mile radius of Atlanta that we will use to assess differences and trends in temperatures during the past 20-25 years. Within the next year maximum and minimum temperatures (e.g. Figure 17) will be evaluated for urban and rural environments on single dates when cloud-free satellite data are available and over several days when composites of satellite data must be used. Additionally urban and rural trends will be assessed for stations within the Atlanta region. The weather observation stations will be geographically located within the satellite images for this analysis. Ancillary data will be available to exclude the inclusion of non-land surfaces (rivers, lakes, steams) from the analyses.

FY98 Science Task Plans:

The focus for this science task in FY98 will be to complete the following:

1. Analyze 1997 intra-seasonal AVHRR-derived surface temperature and vegetation index values and model fractional vegetative cover and heat flux values;
2. Relate urban land cover data from Landsat MSS/TM to AVHRR-derived parameters acquired in the above task and assess the influence of urbanization and related changes on observed maximum and minimum air temperatures at *in situ* NWS and Cooperative meteorological stations;
3. Assemble both *in situ* data from the mesonet network put in place for the 1996 Olympic Games (now run by the University of Georgia) and retrospective AVHRR and Landsat MSS/TM land cover classified data.

4.4 Meteorological and Air Quality Modeling (Task Leaders: R. Bornstein, San Jose State University & H. Taha, Lawrence Berkeley National Laboratory)

In this science task, two state-of-the-art mesoscale models were run at the Lawrence Berkeley National Laboratory (LBNL). A meteorological model (CSUMM) was run off-line to provide input to an airshed model (UAM) and its emission pre-processing systems (for anthropogenic and biogenic emissions correction and update). Several modifications were performed at LBNL to update these models and enable them to accept gridded, satellite-based surface characterization input, better account for anthropogenic heat flux, as well as better account for heat storage fluxes in urban areas.

With respect to anthropogenic heating, a method was devised to implement time- and space-varying fluxes into the mesoscale meteorological model. A Fourier series representation was used to prescribe the anthropogenic heat fluxes' diurnal profile as a function of a value assigned to each LULC type and averaged for each grid cell in the modeling domain. In addition to these model modifications, a pre-processing step was devised in the mesoscale model to process and use USGS-developed land use and land cover data.

FY97 Science Task Highlights: Meteorological Modeling of the Atlanta Metropolitan Area

With respect to the mesoscale meteorological and airshed modeling task, significant progress was made during the first year of this project. Two summer episodes (one 2-day and one 5-day) were simulated for the northern Georgia region. Of interest to this study, the model simulates a daytime heat island of 1.5^{o}C and a nighttime heat island of about 2-3^{o}C over the Atlanta area. A basecase model performance evaluation process was initiated following the establishment of a meteorological base case for each episode. For the validation purpose, Mesonet data from the Georgia Automated Environmental Monitoring Network were obtained. Fifteen-minute meteorological data from the summers of 1996 and 1997 for about 30 stations in Georgia were obtained from the University of Georgia and used to test the model performance. The tests suggest that the mesoscale model performs well (simulates more accurately) clear days during the selected episodes. During overcast days, the model simulations diverged to a certain extent from observed mesoscale conditions. Of course, this was expected since the model used during the first year did not have cloud physics or parameterization capabilities. Thus model modification (e.g., cloud parameterization) should be considered during the second phase of the project so as to improve the simulation of overcast periods that are common in the Atlanta region. Another alternative would be to use a model with built-in cloud physics such as the PSU/NCAR MM5. Work is currently progressing on implementing the MM5 model on LBNL computers so that we can use it during the second year of the project. In addition, modifications have also been made to the current model (CSUMM) to "urbanize" it by increasing the resolution of the simulation grid (from 25km^2 to 4km^2), increasing the resolution of input to the model, especially in urban areas, and modifying the model's physics so that urban heat storage flux is better accounted for. The latter task involved integrating an objective hysteresis model with the mesoscale (boundary-layer) meteorological model. This method was selected after examining several possible alternatives, including the possibilities of nesting canopy-layer models within boundary-layer models, modifying the surface-layer formulation and parameterization, and including semi-empirical models in BLMs. The selected scheme will be replaced by more up-to-date ones when they become available; e.g., from San Jose State University (SJSU) later during the second year of this project. A report was written on the subject matter and sent out for peer review.

Following the validation of the base-case models' performance, a preliminary set of land-use/land-cover change scenarios for north Georgia were developed. These will be refined during the second year of this project using NASA's satellite and aircraft data from the other project investigators as well as regional plans developed by the Atlanta Regional

Commission (ARC). The preliminary scenarios were simulated with the mesoscale model to gain an understanding of their potential meteorological impacts during the selected episodes. In particular, preliminary sensitivity simulations for changes in urban surface albedo in North Georgia, including the Atlanta area, were performed. These simulations suggest temperature depressions on the order of $1^{o}C$ following the increases in urban surface albedo. Using the LBNL-improved version of the model, the simulated daytime heat island reaches $2.5^{o}C$ and the temperature reduction due to increased surface albedo reached some $1.6^{o}C$. These findings are preliminary and should change as more updated surface characterization becomes available. Figures 18-22 illustrate the modeling domain and base-case mesoscale simulations of the greater Atlanta region, along with some examples of the gridded surface properties used in these simulations.

Case study of Atlanta area meteorological fields:1400 LST, 8 February 1996

One of the more significant highlights from the meteorological modeling efforts in Project ATLANTA during FY97 has been the identification of an interesting case analysis showing how the meteorology over Atlanta effects extra-regional meteorology downwind from the Atlanta metropolitan area. As part of the science task efforts conducted by the San Jose State University (R. Bornstein), data analysis has shown that it is possible that the Atlanta daytime urban heat island produced a downwind convergence zone in which a highly localized precipitation event occurred.

The topography of the Atlanta area (Figure 23) shows generally flat terrain over the area, with a sloping hill (up to about 700m) to the north of the city. Observed winds at 1400 LST on 8 February 1996 (Figure 24) show a weak westerly flow south of Atlanta, and a weak northwesterly flow in the area northwest of the city. Note that Tifton (due south of Atlanta) frequently shows high wind speeds during such periods, a situation that requires additional investigation to verify.

Interpolation of the observations in Figure 24 shows a confluence zone downwind (i.e., east) of the urban center of Atlanta (Figure 25). The confluence region is also seen in the areas north and south of Atlanta. The northern and downwind lobes of this zone are co-located in the areas of maximum surface temperature (Figure 26), i.e, downwind of the urban center of Atlanta. This area could result from advective displacement of the Atlanta urban heat island (Figure 27). The northeast segment of this warm area is associated with the area of minimum relative humidity (Figure 28), located northeast of downtown Atlanta.

Only one site reported precipitation during this period (Figure 29), and it is located south of the city. Given the lack of precipitation data downwind of Atlanta, it is hard to verify the following hypothesis: that Atlanta initiated this precipitation event.

Observations by R. Bornstein at SJSU have shown that thunderstorm activity over New York City is a maximum downwind of the city, as well in both adjacent (to the city) lateral regions (looking downwind). The current lack of data in two of three of those regions could be corrected if additional data for this case are located. During the second year, additional cases will also be identified, and some of those cases could be simulated by either the SJSU and LBNL groups.

FY97 Science Task Highlights: Air Quality Modeling of the Atlanta Metropolitan Area

A photochemical (air quality) base case for Atlanta was established using the Urban Airshed Model (UAM) for the episode July 29-August 1. This episode was selected to be long enough to satisfy the U.S. Environmental Protection Agency (EPA) airshed modeling requirements and to minimize contamination of the simulated meteorological and air pollutant concentration fields with data from initial conditions. It was also selected to coincide with the State Implementation Plan (SIP) episode used by the Atlanta air pollution control districts. Input data were obtained from Georgia Tech and the Georgia Department of Natural Resources. The first two days of the photochemical simulations were used to spin off the model and the last two days for data analysis. While the mesoscale meteorological simulations were initiated at 7 am on July 28 and stopped at midnight of August 1st (113 hours simulated time) the airshed model simulations were started at 00:00 on July 29 and ended at 24:00 on August 1st. The simulated air pollutant concentrations are currently being compared to observed concentrations and photochemical model performance evaluation is being assessed accordingly. Figures 30-31 provide an illustration of the results from this UAM simulations for 8:00 a.m. and 5:00 p.m. local time over Atlanta on July 29.

The Urban Airshed Model was used in this project because it is the EPA-designated tool for attainment demonstration and regulatory and implementation purposes. We will continue to use it. During the second or third years of this project, and in parallel to using the UAM, other, more advanced models may be run as well. Several more advanced models exist and H. Taha from LBNL will consult with others to determine the project's needs and decide on other photochemical models to use in addition to UAM.

FY98 Science Task Plans:

1. Finalize past-year and base-case NDVI and albedo. These will be based on the latest remote sensing information (TM, ATLAS, AVHRR) to be made available by other investigators in this project (Lo, Quattrochi, Luvall, Gillies, Gallo). Using these data and other urbanization trend information, perform past-year meteorological simulations of the region;
2. Finalize modified-case albedo based on distribution of eligible urban LULC in the modeling region. Simulate the meteorological and air quality conditions associated with changes in albedo;
3. Test model "urbanization" and new soil moisture schemes in the meteorological model using LBNL-developed algorithms or those to be developed by Bornstein, when these become available;
4. Run improved base- and modified-case airshed model (UAM) scenarios and perform model performance evaluation using observational data from the state of Georgia. Airshed simulations will be repeated after emission input is updated to reflect changing meteorological conditions;
5. Perform mesoscale meteorological simulations at finer resolution, e.g., 2x2 km for base- and future-year scenarios;
6. Refine and use a procedure to "paste" 4-dimensional differences in the thermal and diffusive environments onto UAM-ready input to simulate the air quality conditions associated with various meteorological scenarios and modified surface conditions;

7. Provide comparison distributions for the LBNL modeling results. These efforts will be intensified during the second year as additional NWS and SOS data will be sought to augment data-sparse areas in the LBNL modeling domain, especially over the Atlanta urban area;
8. Identify interesting regional and urban meteorological patterns that could be investigated via LBNL and/or SJSU modeling efforts;
9. Obtain meteorological data from additional observational sites for the 8 Feb 1996 case that was previously analyzed;
10. Obtain the SOS Atlanta intensive data set for analysis of urban climate and air quality patterns. This data is the only Atlanta data set that is rich in observations of the vertical structure of the PBL;
11. Development of an advanced SBL and urbanization scheme for use in the LBNL/MM5 and SJSU/URBMET modeling efforts; and
12. Application of the modified SJSU/URBMET model to simulate the observed Atlanta SOS urban climate data set

4.5 Analysis of Cloud Effects on Urban Climate (Task Leader: S. Kidder, CIRA, Colorado State University)

The key goal of Project ATLANTA is "to derive a better scientific understanding of how land cover changes associated with urbanization, principally in transforming forest lands to urban land covers through time, has, and will, effect local and regional climate, surface energy flux, and air quality characteristics." Clouds are significant intermediaries in this land cover–climate connection. Changes in land cover will change the cloud cover—particularly of the small clouds—which will change the solar insolation, the outgoing infrared radiation, and thus the climate and the air quality. CIRA is performing three tasks aimed at improving our understanding of the role of clouds in the land cover–climate connection:

1. Use GOES 8 data to construct a cloud climatology over Atlanta for the summer of 1996. This will serve as a basis for the mesoscale modeling study of clouds described in Task 4.4;
2. Use GOES 8 data to understand the diurnal variability of albedo, soil moisture availability, thermal inertia, and surface roughness needed to initialize the mesoscale models.; and
3. Run the RAMS model to simulate the cloud field which is prevalent around Atlanta in the summer. Compare the clouds produced in the model with the clouds deduced from GOES 8 data. Determine what effects changes in land use/land cover would have on the modeled cloud field.

FY97 Science Task Highlights: Cloud Climatology Modeling of the Atlanta Metropolitan Area

1. Collected GOES 8 data from the CIRA Ground Station for the period 5 July–5 September 1996.;
2. Made video tape and CD-ROMs of daytime clouds for the two-month period;
3. Did a crude cloud classification for each day and did a detailed, but preliminary, cloud analysis for two days (21 and 23 August 1996);
4. Acquired ozone data from the Georgia Department of Natural Resources and did preliminary comparisons with the cloud data; and
5. Performed initial modeling studies.

Preliminary Conclusions from FY97 Cloud Effects Research:

Atlanta, in the summer, is a very cloudy place. In our 63-day period (5 July–5 September 1996) there were zero days which were clear for the entire daylight period. Days which are cloud-free in the morning become partly cloud in the afternoon in response to solar heating. Figure 32 shows an afternoon scene of a typical day which was clear in the morning. This result casts doubt on the applicability of California-style air quality models which run in perpetual clear skies.

Cloud cover can be relatively easily retrieved from GOES data. Figure 33 shows the cloud cover on one day. Days which are clear in the morning have higher ozone than those which are cloudy in the morning. Figure 34 shows the maximum hourly ozone concentration from the six Atlanta monitoring stations for each of the 63 days. The days which were clear in the morning are white, blue bars indicate days which were cloudy in the morning. Clear mornings tend to be higher ozone days.

Ozone is produced by photochemical processes, but is destroyed by other processes. Figure 35 shows that the rise of ozone concentrations is in phase with solar insolation and also with cumulus cloud formation, but ozone persists after the insolation and the clouds decay.

RAMS does model the formation of small clouds. Figure 36 shows the comparison between modeled and observed clouds. [Note that the cloud amounts in Figures 33 and 36 were derived differently for slightly different areas and therefore do not correspond exactly.] However, the modeled clouds continue to increase after 1300 LT, while the observed clouds decay due to a decrease in solar insolation. This is a problem in the model parameterizations which must be addressed.

The Urban Heat Island (UHI) effect can be estimated by taking the difference between two model runs, one with the urban parameters (albedo, soil moisture, thermal inertia, roughness, etc.) in place, and the other with the urban parameters replaced with rural parameters. Similarly, the cloud effect can be studied by the difference between two model runs, one with microphysics turned on (with clouds) and the other with microphysics turned off (no clouds). Both effects are plotted in Figure 37. The UHI effect warms the city, while clouds definitely cool the city.

The effect of land use/land cover on clouds is presented in Figure 38. The urban area produces more clouds in the morning, but the rural area has more clouds in the afternoon. However, the simulations are not accurate after about 1300 LT because the modeled clouds persist while the real clouds decay.

FY98 Science Task Plans:

1. Construct a more detailed cloud climatology for each day of the 63-day period;
2. Investigate properties of the clouds as they affect climatology over the Atlanta region;
3. Run a newer version of RAMS, with more detailed surface parameterizations to investigate cloud climatology over the Atlanta area; and

4. Investigate the reason that small clouds do not decay as they should in the late afternoon, although the new version of RAMS may better simulate clouds than the version used in this year's research.

4.6 Applications Strategy Assessment (Task Leader: M. Estes, Global Hydrology and Climate Center)

During FY97, an effort was initiated to relate the science tasks associated with Project ATLANTA with the needs of the user community in the Atlanta metropolitan area. The application of the results achieved in Project ATLANTA by decision-makers, planners, and other individuals and agencies to make the Atlanta area a more sustainable and habitable urban environment, is viewed as the ultimate demonstration that the science tasks described above, produce results that can be effectively used to make the Atlanta metropolitan area a better place in which to work and live. To this end, an Applications Strategy meeting was held in Atlanta on September 3, 1997 to facilitate interaction between Project ATLANTA science team members and individuals in the Atlanta community who are interested in applying the data and results from this EOS IDS project. Mr. Maury Estes, an environmental urban planner at the Global Hydrology and Climate Center, has been selected as the task leader and point-of-contact for disseminating the science results from Project ATLANTA to the user community. Mr. Estes was funded in November 1997 to support his involvement as an applications specialist for Project ATLANTA via a supplemental proposal that was submitted to the MTPE office at NASA Headquarters entitled "Applications of Project ATLANTA Remote Sensing Data and Model Output: Meeting the Needs of the User Community".

Project ATLANTA Applications Tasks:

Task 1: Maintain effective contact with the recently organized Project ATLANTA Applications Working Group to ensure that data products are developed that are responsive to the group's needs and interests. This will be accomplished by keeping the working group members informed regarding the types of remote sensing data collected, plans to utilize this data, and how we hope to use the data to advance knowledge of the urban heat island and its impact on air quality and the energy budget. Initially, data products will be developed from the high spatial resolution day/night ATLAS data collected over Atlanta in May, 1997 and shared with the working group for the purpose of receiving feedback. The feedback will be used to modify and/or develop new data products that will be utilized by stakeholders in the Atlanta region. Additionally, the Applications Working Group has expressed a great deal of interest in obtaining the land cover classifications of the Atlanta metropolitan area derived from Landsat MSS data for 1973, 1979, 1983, 1988, and 1992. These data will also be made available for use by the working group. This iterative process of the science investigation team providing and receiving feedback on data products to the Applications Working Group will be continued as other data are collected and products developed over the course of the Project ATLANTA study. An applications strategy document is in draft form and will be updated periodically with input from the working group members. Finally, the applications specialist will work with the working group to identify data sources that may be of use in the science study and in developing tools that can be used to develop data products.

Task 2: Evaluate the tools and resources available for integration with the remote sensing data and model output products from Project ATLANTA. This includes a survey of GIS-based tools and software packages that are of interest to the user community in the Atlanta area. It is evident from contacts already made within the Atlanta regional user community that incorporation of the remote sensing data and model output from Project ATLANTA within a GIS framework is imperative to achieve a successful transition from scientific results to applications. This task will also focus on how data available from the user community, such as land use plans or transportation corridor information, can be employed to complement and enhance the project's science results. Additionally, this task will include developing a cooperative link with the Center for GIS and Spatial Analysis located at the Georgia Tech Research Institute, to explore how visualization techniques can be used to enhance the remote sensing data and model results from Project ATLANTA within an applications framework.

Task 3: Transfer the remote sensing and data and model output results from Project ATLANTA to the user community. This will be accomplished via communication with the Applications Working Group and by addressing the user community concerns defined from the September 3 Applications Working Group meeting. The Internet will be used to the maximum extent possible as a distribution vehicle via the Project ATLANTA home page and as a way to enhance feedback from the broader user community on the utility of Project ATLANTA data products.

FY97 Applications Task Highlights: Project ATLANTA Applications Initiative

The applications initiatives for Project ATLANTA focused on establishing an Applications Working Group that resulted from a meeting held in Atlanta on September 3, 1997. An applications strategy document that was distributed to invited individuals from the Atlanta user community is attached as Appendix A. A synopsis of the the results from the Atlanta Applications Strategy meeting that relates the needs and concerns of the Atlanta user community and the required data products is attached as Appendix B.

FY98 Applications Task Plans:

1. Develop initial data products per the Applications Strategy tasks using ATLAS data. Initial products to be developed are:
    a. Existing land use classification for the Atlanta Regional Commission area.
    b. Thermal map of selection regions of the study area depicting temperature differences in vegetated areas versus areas covered by impervious surfaces.;
2. Facilitate communication of initial air quality model outputs to decision and policy makers. "What if" scenarios will be developed based on a combination of tree planting, changes in reflective surfaces, and land use strategies to identify mitigation plans with the potential to decrease ozone production;
3. GIS tools and image processing algorithms will be used to effectively develop data products and present science results to the user community;
4. Share ATLAS data with elementary schools assisting with temperature data collection and provide training for use of the data in the classroom by connecting schools to the GLOBE Program. CD-Rom's are in development with image files containing: false color images, thermal images, and separate files in the visible and middle reflective infrared spectrum for the school sites and the Atlanta central business district;
5. Research the literature and design cost/benefit techniques for assigning dollar values to mitigation scenarios and science results to enhance their use by the user community; and
6. Periodically, review preliminary data products, including meteorological and air quality model outputs, with the Applications Working Group and incorporate feedback into data product development. Two Working Group meetings are anticipated in 1998.

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References

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. Geological Survey

Professional Paper 964, United States Government Printing Office, Washington, D.C.

Anderson, J. E., 1992. Determination of water surface temperature based on the use of thermal infrared multispectral scanner data. *Geocarto International* 3:3-8.

Berk, A., L. S. Bernstein, and D. C. Robertson., 1989: Modtran: *A Moderate Resolution Model for Lowtran 7*. U.S. Air Force Geophysics Laboratory, Environmental Research Papers GL-TR-89-0122, Hanscom Air Force Base, MA, 37 pp.

Congalton, R., 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37:35-46.

Gillies, R. R., and T. N. Carlson, 1994: A physically based modeling approach for including remotely derived measurements in the study of land use change. Effects of Human-Induced Changes on Hydrological Systems, for *American Water Resources Association* (AWRA) Summer Symposium in Jackson Hole, Wyoming, June 26–29, 1994. Solicited for publication in *Water Resources Bulletin.*

Gillies, R. R., and T. N. Carlson, 1995: Thermal remote sensing of surface soil water content with partial vegetation cover for incorporation in climate models. *Journal of Applied Meteorology*, 34, 745–756.

Graham, M.H., B.G. Junkin, M.T. Kalcic, R.W. Pearson and B.R. Seyfarth, 1986. *ELAS - Earth resources laboratory applications software. Revised Jan.1986*. NASA/NSTL/ERL Report No. 183.

Hall, F.G., D.E. Strebel, J.E. Nickeson, and S.J. Goetz, S.J. 1991. Radiometric rectification: toward a common radiometric response among multidate, multisensor images. *Remote Sensing of Environment*. 35:11-27.

Jensen, J.R., K. Rutchey, M.S. Koch, and S. Narumalani 1995. Inland wetland change detection in the Everglades water conservation area 2A using a time series of normalized remotely sensed data. *Photogrammetric Engineering and Remote Sensing* 61:199-209.

Lo, C.P., D.A. Quattrochi, and J.C. Luvall, 1997. Application of high-resolution thermal infrared remote sensing and GIS to assess the urban heat island effect. *International Journal of Remote Sensing* 18:287-304.

Luvall, J.C., and H. R. Holbo, 1989: Measurements of short-term thermal responses of coniferous forest canopies using thermal scanner data. *Remote Sensing of Environment*, 27, 1-10.

Luvall, J.C., 1997. The use of remotely sensed surface temperatures from an aircraft-based thermal infrared multispectral scanner (TIMS) to estimate the spatial and temporal variability of latent heat fluxes and thermal response numbers from a white pine (*Pinus strobus L.*) plantation. In *Scale in Remote Sensing and GIS*, D.A. Quattrochi and M.F. Goodchild, eds. CRC/Lewis Publishers, Boca Raton, FL, pp. 169-185.

Owen, T. W., 1995: *An Approach Towards Quantifying the Climatic Effect of Urbanization Using Satellite Remotely Sensed Land Cover Parameters*. Master's Thesis, Dept. of Meteorology, The Pennsylvania State University, University Park, PA 16802.

Quattrochi, D.A. and M.K. Ridd, 1994. Measurement and analysis of thermal energy responses from discrete urban surfaces using remote sensing data. *International Journal of Remote Sensing* 15:1991-2022.

Quattrochi, D.A. and J.C. Luvall, 1997. High spatial resolution airborne multispectral thermal infrared data to support analysis and modeling tasks in EOS IDS Project ATLANTA. *The Earth Observer* 9(3):22-27.

Quattrochi, D.A. and M.K. Ridd, 1998. Analysis of vegetation within a semi-arid urban environment using high spatial resolution airborne thermal infrared remote sensing data. *Atmospheric Environment* 32(1):19-33.

Research Atlanta, Inc., 1993. *The Dynamics of Change: An Analysis of Growth in Metropolitan Atlanta over the Past Two Decades*. Policy Research Center, Georgia State University, Atlanta.

SOS, 1995. *The State of the Southern Oxidants Study: Policy-Relevant Findings in Ozone Pollution Research 1988-1994*. Southern Oxidants Study: Raleigh, NC, 94 pp.

Veitch, N., J.R. Treweek, and R.M. Fuller, R.M., 1995. The land cover map of Great Britain-a new data source for environmental planning and management. In F. M. Danson and S.E. Plummer (eds), *Advances in Environmental Remote Sensing*. Chichester, England: Wiley, pp.157- 170.

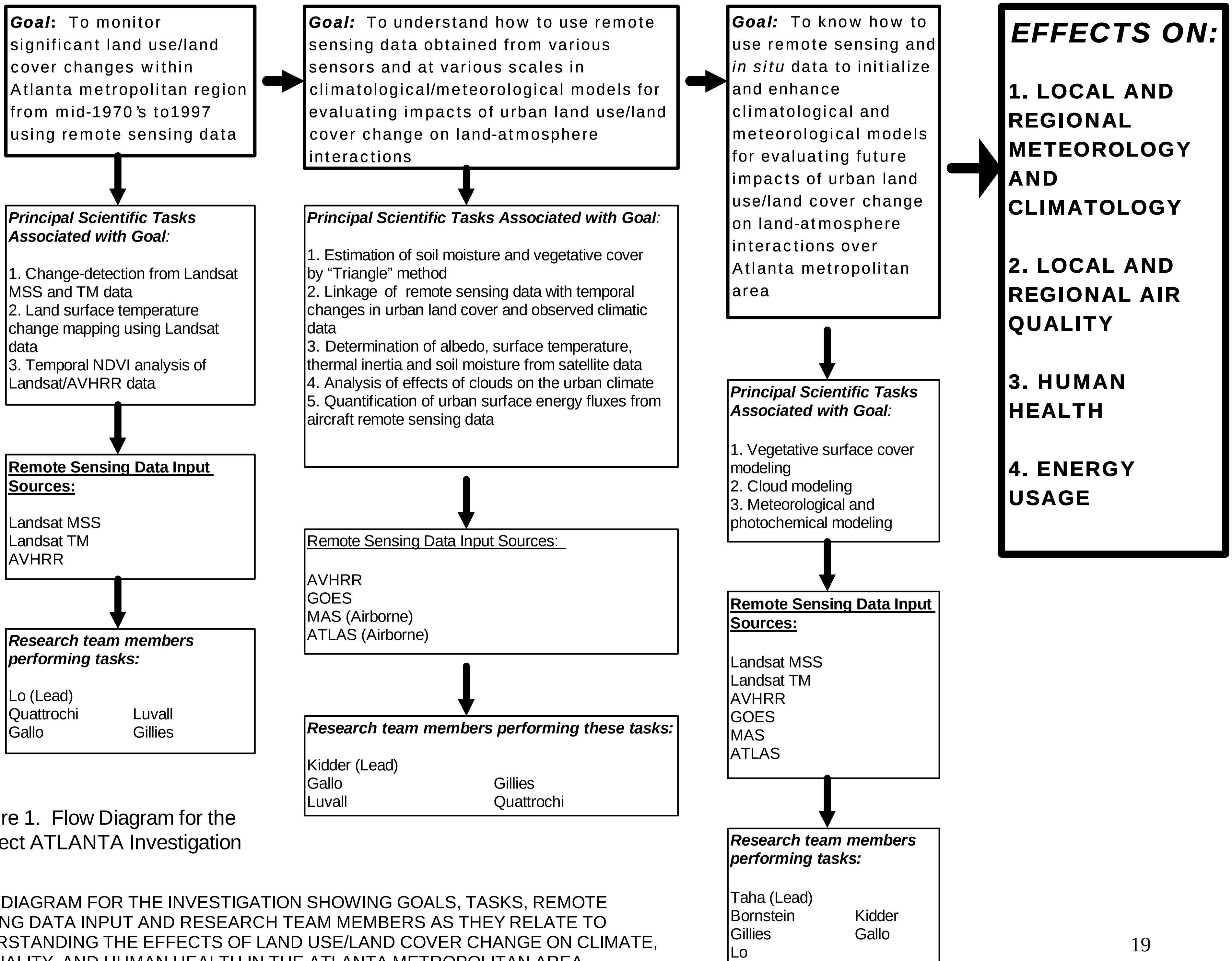

Figure 1. Flow Diagram for the Project ATLANTA Investigation

FLOW DIAGRAM FOR THE INVESTIGATION SHOWING GOALS, TASKS, REMOTE SENSING DATA INPUT AND RESEARCH TEAM MEMBERS AS THEY RELATE TO UNDERSTANDING THE EFFECTS OF LAND USE/LAND COVER CHANGE ON CLIMATE, AIR QUALITY, AND HUMAN HEALTH IN THE ATLANTA METROPOLITAN AREA

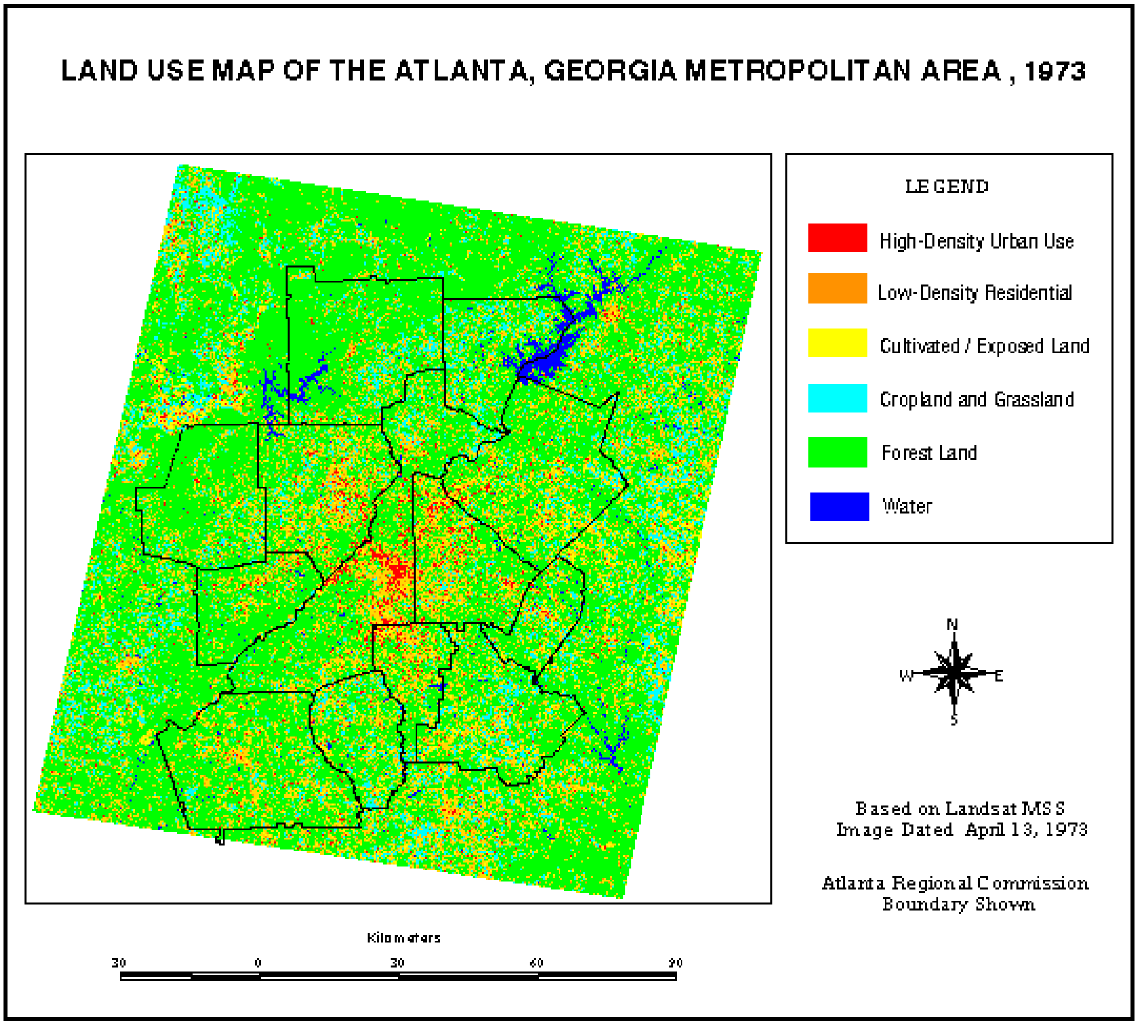

Figure 2. Land use map of the Atlanta metropolitan area for 1973 derived from Landsat MSS data. The counties embraced by the Atlanta Regional Commission (ARC) are outlined in black.

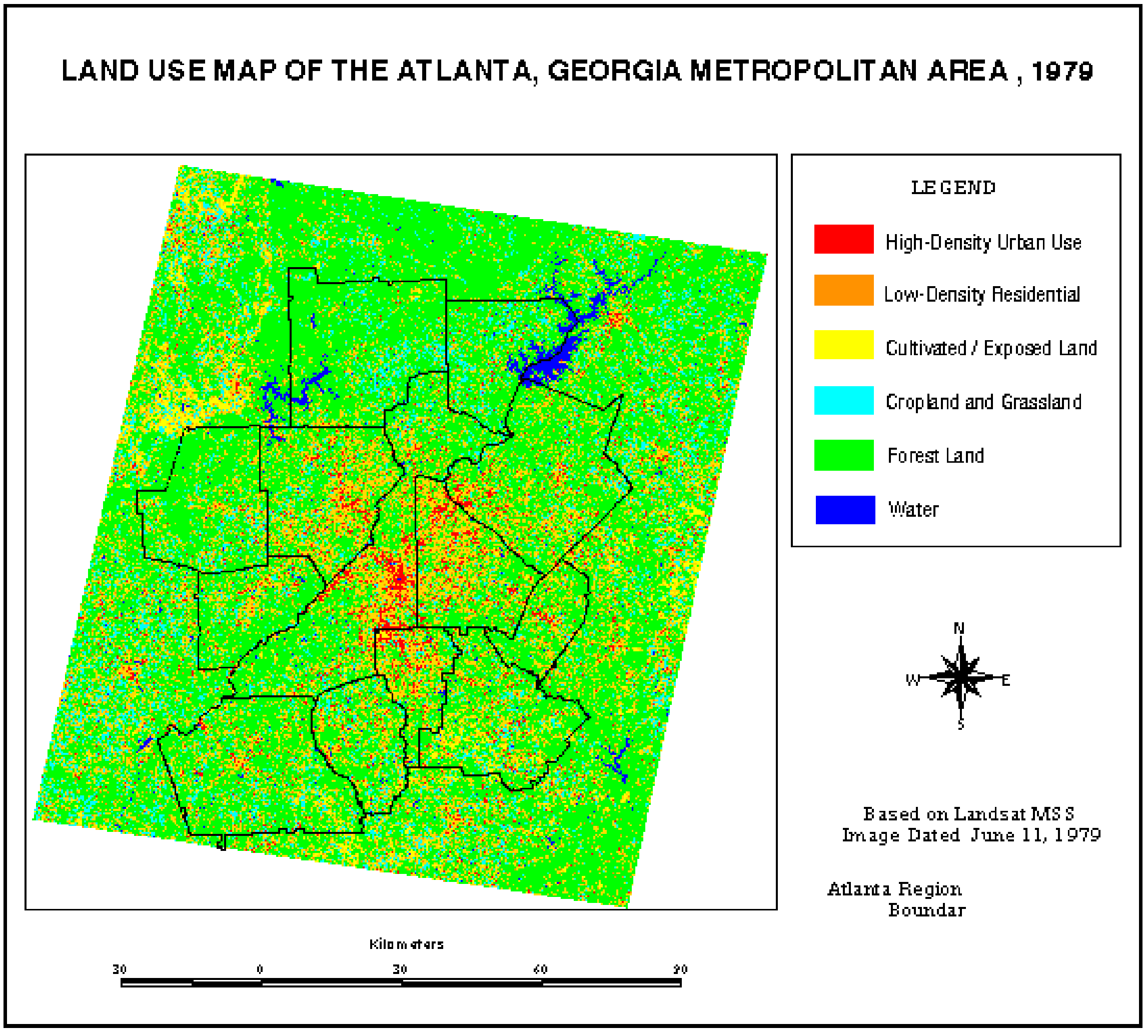

Figure 3. Land use map of the Atlanta metropolitan area for 1979 derived from Landsat MSS data. The counties embraced by the Atlanta Regional Commission (ARC) are outlined in black.

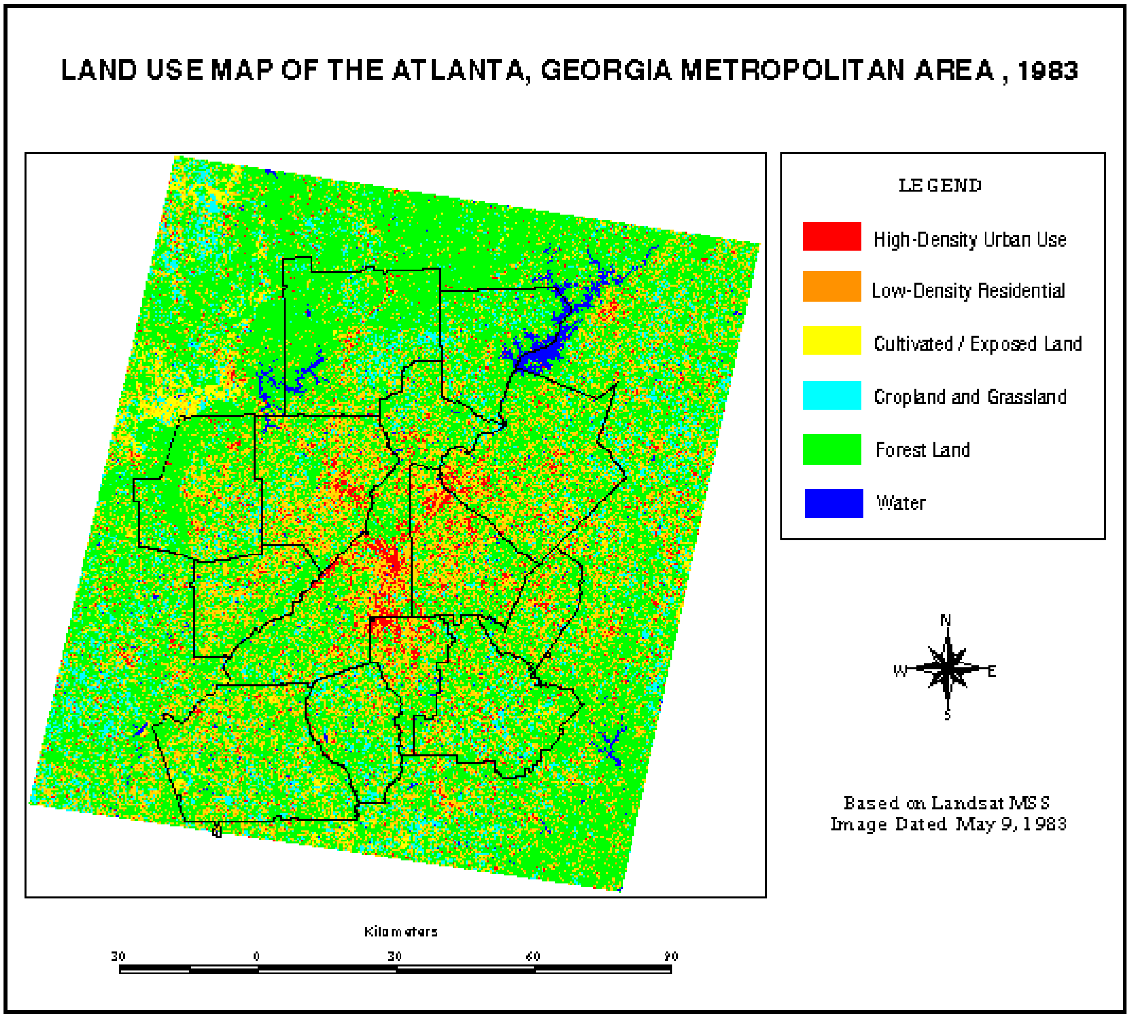

Figure 4. Land use map of the Atlanta metropolitan area for 1983 derived from Landsat MSS data. The counties embraced by the Atlanta Regional Commission (ARC) are outlined in black.

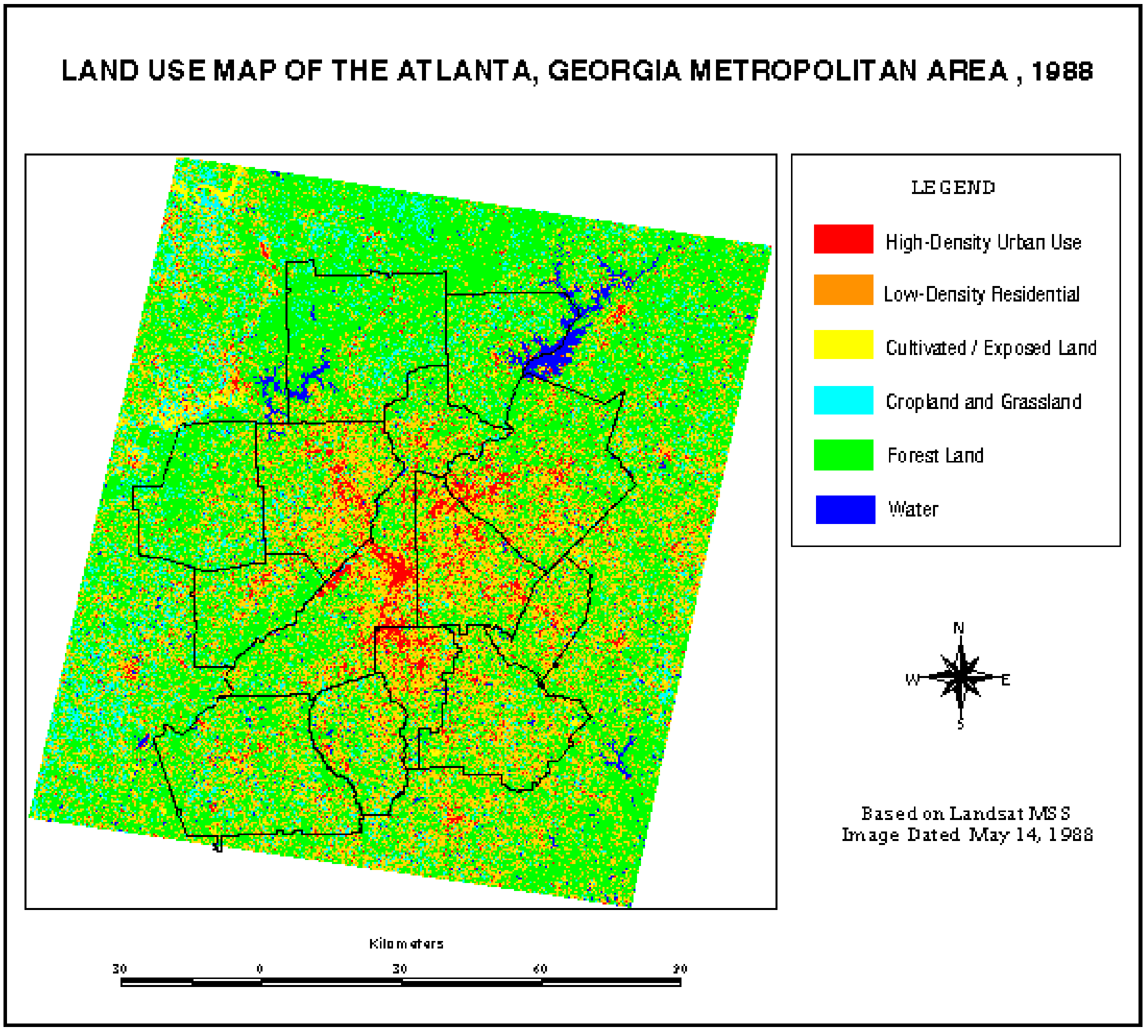

Figure 5. Land use map of the Atlanta metropolitan area for 1988 derived from Landsat MSS data. The counties embraced by the Atlanta Regional Commission (ARC) are outlined in black.

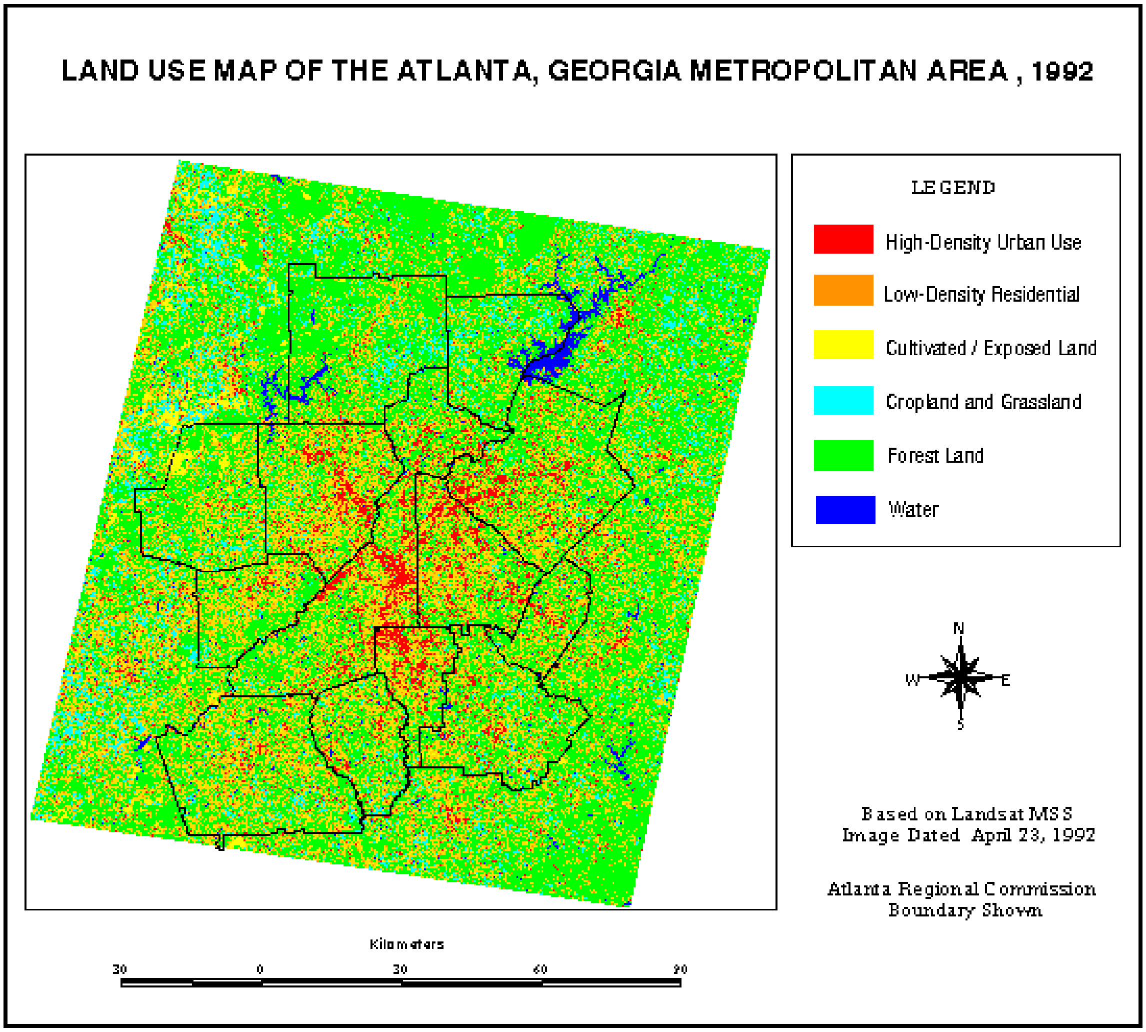

Figure 6. Land use map of the Atlanta metropolitan area for 1992 derived from Landsat MSS data. The counties embraced by the Atlanta Regional Commission (ARC) are outlined in black.

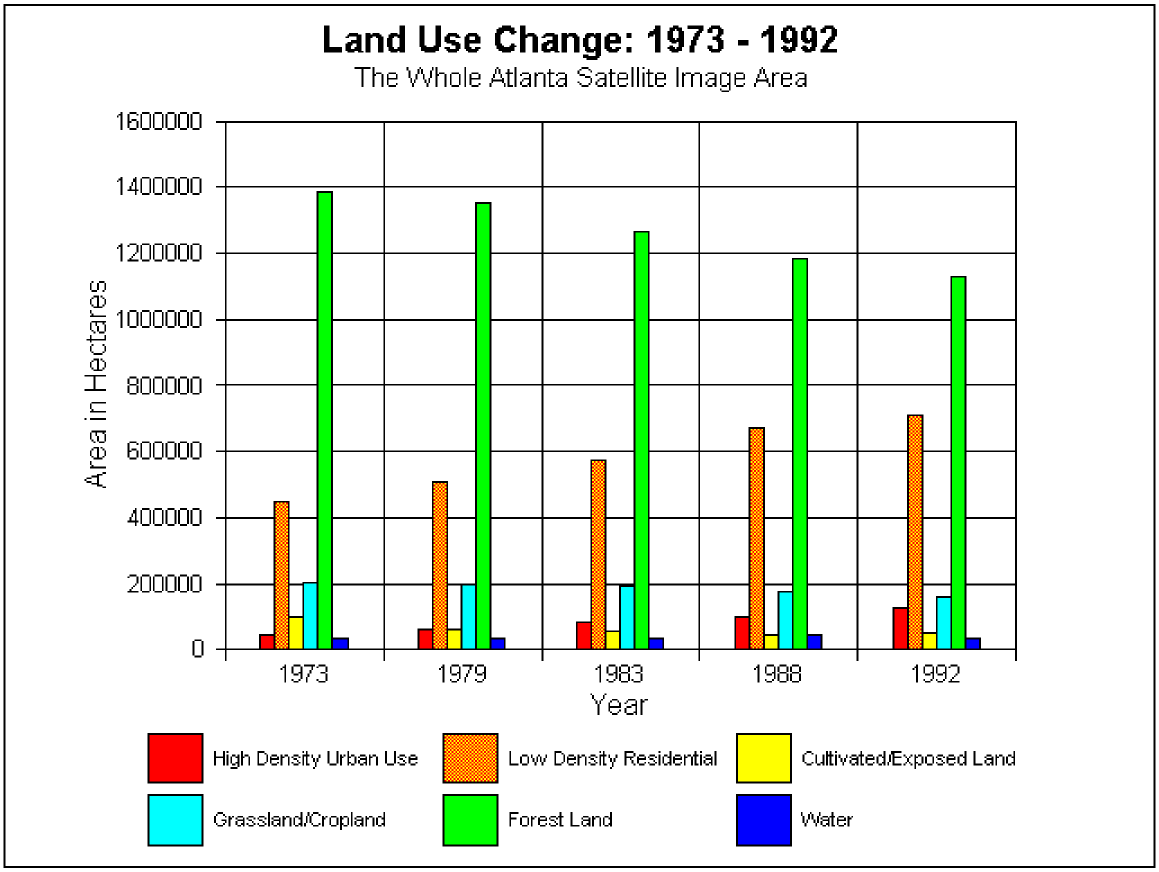

Figure 7. Graph of land use change by general land cover class for the entire area Atlanta covered by the Landsat MSS data used in this analysis between 1973-1992.

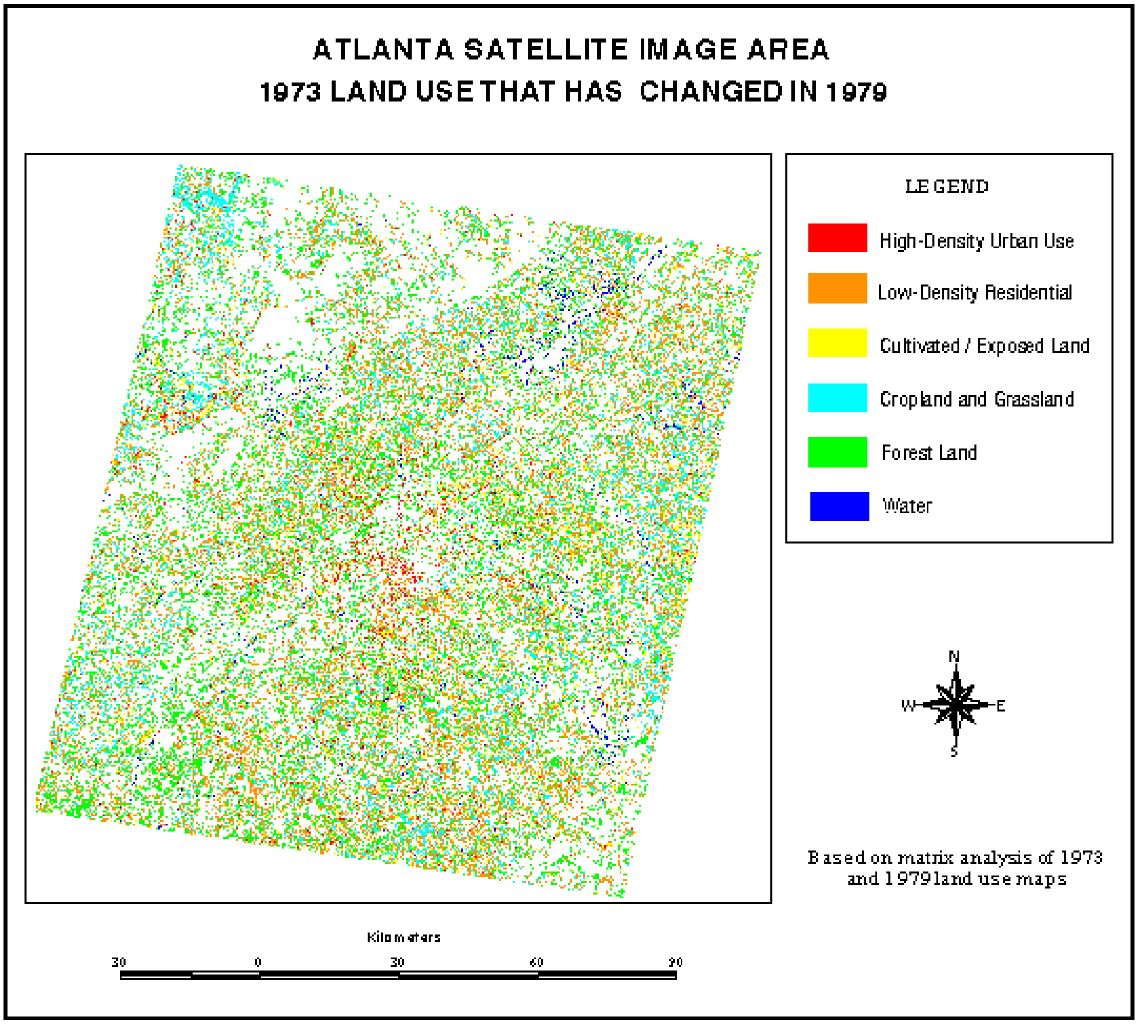

Figure 8. Map showing where and what types of land use/land cover have been involved in change between 1973 and 1979 as derived from Landsat MSS data.

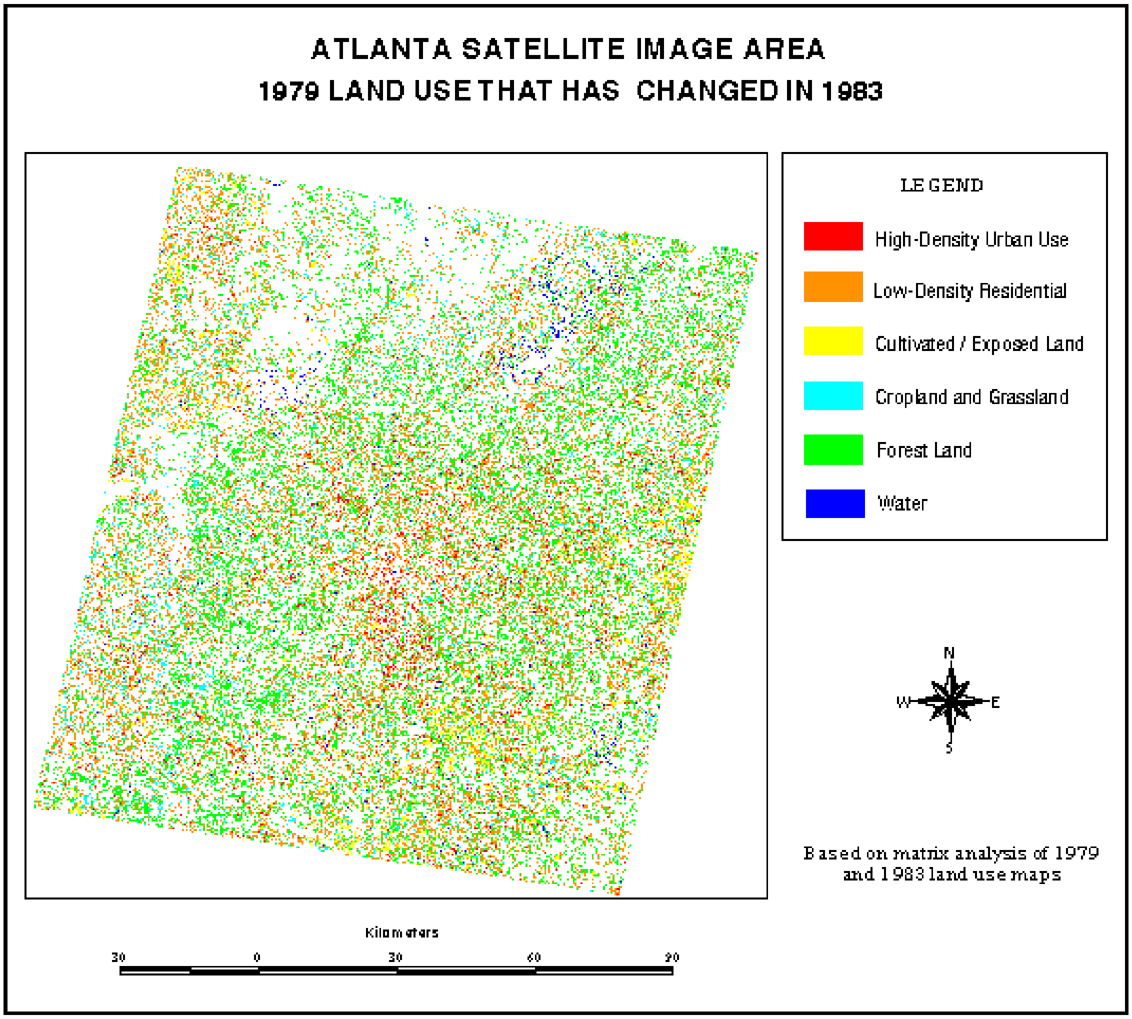

Figure 9. Map showing where and what types of land use/land cover have been involved in change between 1979 and 1983 as derived from Landsat MSS data.

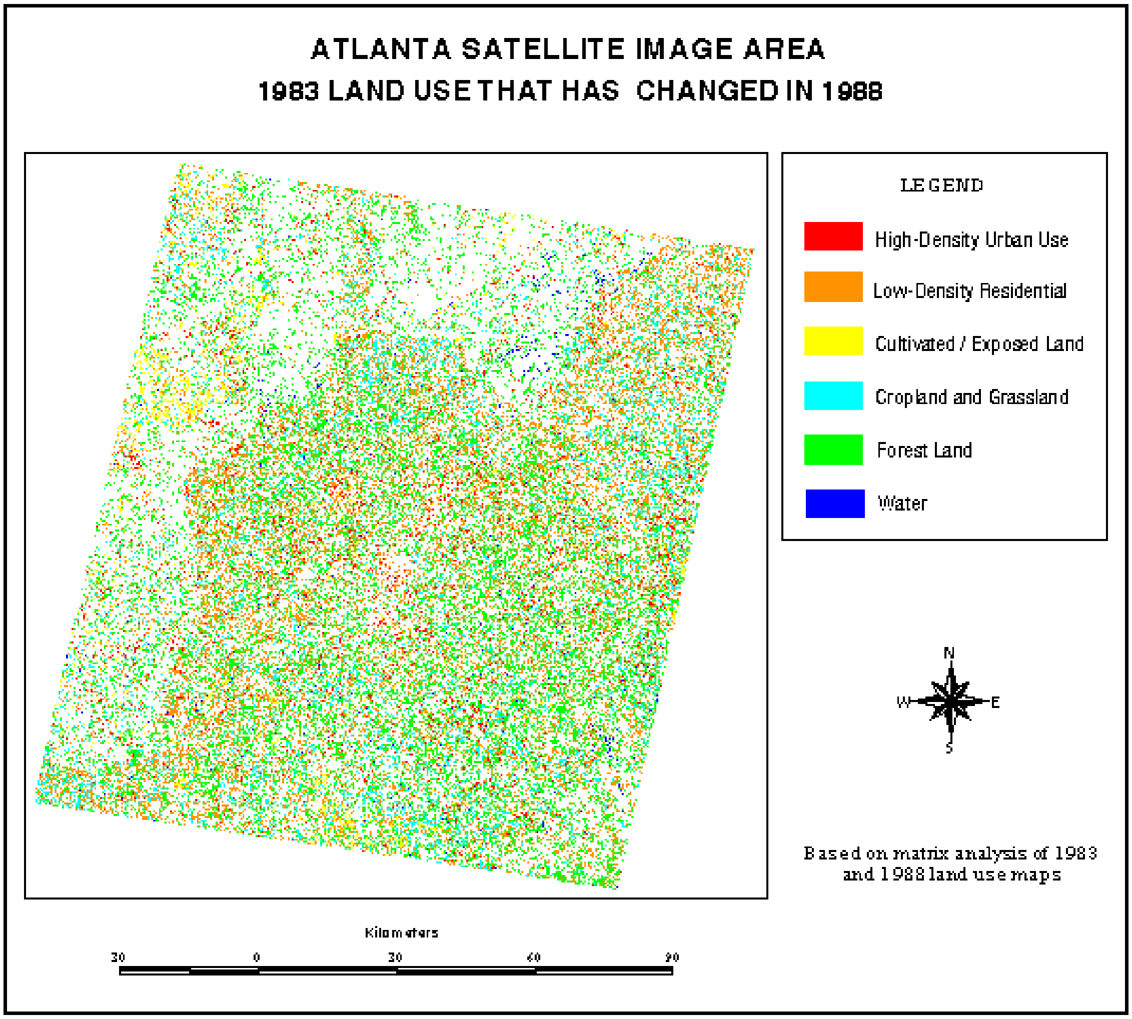

Figure 10. Map showing where and what types of land use/land cover have been involved in change between 1983 and 1988 as derived from Landsat MSS data.

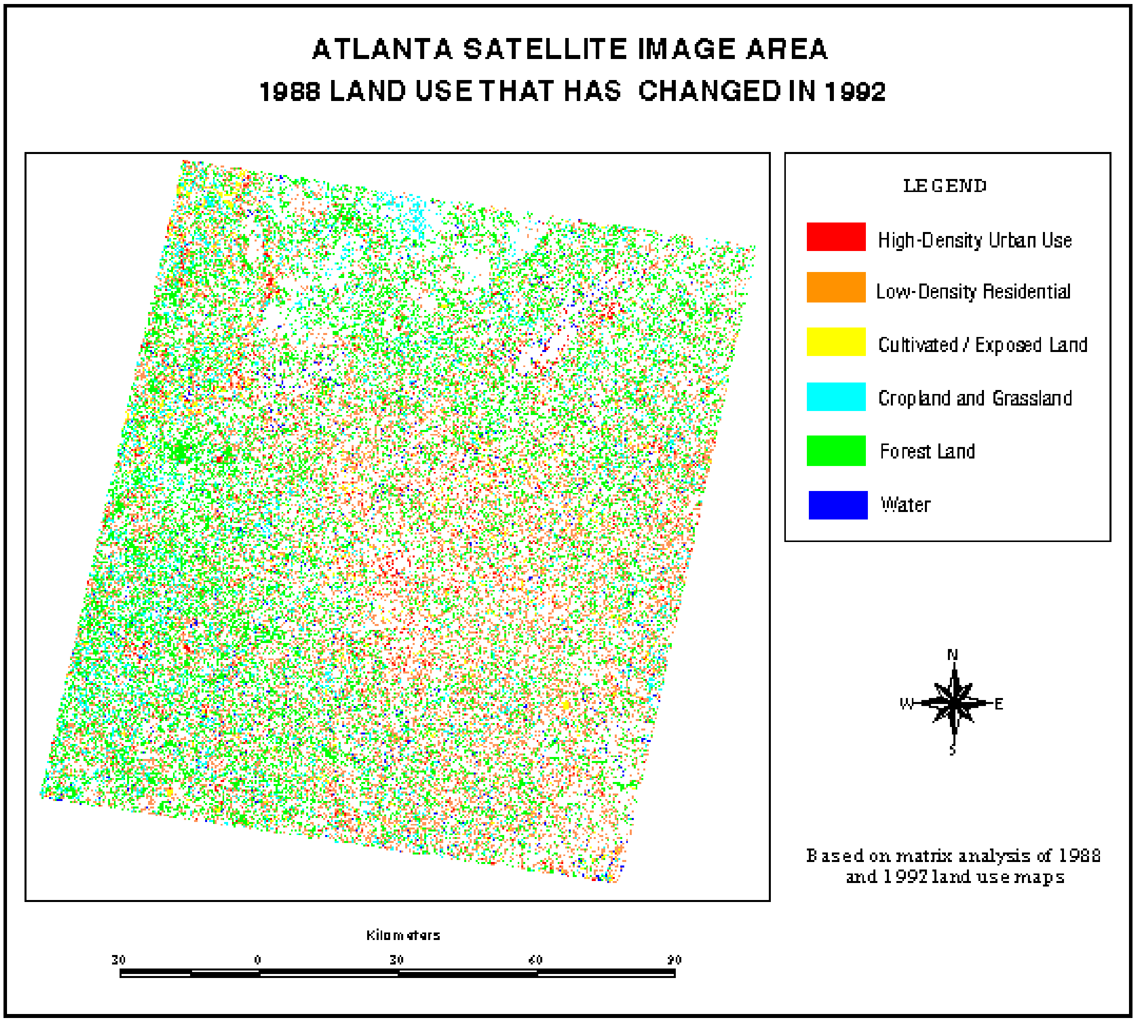

Figure 11. Map showing where and what types of land use/land cover have been involved in change between 1988 and 1992 as derived from Landsat MSS data.

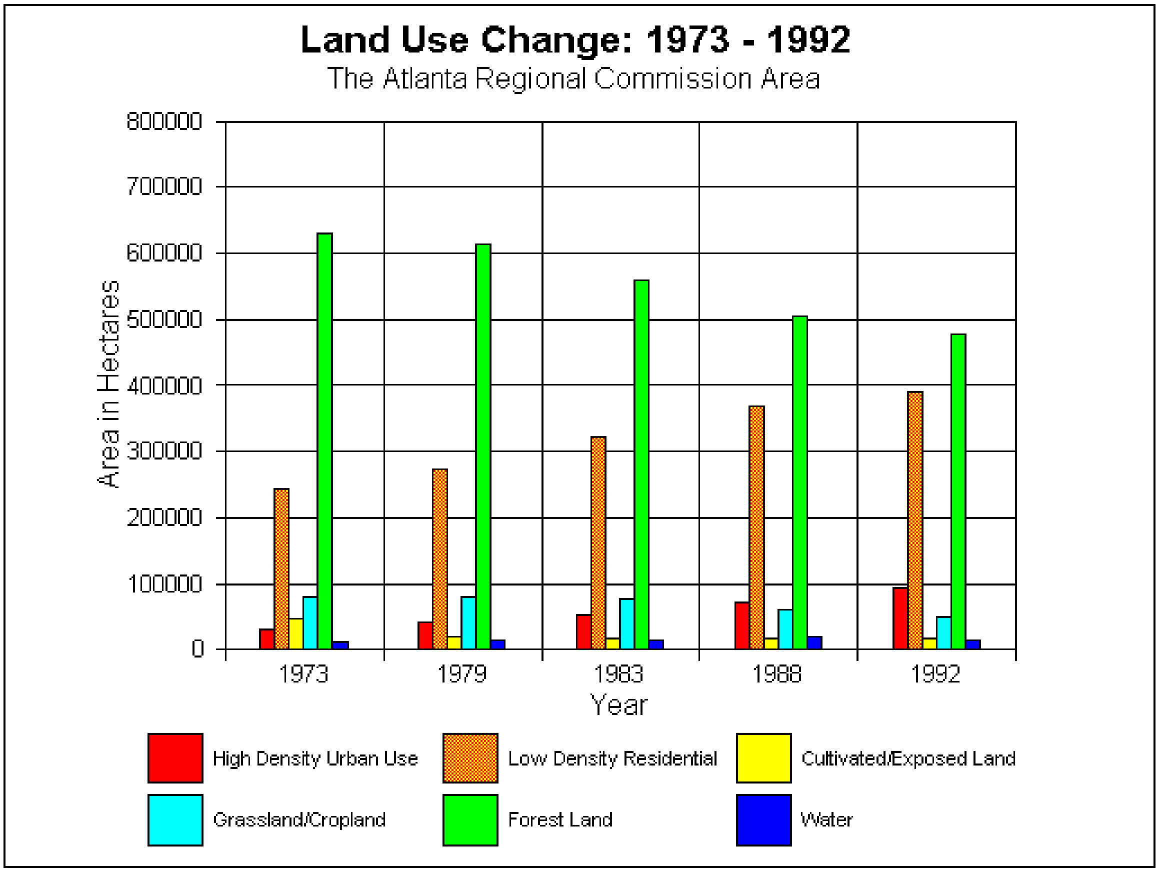

Figure 12. Graph of land use change by general land cover class for the area encompassed by the Atlanta Regional Commission (ARC) (i.e., the regional planning agency for the Atlanta metropolitan area) as determined from the Landsat MSS data used in this analysis between 1973-1992.

Figure 13. ATLAS daytime thermal image (channel 13 -- 9.60-10.2 λm) of the Atlanta central business district area. These data have not been geometrically or atmospherically corrected.

Figure 14. ATLAS nighttime thermal image (channel 13 -- 9.60-10.2 λm) of the Atlanta central business district area. These data have not been geometrically or atmospherically corrected.

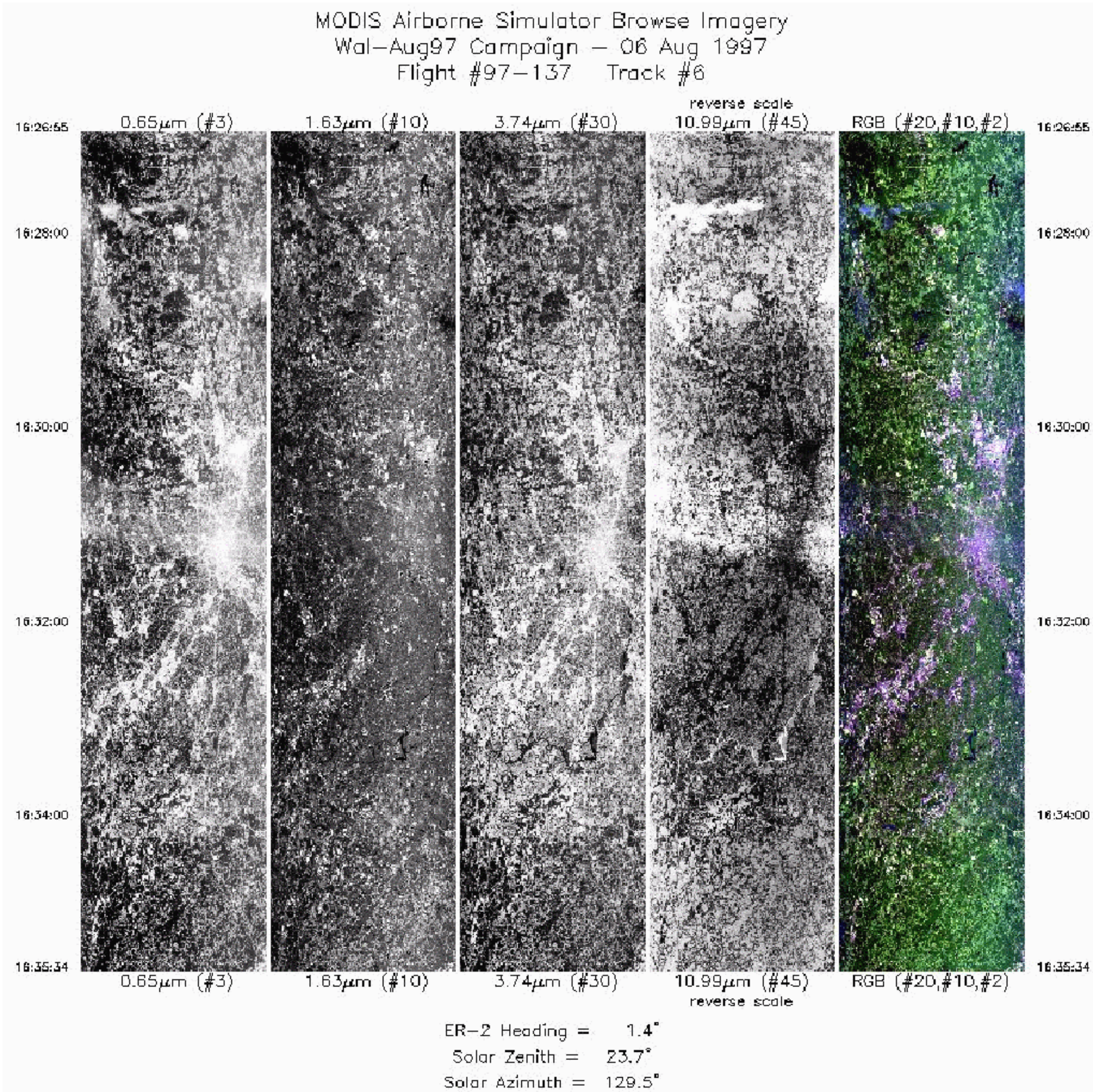

Figure 15. Example of MAS quick look data over Atlanta (supplied by Ames Research Center).

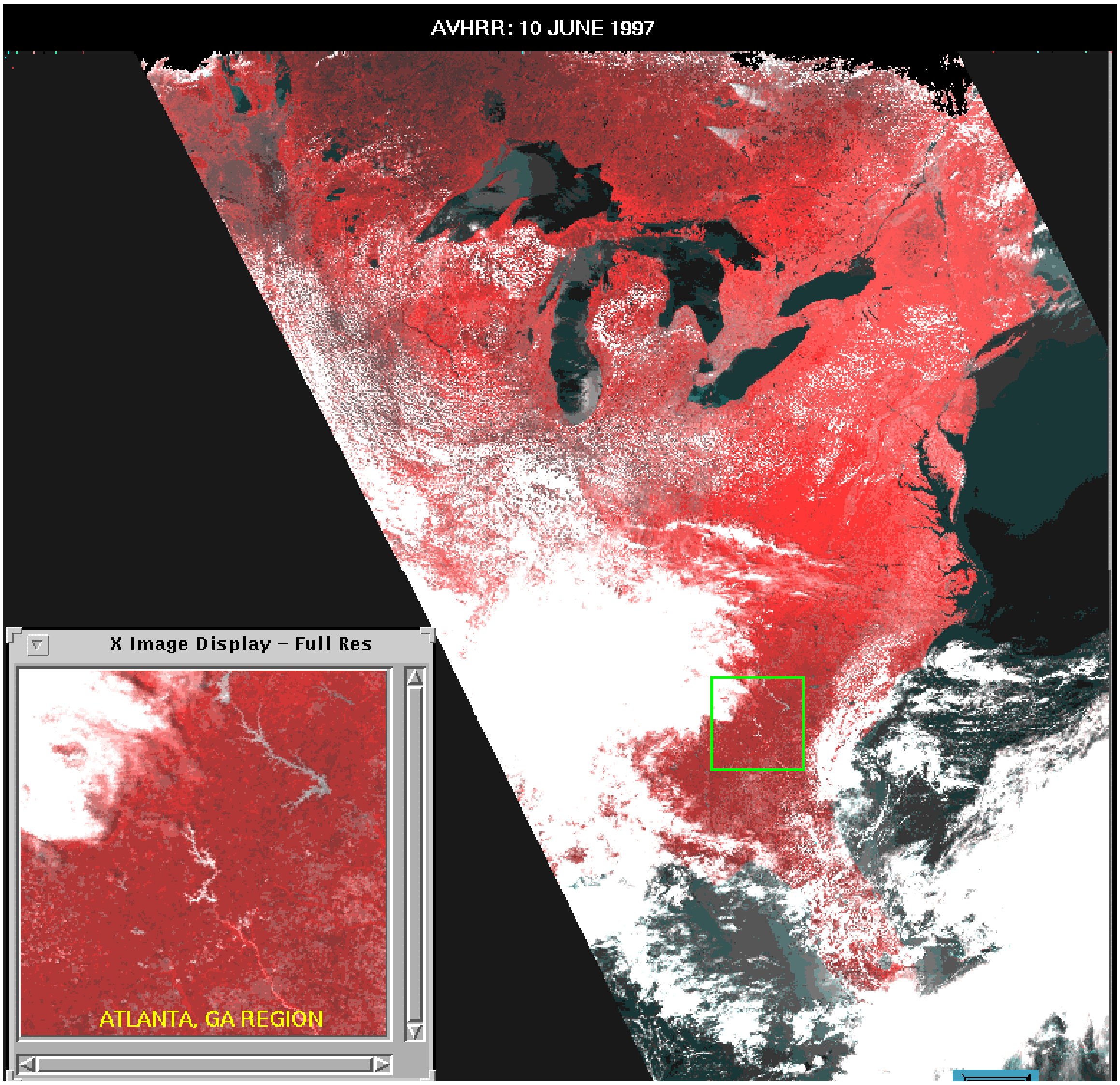

Figure 16. Eastern USA AVHRR scene for 10 June 1997 displayed as false color image. Data have been calibrated and geographically registered at USGS EROS Data Center. Full resolution data for Atlanta region displayed in lower corner.

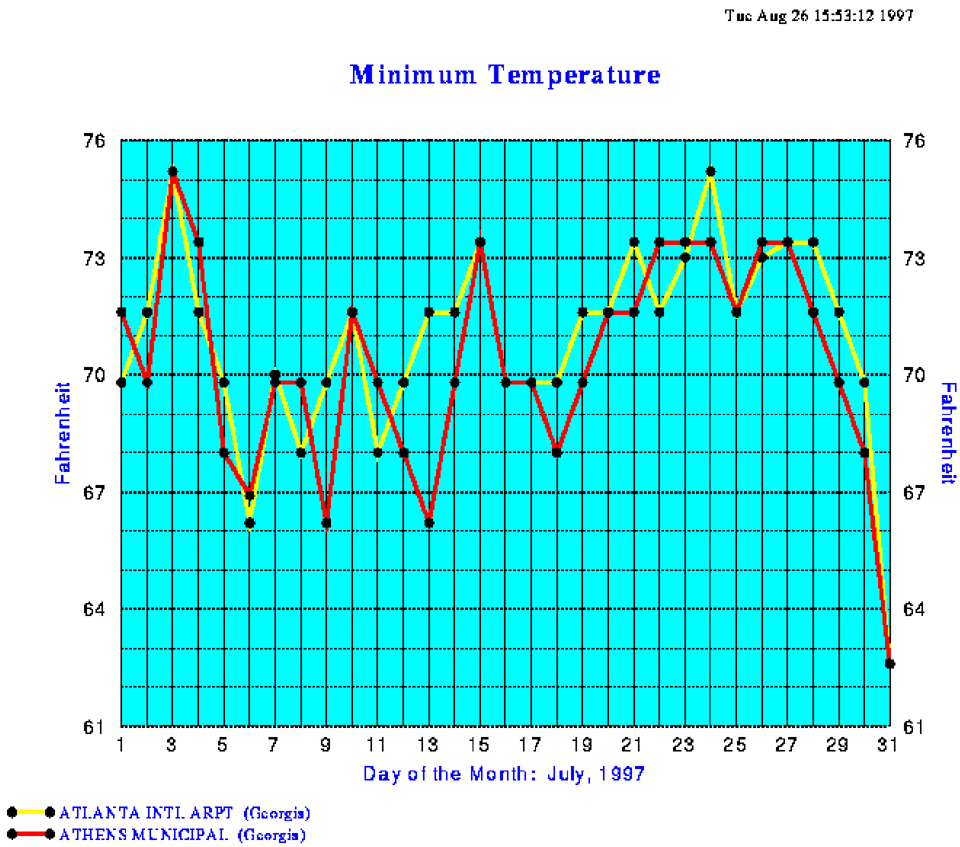

Figure 17. Time series of daily minimum temperatures for weather observation stations at Atlanta Intl. Airport and Athens, GA for July 1997. The lower minimum temperatures at Athens would be expected as it is a more rural observation location than that of Atlanta Intl. Airport.

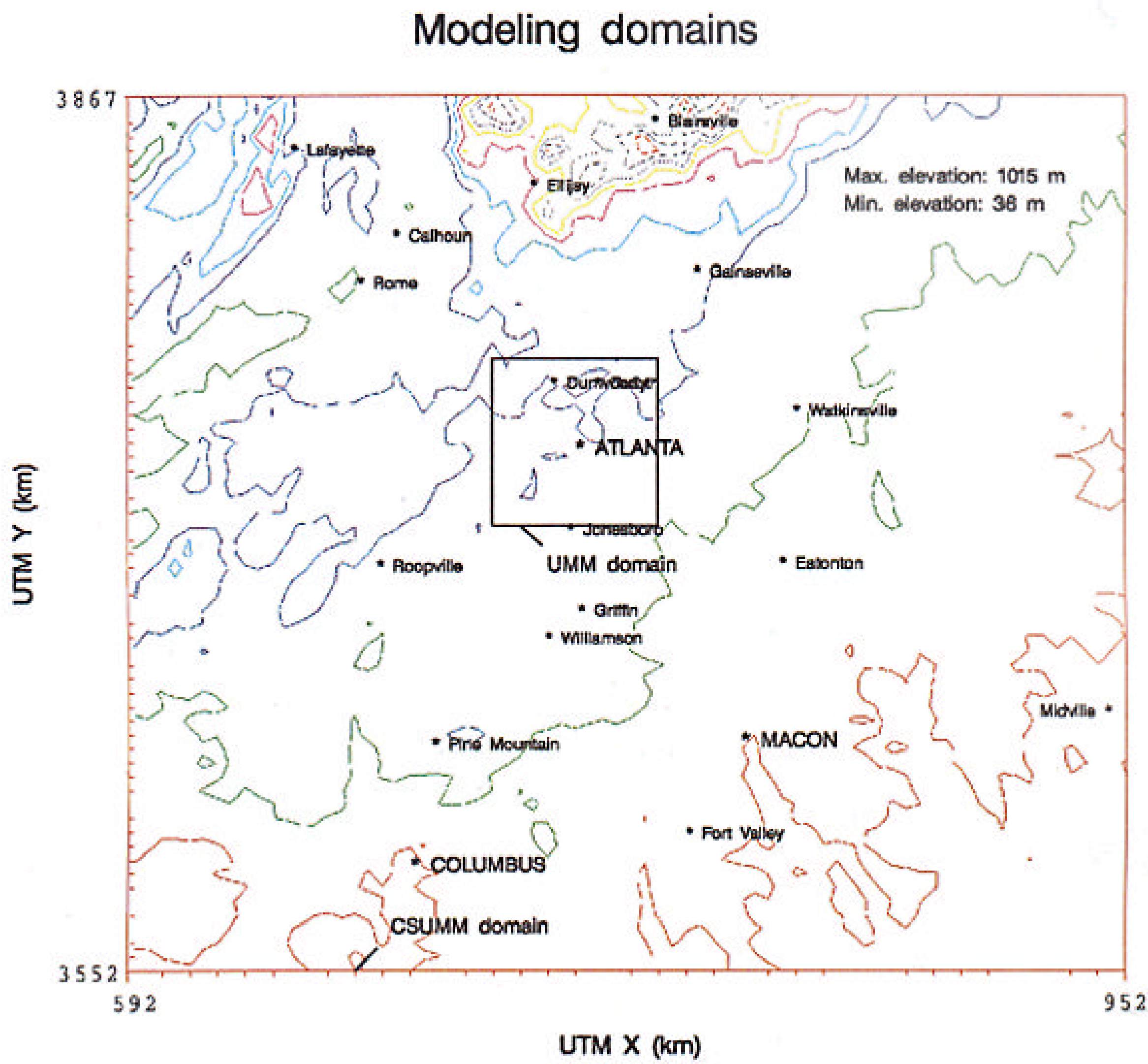

Figure 18. The north Georgia domains adopted in the LBNL modeling tasks. The larger domain is for the mesoscale meteorological model. The smaller domain (inner square) is for the air quality (UAM) model. Contours depict the region's topography (elevation).

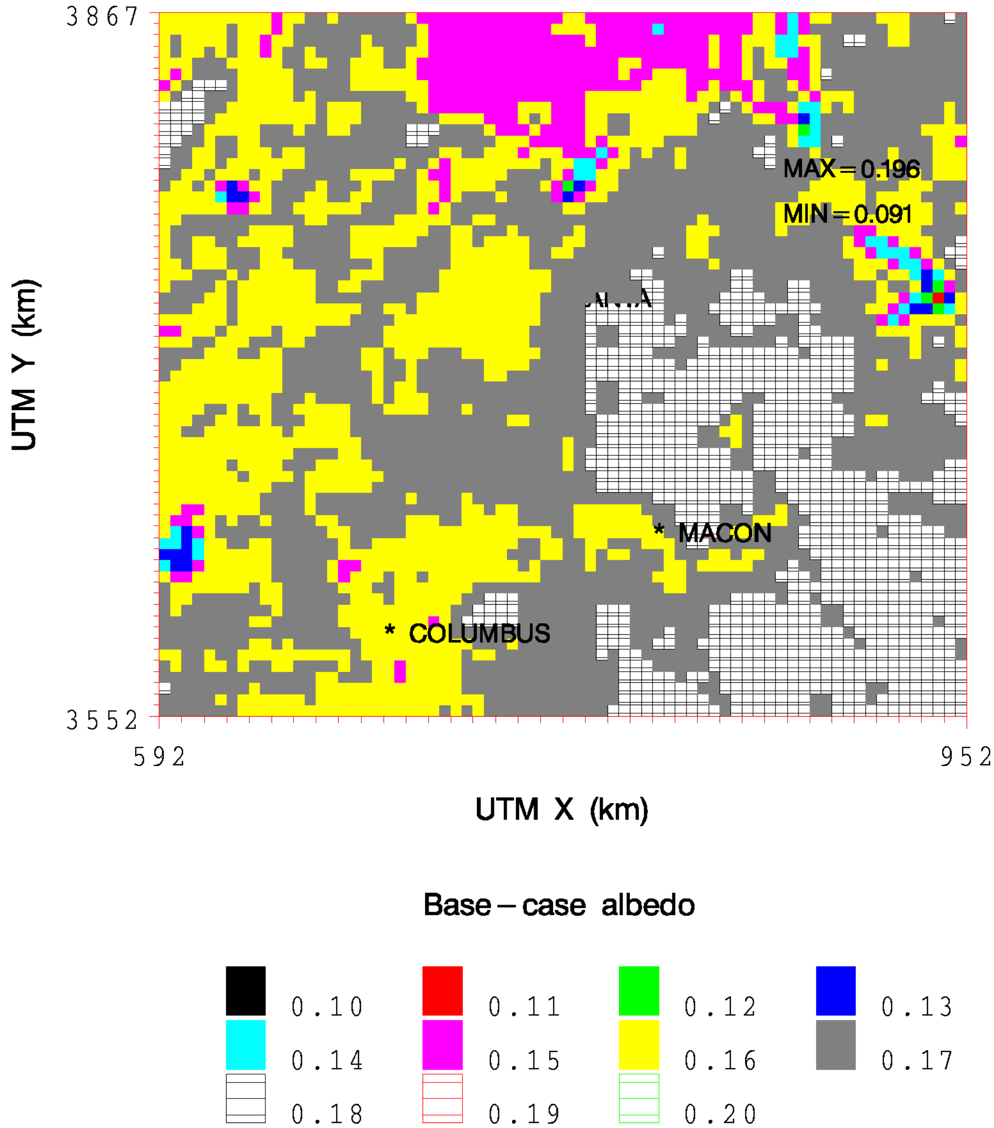

Figure 19. Base-case albedo input to the meteorological model. This 5x5 km gridded albedo input for the north Georgia region was developed based on USGS 200m resolution land use/land cover data. This type of input will be replaced by gridded albedo data derived from satellite and aircraft data collected over Atlanta.

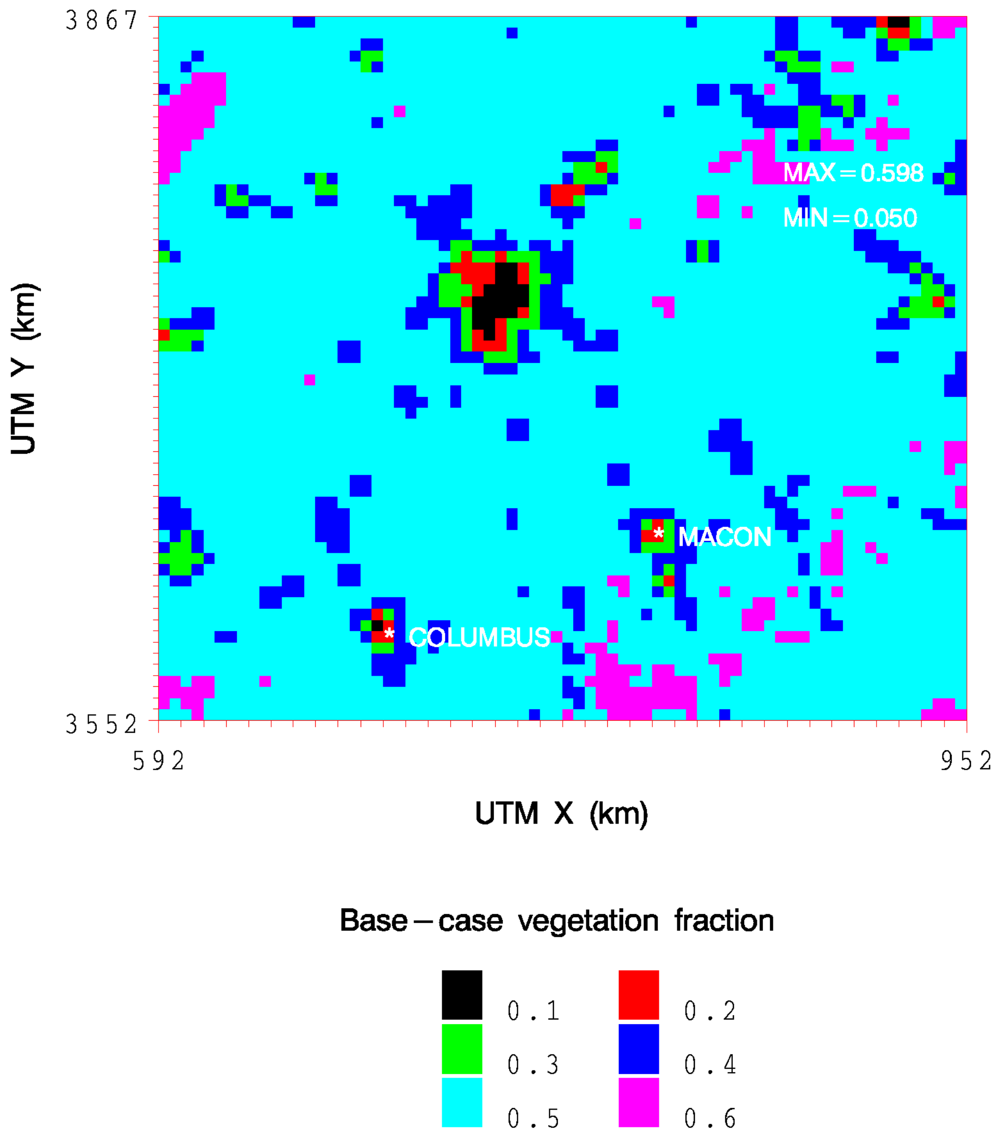

Figure 20. Base-case vegetation fraction input to the meteorological model. This 5x5 km gridded vegetation fraction input for the north Georgia region was developed based on USGS 200m resolution land use/land cover data. This type of input will be replaced by gridded albedo data derived from satellite and aircraft data collected over Atlanta.

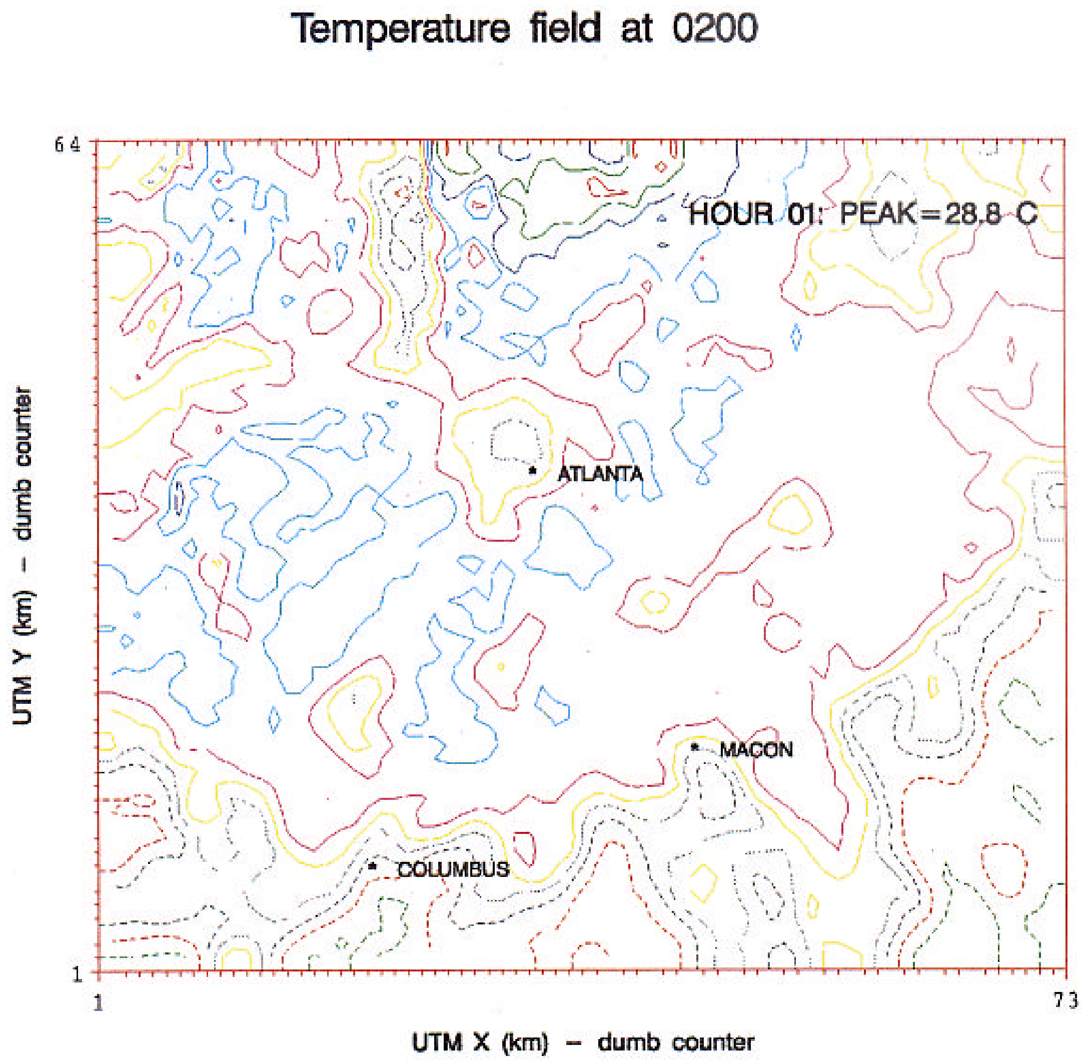

Figure 21. Results from the mesoscale model simulations showing air temperature at 5m above ground at 2 a.m. local time on July 29. Note the heat islands (closed contours) around Atlanta, Macon, and Columbus, Georgia.

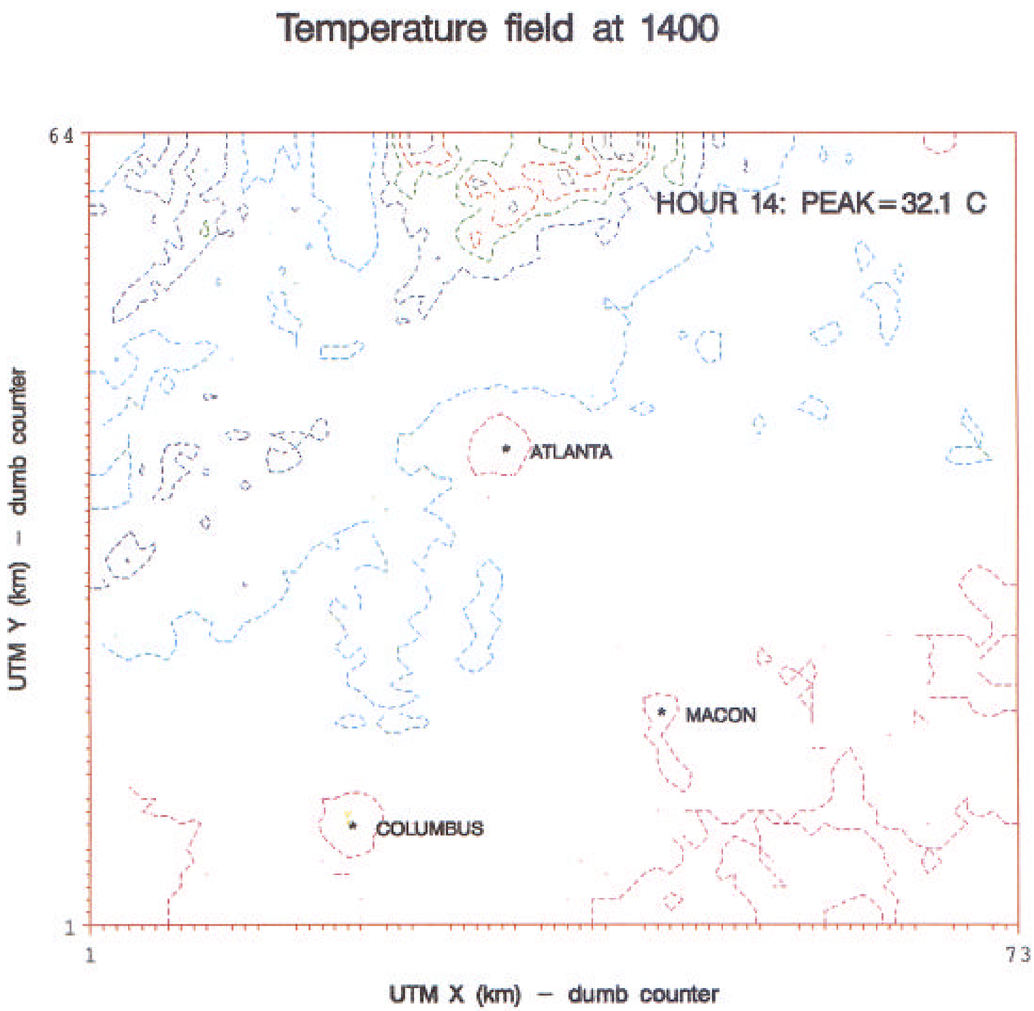

Figure 22. Results from the mesoscale model simulations showing air temperature at 5m above ground at 2 p.m. local time on July 29. Note the heat islands (closed contours) around Atlanta, Macon, and Columbus, Georgia.

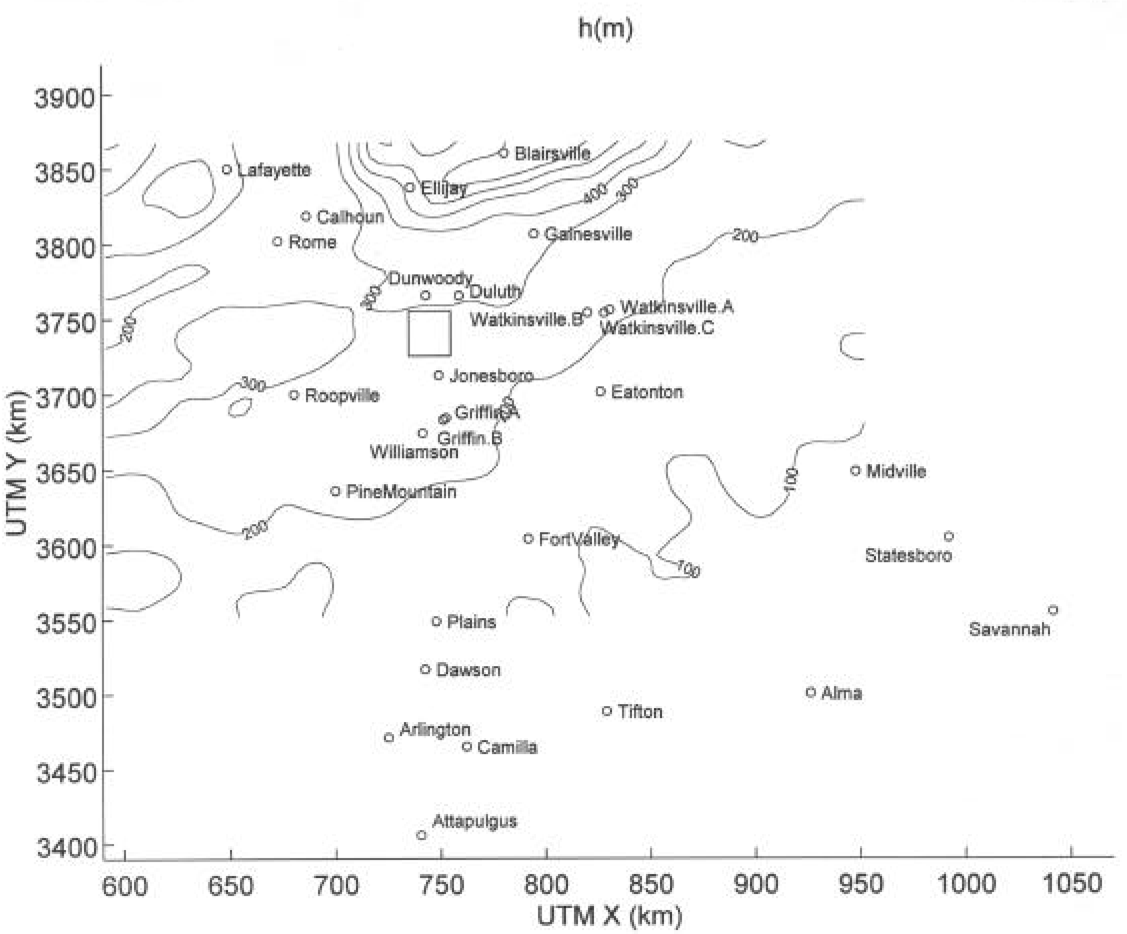

Figure 23. Topographic height values (m) for the Atlanta area, where the city is shown as a square.

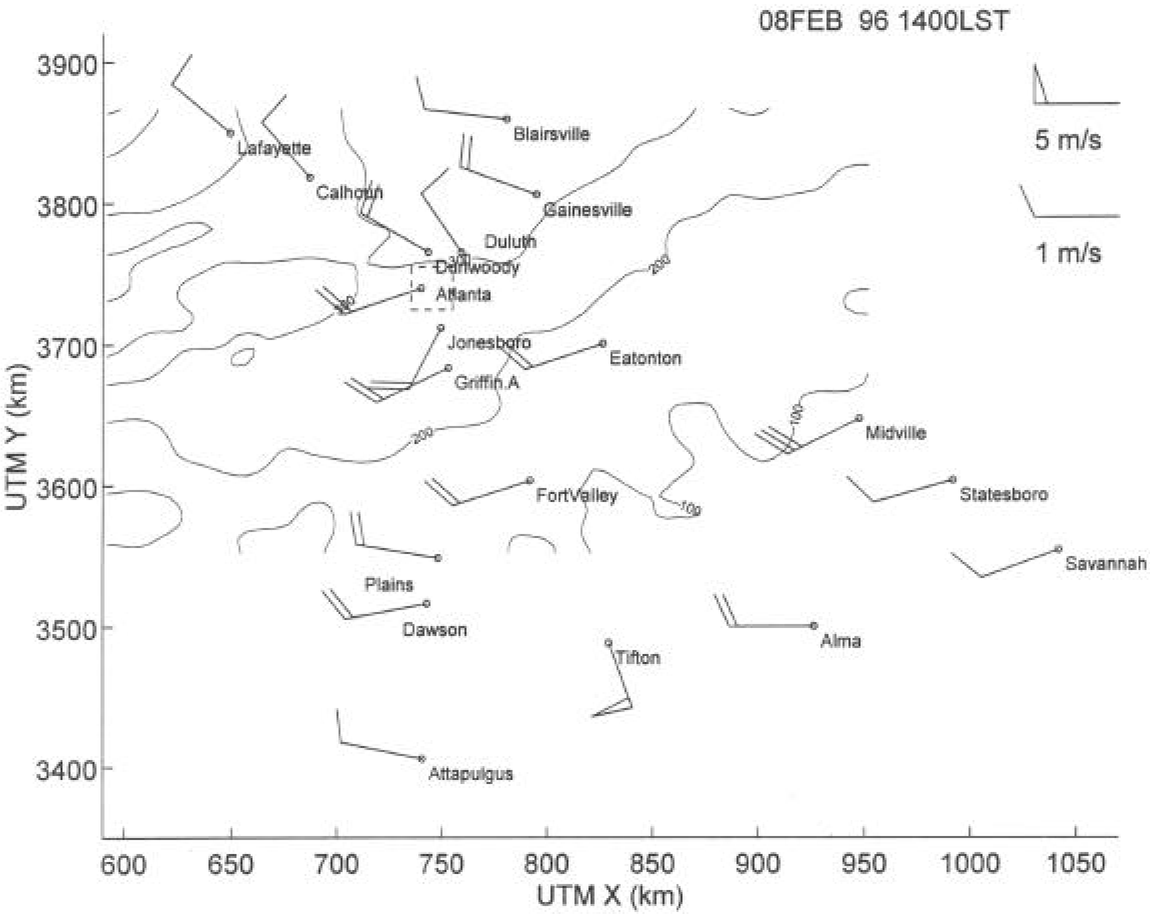

Figure 24. Surface wind velocity (mps) observations for the Atlanta area for 1400 LST on 8 February 1996.

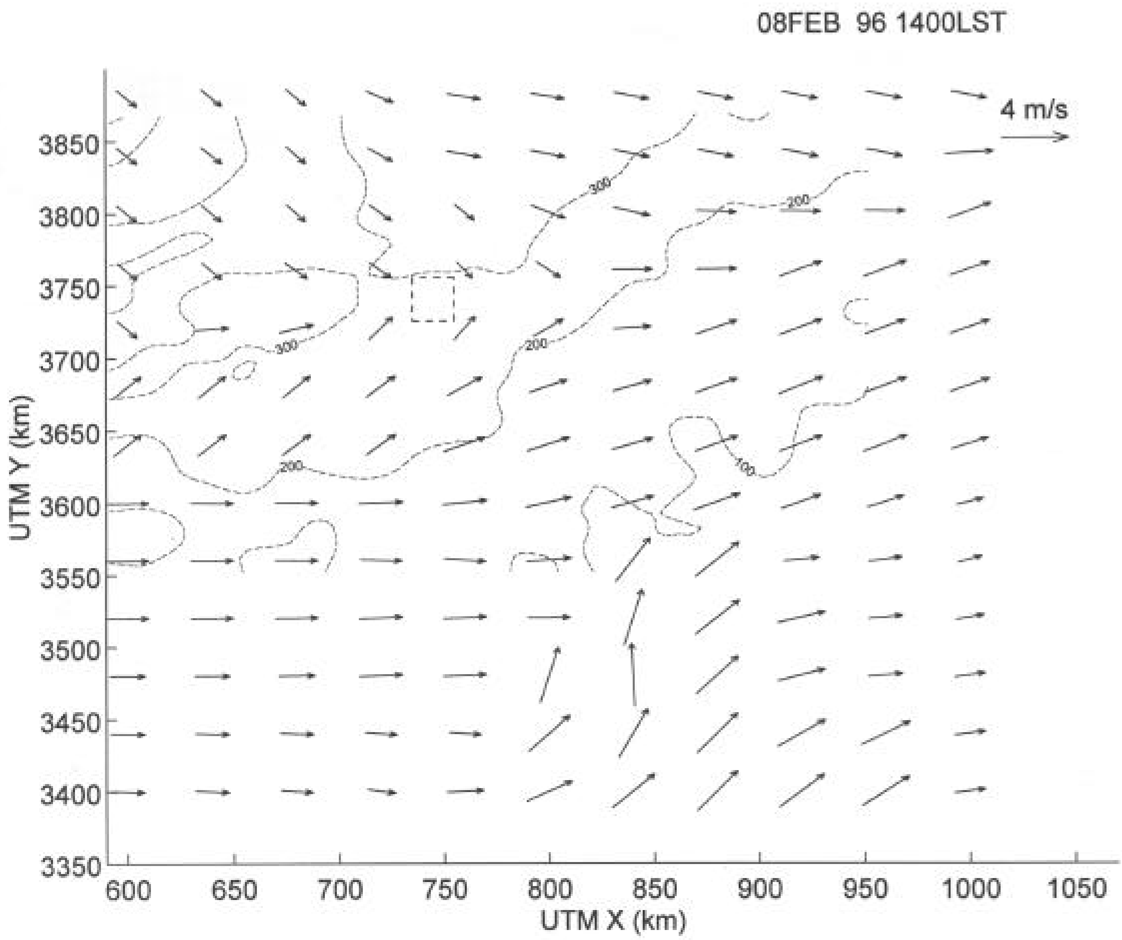

Figure 25. Surface wind velocity (mps) analysis for the Atlanta area for 1400 LST on 8 February 1996.

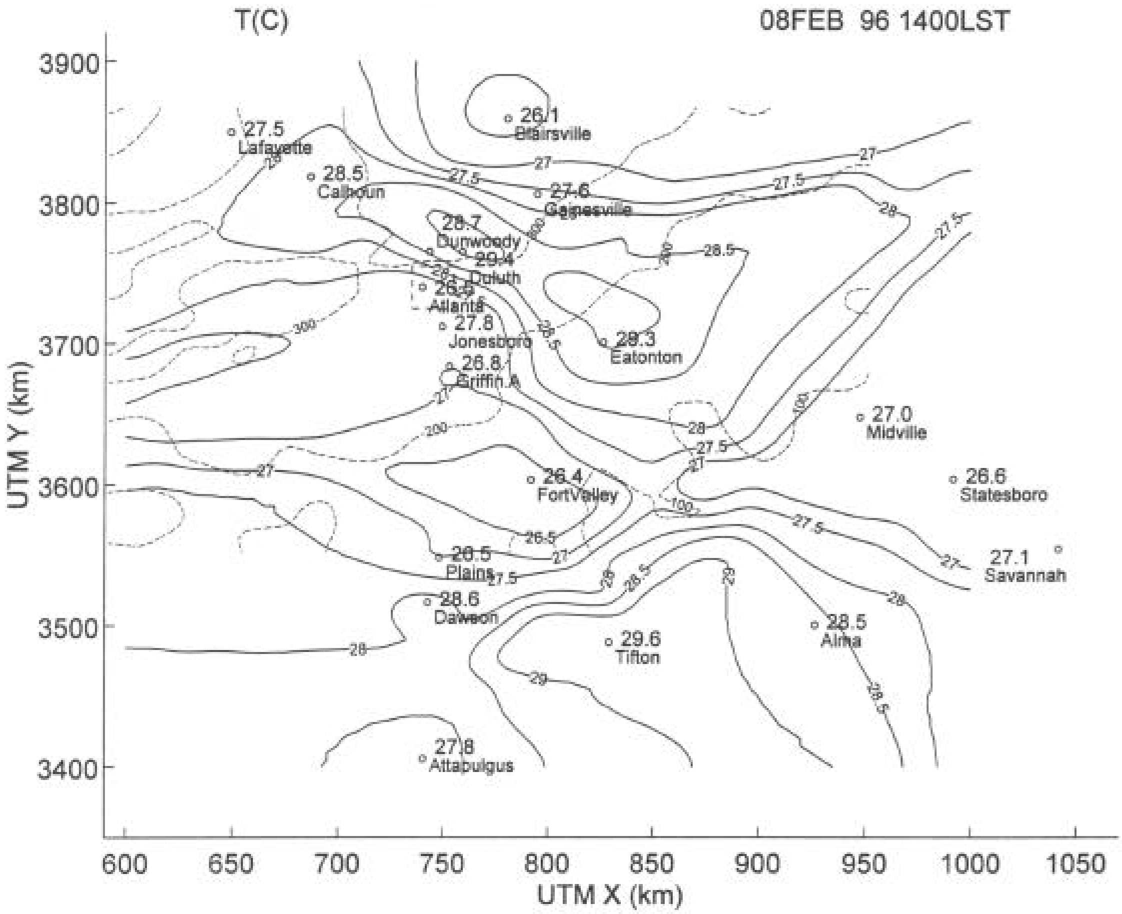

Figure 26. Surface temperature (C) analysis for the Atlanta area for 1400 LST on 8 February 1996.

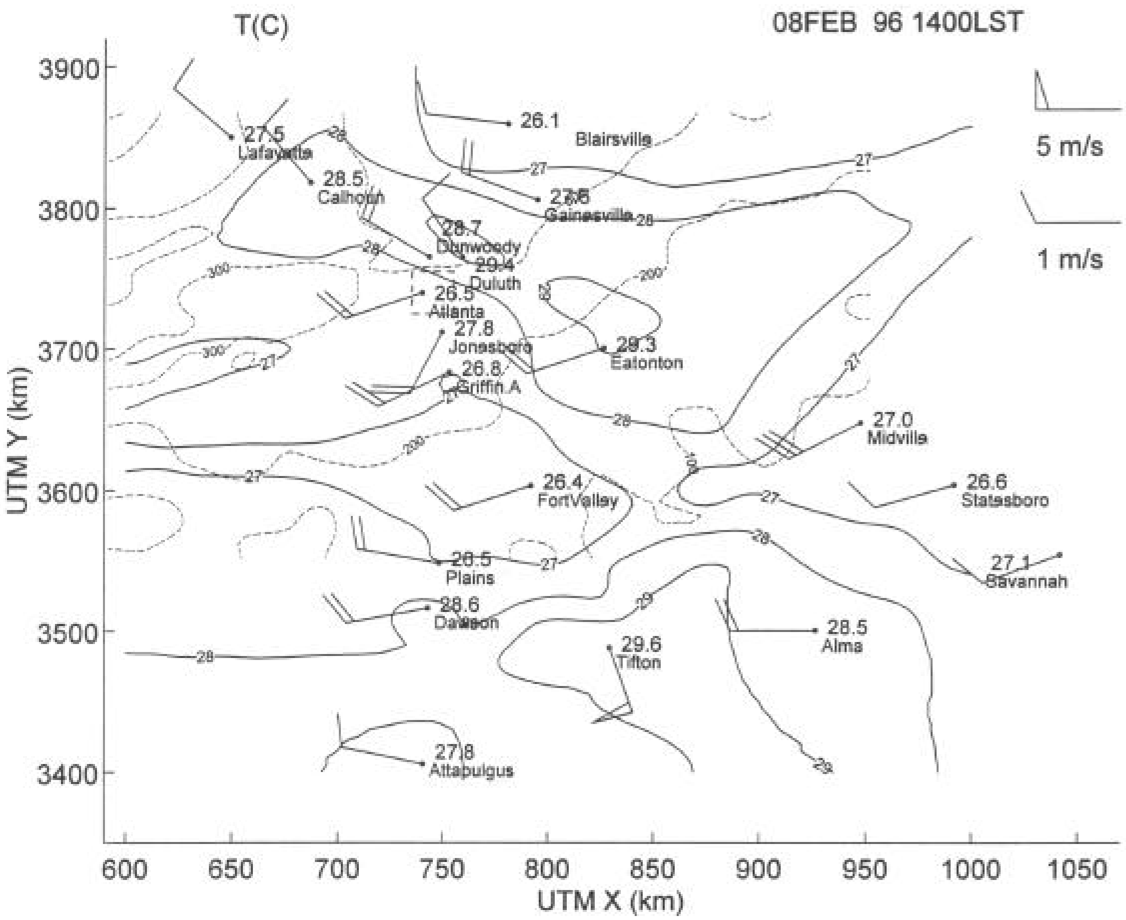

Figure 27. Surface temperature (C) analysis for the Atlanta area for 1400 LST on 8 February 1996; also shown are the wind velocity (mps) observations.

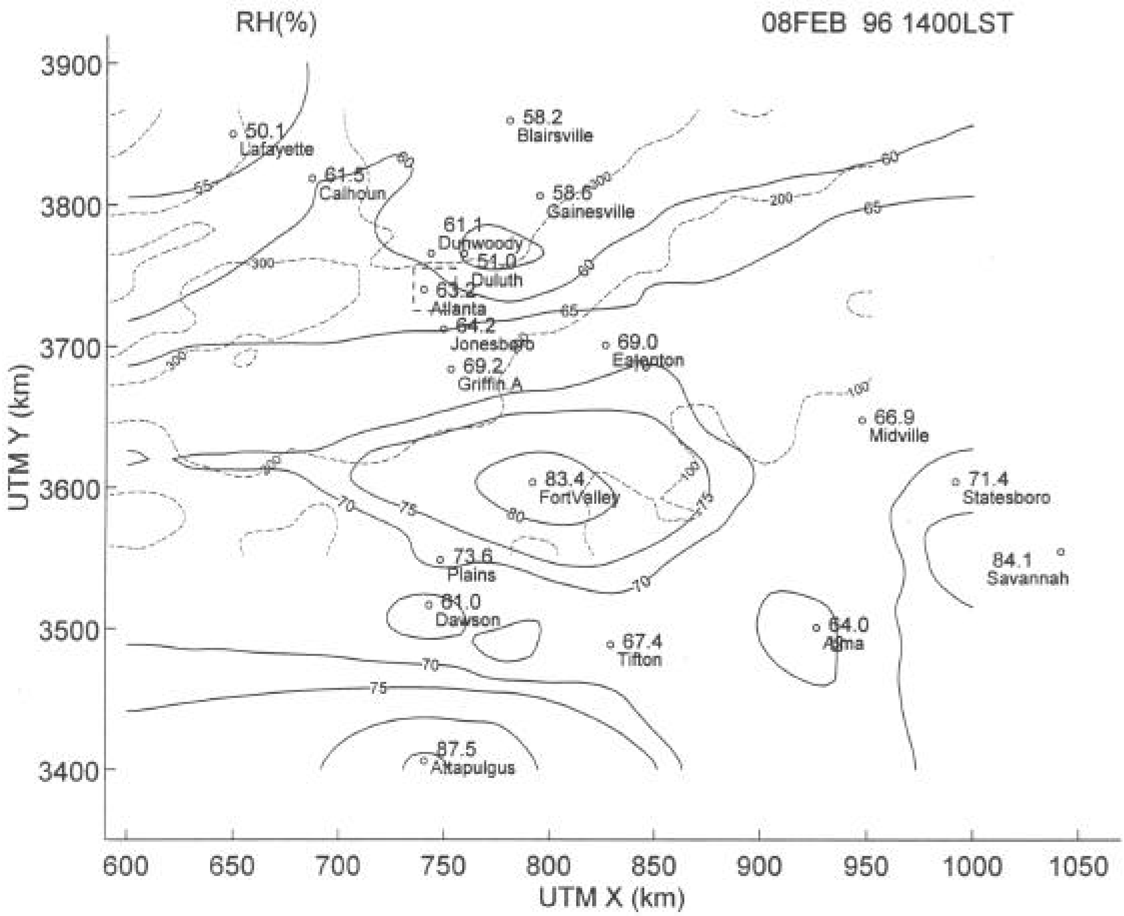

Figure 28. Surface relative humidity (%) analysis for the Atlanta area for 1400 LST on 8 February 1996.

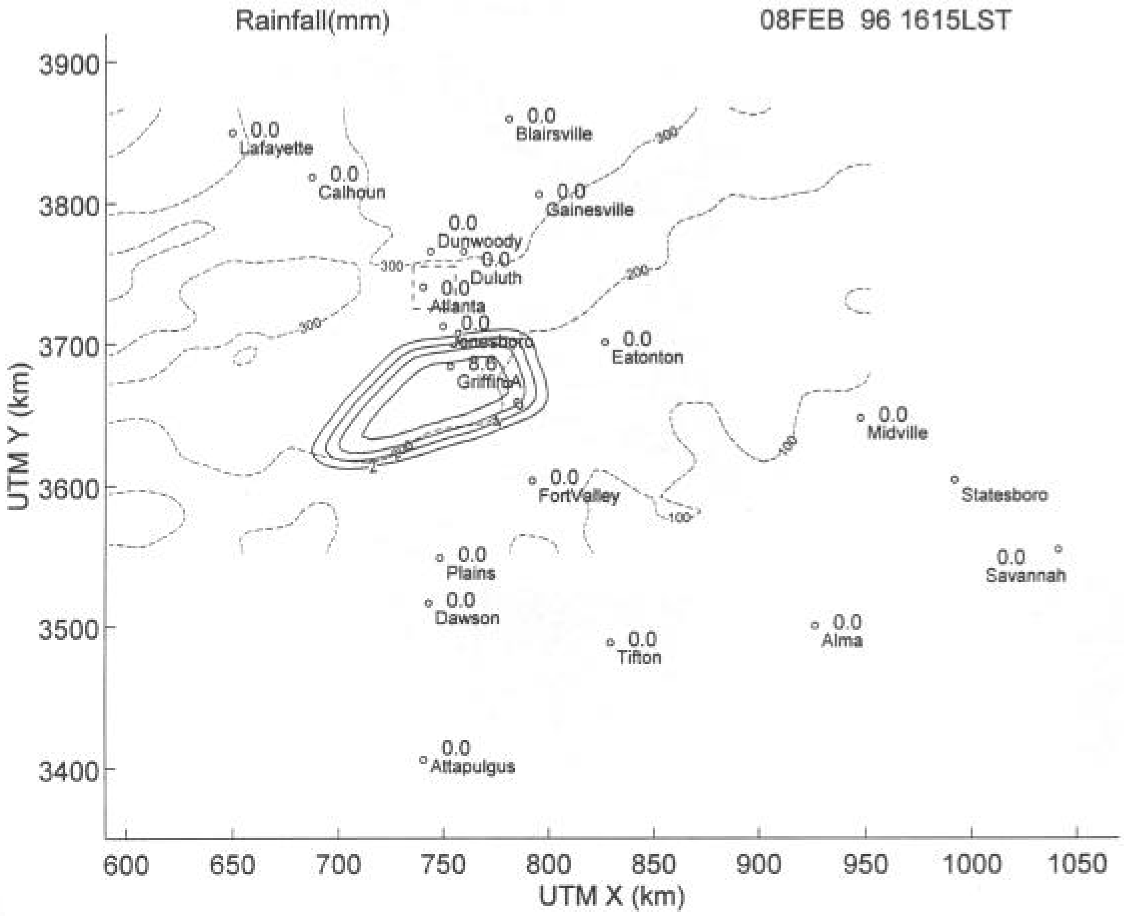

Figure 29. Rainfall amounts (mm) for the Atlanta area for 1400 LST on 8 February 1996.

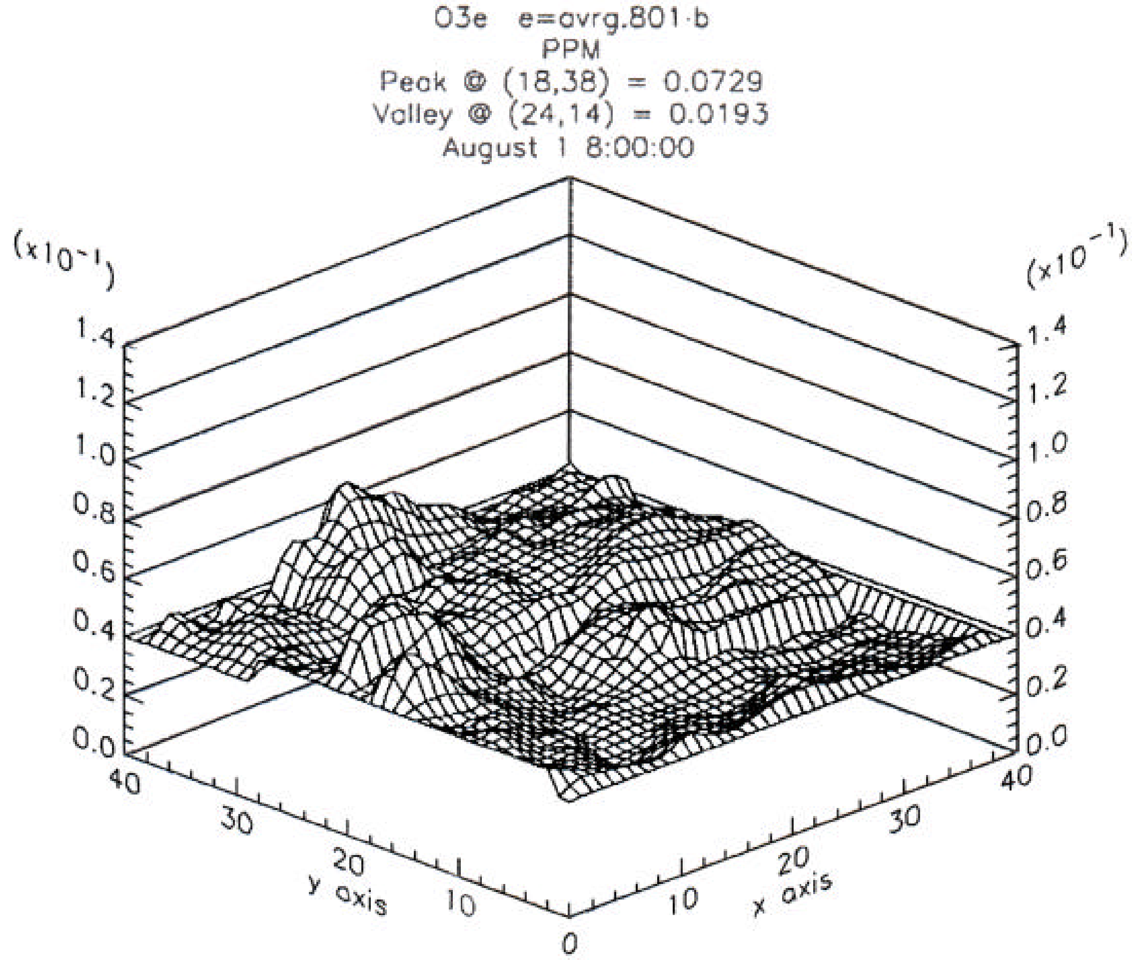

Figure 30. Base-case UAM simulated ozone concentrations at 8a.m. August 1 for the Atlanta region. Highest concentration is 73 ppb.

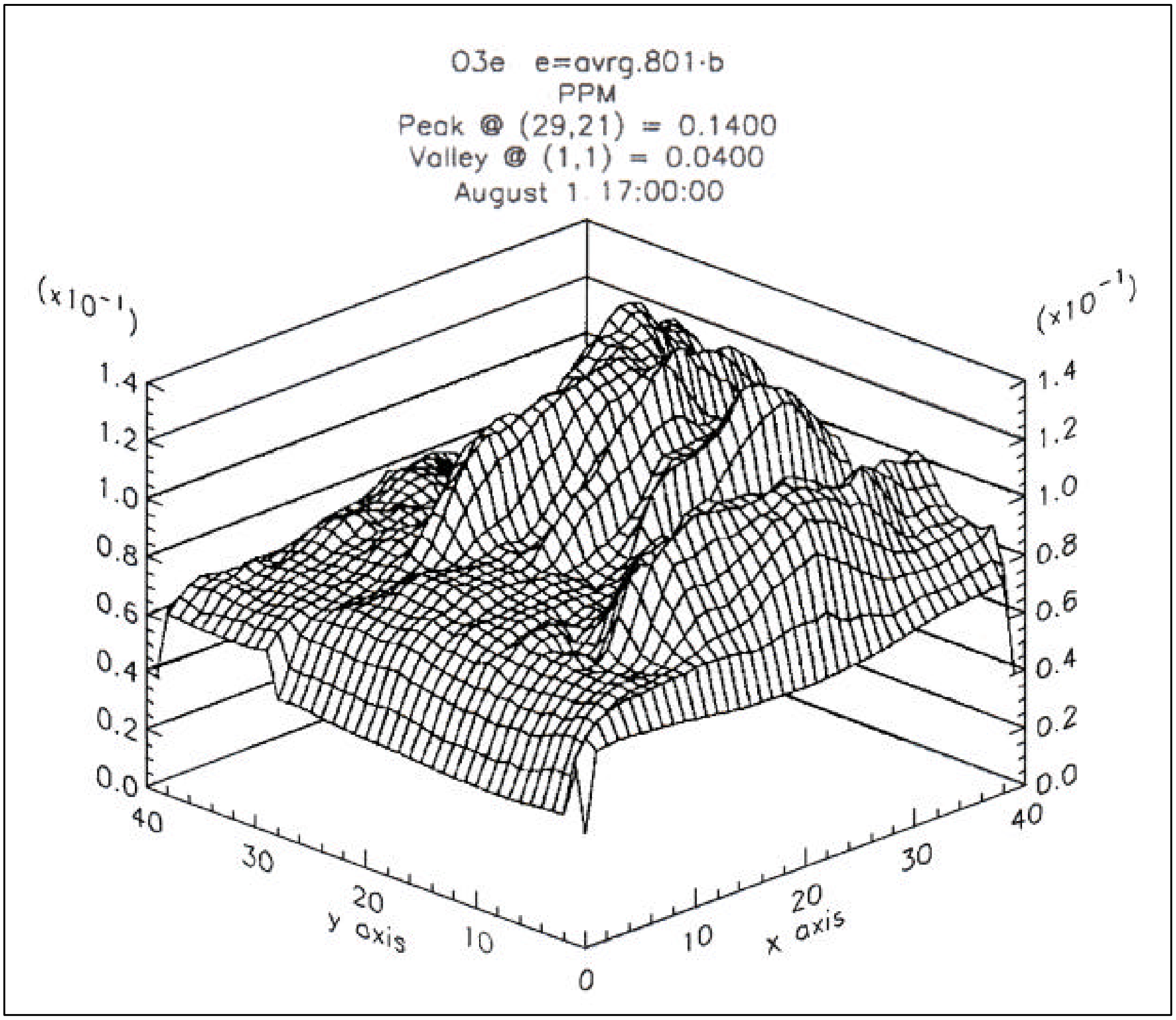

Figure 31. Base-case UAM simulated ozone concentration at 5 p.m. on August 1 for the Atlanta region. Highest concentration is 140 ppb, exceeding the older federal standard of 120 ppb and the newer EPA standard of 80 ppb.

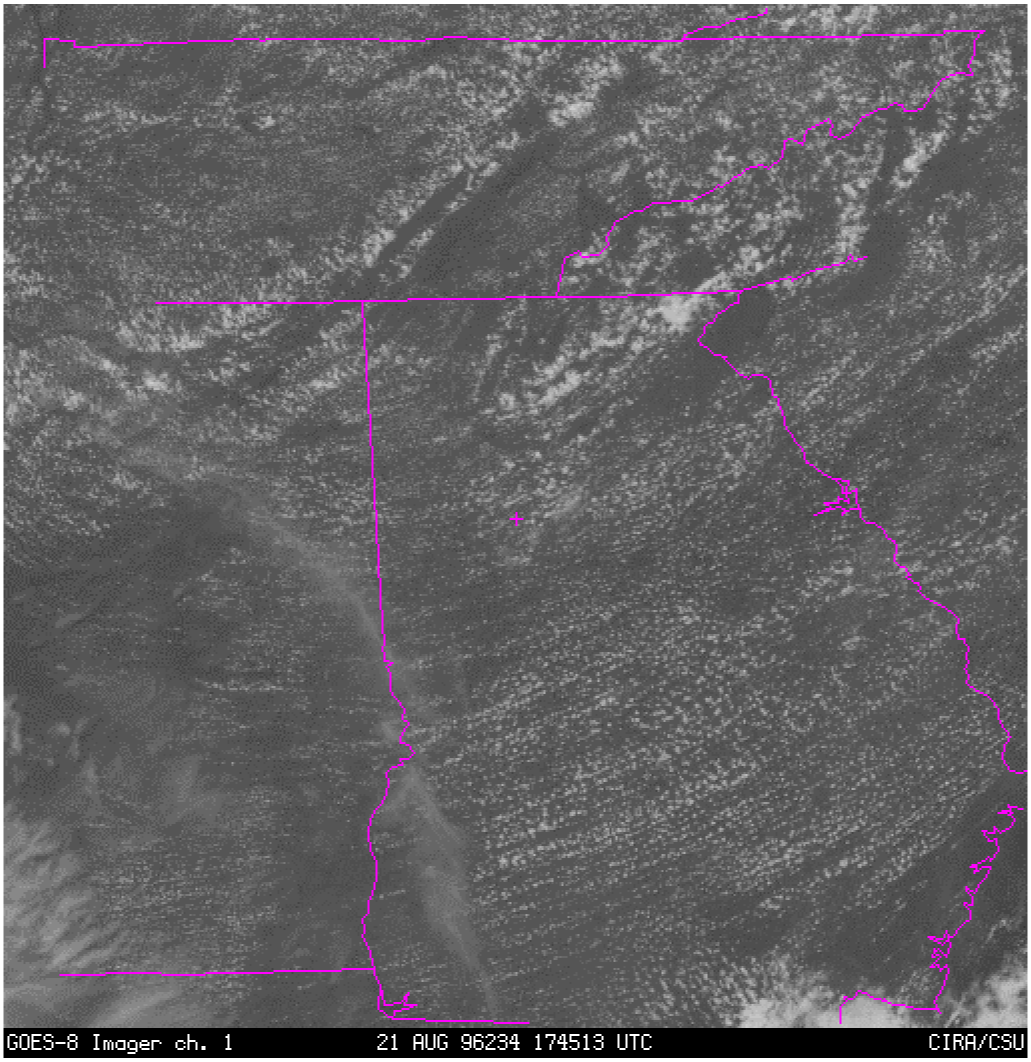

Figure 32. GOES 8 visible image of the Atlanta area. The location of Atlanta is marked by the '+' sign on the image. This is typical of otherwise clear days in the Southeast in the summer. Small clouds always break out in response to solar heating of a humid environment.

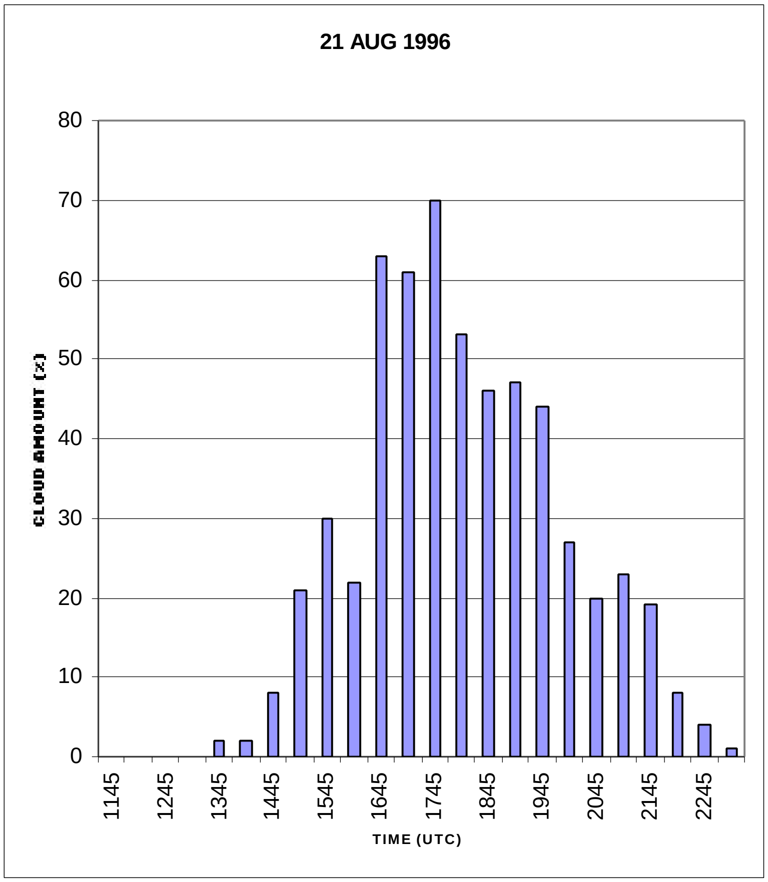

Figure 33. After correcting the GOES-measured radiance for the solar zenith angle, a histogram technique can be applied to determine the fraction of the area around Atlanta which are covered with clouds. The cloud cover rises and falls with solar insolation. This technique is preliminary, so that the calculated cloud amount cannot be considered final or exact, but at the peak of the afternoon cloudiness, over 50% of the area is cloud covered, which reflects sunlight back to space, cools the area, and possibly decreases the production of ozone and other photochemical species.

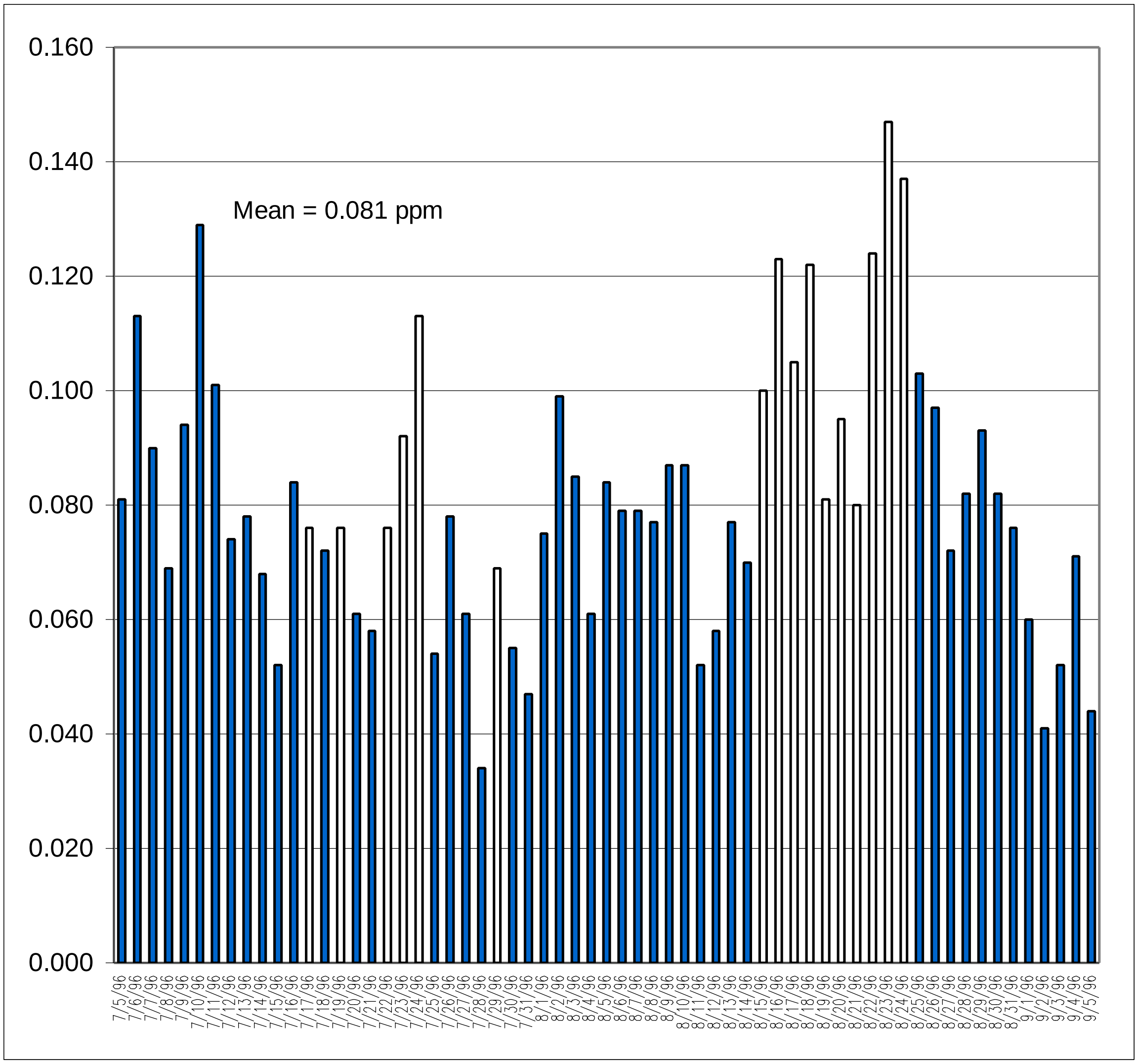

Figure 34. Days which are clear in the morning (white bars) tend to have higher ozone concentrations than days which are cloudy in the morning (blue bars). Figure 1 is typical of the afternoon satellite images for these days. [Ozone data supplied by the Georgia Department of Natural Resources.]

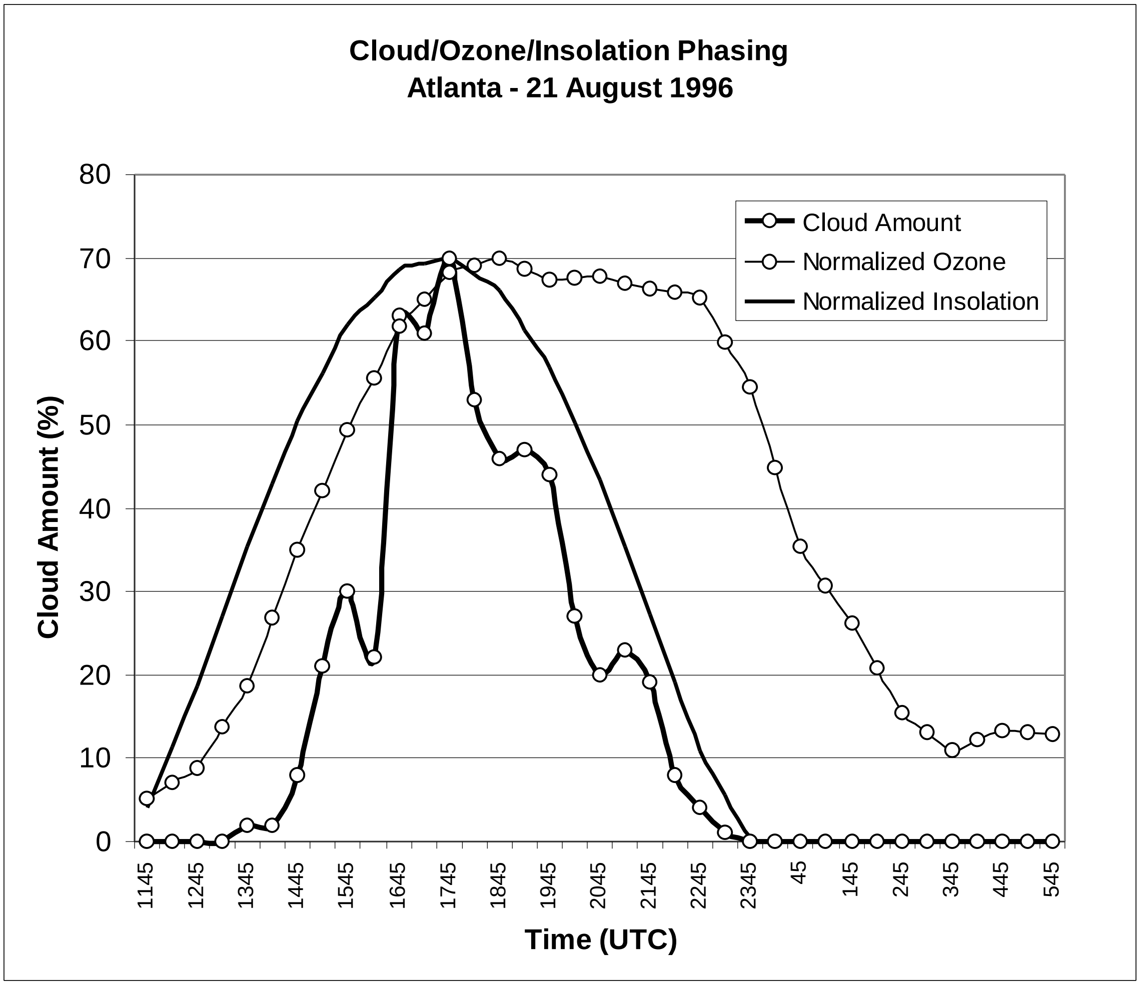

Figure 35. The relative phasing of clouds, ozone, and solar insolation for one day in Atlanta. Clouds and solar insolation are nearly in phase. The rise of ozone is in phase with solar insolation, but its destruction is not.

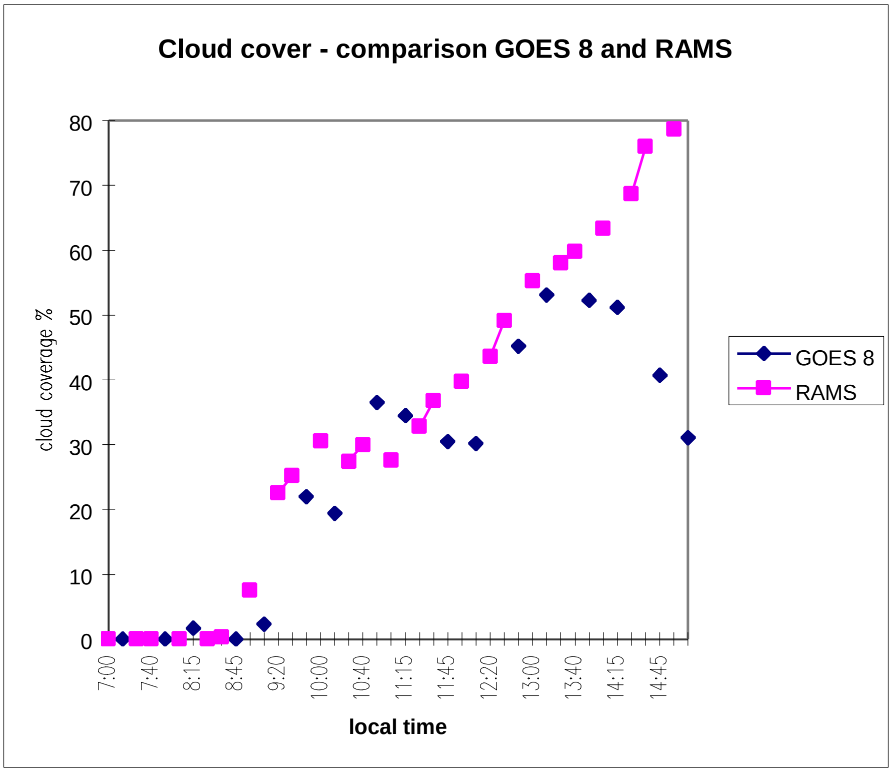

Figure 36. Modeled and observed clouds on 21 August 1996. Perhaps surprisingly, the RAMS model does produce small clouds of roughly the right cloud cover. The one problem is that after about 1300 LT, the model clouds persist and continue to grow while the real clouds begin to decay due to decreasing solar insolation.

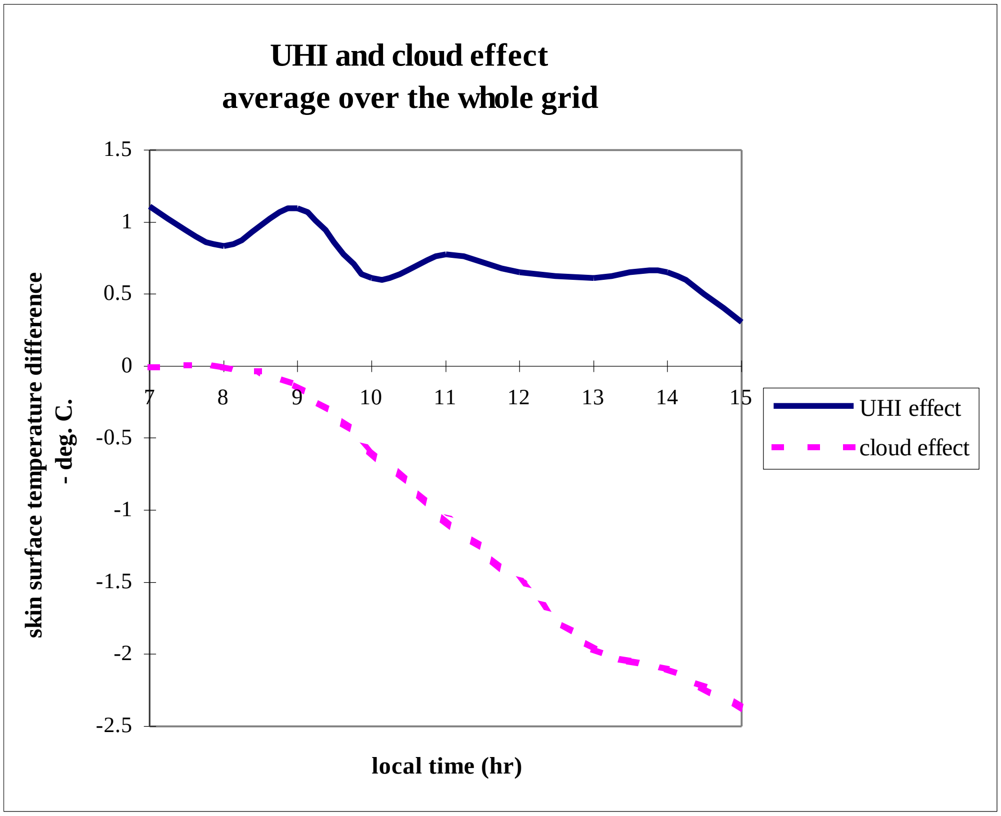

Figure 37. The solid blue line is the difference between urban and nonurban RAMS simulations (clouds included) for 21 August 1996. The conclusion is that the urban area increases the temperature by 0.5 to 1°C. The dashed magenta line is the difference between two urban simulations, one with clouds, and one without clouds. (The microphysics were turned off so clouds could not form.) The conclusion is that clouds cool the urban area

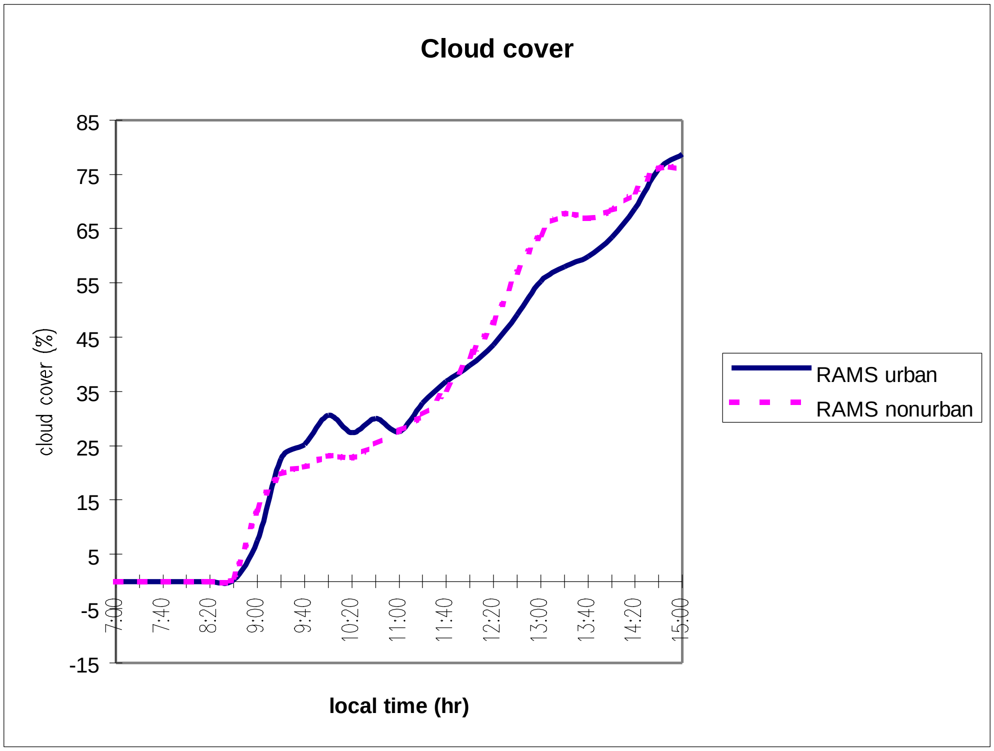

Figure 38. The effect of land use on cloud cover. Comparison of urban and nonurban modeled cloud cover (%) for 21 August 1996. The urban area produces more clouds in the morning, but the rural area has more clouds in the afternoon. However, the simulations are not accurate after about 1300 LT because the modeled clouds persist while the real clouds decay.

Table 1.

Land Use/Land Cover Change by Class in the Whole Atlanta Satellite Image Area: 1973-1992

Year	1973		1979		1983		1988		1992	
Land Use	hectares	%	hectares	%	hectares	%	hectares	%	hectares	%
High Density Urban Use	43466.75	1.96	63143.67	2.85	80929.02	3.68	98961.29	4.47	125418.22	5.67
Low Density Residential	449004.98	20.29	506809.56	22.91	571802.23	25.97	669608.83	30.26	711506.96	32.14
Cultivated/Exposed Land	99573.73	4.50	62678.73	2.83	55942.91	2.54	43708.15	1.97	51014.82	2.30
Grassland/Cropland	201362.95	9.10	196349.74	8.87	193361.64	8.78	173718.83	7.85	157588.85	7.12
Forest Land	1385959.39	62.64	1350431.90	61.04	1266075.84	57.50	1181839.35	53.40	1130999.97	51.09
Water	33384.77	1.51	33079.69	1.50	33765.88	1.53	45312.50	2.05	37113.98	1.68
Total	2212752.57	100.00	2212493.30	100.00	2201877.52	100.00	2213148.95	100.00	2213642.79	100.00

Table 2.

Land Use/Land Cover Change by Class in the Atlanta Regional Commission Area: 1973-1992

Year	1973		1979		1983		1988		1992	
Land Use	hectares	%	hectares	%	hectares	%	hectares	%	hectares	%
High Density Urban Use	30302.12	2.90	42562.87	4.08	53107.18	5.09	72550.17	6.95	93258.97	8.94
Low Density Residential	242758.78	23.27	272741.85	26.15	323049.69	30.97	368683.85	35.34	391083.43	37.49
Cultivated/Exposed Land	47063.06	4.51	19864.71	1.90	17558.57	1.68	17008.52	1.63	16206.66	1.55
Grassland/Cropland	80460.19	7.71	79666.13	7.64	76720.59	7.36	60005.78	5.75	49791.57	4.77
Forest Land	629340.40	60.33	614674.41	58.92	558492.70	53.54	505434.91	48.45	477439.90	45.77
Water	13237.40	1.27	13651.97	1.31	14158.49	1.36	19478.73	1.87	15381.09	1.47
Total	1043161.95	100.00	1043161.95	100.00	1043087.23	100.00	1043161.95	100.00	1043161.63	100.00

APPENDIX A

Project ATLANTA Applications Strategy

(Presented and discussed at the Applications Strategy Meeting held in Atlanta, September 3, 1997)

Introduction

Climate variability and climate change or disruption can have significant influence on urban areas and human health in the southeastern United States. Because cities are the home to the vast majority of the population of the southeastern United States, as well as the country as a whole, the interrelationship between human health and the urban environment is inextricable. Thus, climate variability or change would not only impact the functioning and environmental characteristics of the city as an entity, but would also have potentially significant affects on the health of the human populations of cities. Additionally, urbanization exists along with deforestation and agriculture as the most profound example of human alteration of the Earth's surface. Changes that result from urbanization impact biophysical, hydrological, and climatic processes, which in turn, affect adjacent natural ecosystems. These influences brought on by urbanization, particularly those related to the affects on climate, can extend from the local to the regional scale, depending upon the size of the city and other factors. Urban areas, therefore, can not only be affected externally by climate variability or change, but can also affect or influence the development of local or regional climatology. Ultimately, human health can be both directly and indirectly affected by these climatological processes, which can have very pervasive effects on human society.

The ultimate applied goal of Project ATLANTA as a NASA-funded research endeavor, is to view how changes in climate, principally as manifested by the presence of the urban heat island phenomena (i.e., the "dome" of elevated temperature that presides over cities in contrast to adjacent rural areas) and air quality over Atlanta, affects the city as a sustainable, habitable environment. To insure that urban areas will be capable of sustaining habitation by our children and their progeny in the next millennium and beyond, we must become aware of how the perceived impacts of climate variability and change, such as the urban heat island, will affect cities as livable environments.

Science Data

The science focus of Project ATLANTA is: 1) to use satellite data to map the growth of the Atlanta metropolitan area from the early 1970's to the present and to determine the amount of land cover change that has occurred; 2) to use remote sensing data in conjunction with meteorological data to model how the growth of the Atlanta metropolitan area has impacted meteorological and climatic conditions from the early 1970's to the present; 3) to model how air quality has changed between the early 1970's and the present, as a function of land cover change and growth in the Atlanta metropolitan area; and 4) to model how projected growth of the Atlanta metropolitan area in the next 20-25 years will impact the region's meteorology, climate, and air quality. One of the key elements in developing meteorological and climate models for the Atlanta metropolitan area is the measurement of the amount of "heat" or thermal energy that enters the atmosphere from the urban surface. As pavement and buildings replace trees or agricultural lands in the urban growth process, there can be significant impact on the amount of heat that is reflected or emitted back into the atmosphere. The thermal energy emitted into the lower atmosphere over the city is the driving force behind the development of the urban heat island, where temperatures can be 5-8^{o} F higher than surrounding non-urbanized areas. Additionally, as the air temperature heats up over the city as a result of the urban heat island effect, there is an increase in photochemical smog and other pollutants which lead to a degradation in air quality.

To augment the quantitative measurements of land cover change and land surface thermal characteristics derived from current and historical satellite data, we are employing airborne remote sensing data obtained at a very high spatial resolution over Atlanta for use in measuring the amount of thermal energy or "heat" that is emitted by different land surface types typical of the city landscape (e.g., asphalt, concrete, trees, grass, building rooftops). These aircraft data were collected over the Atlanta metropolitan area during the daytime and nighttime on May 11 and 12, 1997. These data will provide very detailed measurements for use in determining the underlying surface responses that lead to development of local and regional-scale urban climate processes, such as the urban heat island phenomenon and related characteristics. These aircraft data will also be used as input for modeling present-day air quality characteristics over the city and will be used as a baseline data base for performing modeling of how future potential changes in land cover will impact climate and air quality over the region. Additional information on Project ATLANTA, including the science approach and samples of the aircraft data collected over Atlanta during May of this year can be found on the Internet at http://wwwghcc.msfc.nasa.gov/atlanta/.

User Areas of Interest and Desired Data Products

In addition to its science objectives, Project ATLANTA seeks to work with local, state and other federal governmental agencies, as well as non-profit organizations and the commercial sector, to translate and apply the scientific results from the project to assist in making Atlanta a "model" for urban sustainability and habitability. In short, we want to insure that our scientific research results in information that is of interest and of use to as wide a user community in Atlanta as possible. Discussions with the Atlanta user community have identified several areas of opportunity for using science data to address regional and local issues. Below, the standard science data products that will be developed over the course of the research study are identified. Many of these standard products are of interest to stakeholders. Also, other data products of interest to stakeholders are noted. Some of these products may also be developed as part of the Project ATLANTA science study, however, most will probably require the commitment of some resources by stakeholders. For those stakeholders will be resources to utilized processed satellite data, the Project ATLANTA staff will assist with training interested users in the access and use of the data.

<u>Land Use and Cover Changes and Characteristics</u>

Urbanization has several significant effects on local and regional climate, such as elevated air temperature, altered precipitation patterns, sunlight intensity, etc. More research into the local and regional effects of urbanization are needed to better understand the magnitude of these impacts. One major aspect of urbanization is land use change. Both scientists and potential users are interested in gaining a better understanding of how land use types are influencing elevated air temperatures and air quality. Questions have been raised such as: Does the urban heat island effect have an impact on growth trends? Will planting more trees or preserving more green areas stimulate growth in selected areas? Land use change detection in selected areas, such as individual or groups of census tracts and transportation corridors , is one major area of interest within the user community.

Remote sensing data can be used to identify natural hazards and environmentally sensitive areas such as wetland and flood prone sites. Data packages that provide details on the site’s physical features such as topography and surface porosity could be especially beneficial to users. Also, interest exists in using remote sensing data to evaluate land cover changes for watershed protection purposes.

Standard Science Data Products

- Raw satellite data: Landsat MSS and Thermal Mapper data, Advanced Very High Resolution Radar (AVHRR) data, Advanced Thermal and Land Applications Sensor (ATLAS) data, GOES data
- Digitally Pre-processed satellite data; e.g. geometric rectification: Landsat MSS and Thermal Mapper, Advanced Very High Resolution Radar (AVHRR), Advanced Thermal and Land Applications Sensor (ATLAS), GOES data

- Land use change detection for the 10 County Atlanta Region from 1973 to 1997 and at periodic intervals of about five years each.
- Development of a land use change packet that includes all of the above

Other Data Products of Interest to Users That Can be Derived from the Science Data Products

- Land use change detection for the following transportation corridors and areas:
    - Atlanta city limits
    - I-75 North to Cobb County
    - I-85 North to Gwinnet County
    - I-75/85 South to the airport
    - Chattahoochee River basin
    - Others?
- Classification of forest and/or tree types within the 10 County region
- Analysis of impervious surfaces and runoff

Energy and Thermal

Elevated air temperatures result in higher energy usage for cooling in urban areas. Consequently, the urban heat island is a factor in power generation requirements. The building materials used and vegetation cover are also significant factors for the energy usage of a particular site or area. Interest has been expressed in using the data and science results from Project ATLANTA to gain a quantifiable understanding of the impact of the heat island on energy usage and cost. Also, to perform cost/benefit or similar analyses to asses the effectiveness of the use of energy efficient building materials, more tree planting, and other mitigation strategies.

Standard Science Data Products

- Thermal maps:
    - 10 County region from AVHRR data
    - City's central business district from ATLAS data
    - Urban core areas at the I-75/I285 and I-85/I285 interchanges from ATLAS data
- Assessment of the impact of land use types on the urban heat island
- Assessment of land-atmosphere thermal responses across the Atlanta landscape

Other Data Products of Interest to Users That Can be Derived from the Science Data Products

- Analysis of the impact of the heat island on winter energy usage
- Analysis of the impact of the heat island on public health; e.g., heat stroke, skin cancer, etc.
- Analysis of the heat differences in asphalt and concrete
- Analysis of vertical temperature profiles and the impact of the heat island
- Others?

Air Quality

Air quality is a major concern of urban areas and contributes to a host of environmental and human health problems. The urban heat island and land use changes directly contribute to air quality degradation through their influence of photochemical processes. More remotely sensed data and modeling simulations are needed to further evaluate these changes. Particular interest has been expressed in mitigation strategies to address the ground level ozone and periodic peak ozone episode problems. Contributing to an overall better understanding of why poor air quality exists in Atlanta will be a benefit to decision and policy makers. Also, model outputs that include potential mitigation strategies such as planting more trees, modification of land use trends, mixes, etc. are also desired.

A major objective of Project ATLANTA is to better understand the cause-and-effect relationships between urbanization and trends in climatology and air quality. Numerical modeling techniques will be used to produce results from a variety of scenarios that will improve our understanding of urbanization and local and regional climate impacts. Model scenarios can be developed in response to particular user interests in ground level ozone, air quality concerns relating to Atlanta's present non-attainment status, heat island mitigation using tree planting strategies, etc.

Standard Science Data Products

- Model outputs will be provided to assess:
    - the impact of land use changes on ozone levels
    - the impact of elevated temperatures on the development of ozone
    - the impact of land use changes on local and regional meteorology
    - the comparative value of selected mitigation strategies; e.g. plant trees, change surface reflectivity, etc.

Other Data Products of Interest to Users That Can be Derived from the Science Data Products

- Analysis of model outputs to enhance the State Implementation Plan (SIP)
- Enhanced model sensitivity to assess impacts at local levels; e.g. individual parcel and/or neighborhood scale
- The impact of biogenic emissions on the development of ozone
- Analysis of the impact of elevated temperatures and air quality on public health; e.g., asthma, other respiratory illness, etc.

Cost-Benefit Analysis

Data products will be quantified and cost-benefit analysis performed on selected mitigation strategies as desired. Presenting data products that include an economic component is an effective approach to securing the attention of stakeholders as well as the public.

Website

The Project ATLANTA website will be modified to add a data products component that will be linked to the State of Georgia GIS Clearinghouse webpage. The focus of this link will be to strengthen the **communication** between Project ATLANTA scientists and the broad user community. Our goal is to effectively communicate the science results to the technical community, policy/decision-makers, and the public. Also, to develop data products that are response to the needs of each group.

Communication to a diverse group of potential data users will require a multi-faceted approach that uses both the Internet and more traditional forms of communication. This link will include raw remote sensing data sets, primarily for use by the scientific community, and data products developed in response to the needs of the Applications Working Group. ATLAS, AVHRR, and GOES are examples of remote sensing datasets that will be placed on the website initially.

APPENDIX B

SYNOPSIS OF RESULTS FROM THE ATLANTA APPLICATIONS STRATEGY MEETING SEPTEMBER 3, 1997

A. Needs and Concerns of the Atlanta User Community

On September 3, 1997, the representatives of those organizations with the most interest in Project ATLANTA met in Atlanta and have been organized into an applications working group. The members of the Project ATLANTA Applications Working Group are provided in Attachment One.

The members of the Applications Working Group expressed interest obtaining remote sensing data and model output results from Project ATLANTA to further their user needs in a variety of topical areas:

Land Use Change

Urbanization has several significant effects on local and regional climate, such as elevated air temperature, altered precipitation patterns, sunlight intensity, etc. More research into the local and regional effects of urbanization are needed to better understand the magnitude of these impacts. One major aspect of urbanization is land use change. Both scientists and potential users are interested in gaining a better understanding of how land use types are influencing elevated air temperatures and air quality. Questions have been raised such as: Does the urban heat island effect have an impact on urban growth trends? Will planting more trees or preserving more green areas stimulate growth in selected areas? Land use change detection in selected areas, such as individual or groups of census tracts and transportation corridors , is one major area of interest within the user community.

Energy Conservation

Elevated air temperatures result in higher energy usage for cooling in urban areas. Consequently, the urban heat island is a factor in power generation requirements. The building materials used and extant land covers present (e.g., vegetation) are also significant factors for the energy usage of a particular site or area. Interest has been expressed in using the data and science results from Project ATLANTA to gain a quantifiable understanding of the impact of the heat island on energy usage and cost. Also, these data can be used to perform cost/benefit or similar analyses to assess the effectiveness of the use of more energy efficient building materials (e.g., roofs with high albedo values to reflect more incoming solar radiation), more tree planting, and other mitigation strategies.

Air Quality

Air quality is a major concern of urban areas and contributes to a host of environmental and human health problems. The urban heat island and land use changes directly contribute to air quality degradation through their influence on photochemical processes. Remotely sensed data and modeling simulations can be used to further evaluate these changes. Particular interest has been expressed in mitigation strategies to address the ground level ozone and periodic peak ozone episode problems. Research contributing to an overall better understanding of why poor air quality exists in Atlanta will be a benefit to decision and policy makers. Also, model outputs that include potential mitigation strategies such as planting more trees, modification of land use trends, changes in land use mixes, etc. are also desired.

Water Supply and Quality

Water supply, volume, and quality are critical to sustaining urban environments. Urban areas and associated elevated air temperatures, tend to change precipitation patterns by effecting rainfall events around the city. Changing precipitation trends and intensities are of particular interest in monitoring water levels (groundwater and surface), runoff capacity, reservoir management, and water quality. Also, interest exists in using remote sensing data to evaluate land cover changes for watershed protection purposes.

Environmentally Sensitive Areas

Remote sensing data can be used to identify natural hazards and environmentally sensitive areas such as wetland and flood prone sites. Data packages that provide details on the site's physical features such as topography and surface porosity could be especially beneficial to users.

B. Required Data Products:

A significant task now is to develop data products to address the needs described above. Potential data products include the following:

Land Use Change Detection

Using GIS and image processing techniques, land use change detection can be quantified over the Atlanta region and subsets of the region, such as selected transportation corridors, census tracts, or other areas as delineated. More progress is needed in defining specific areas for study and understanding the aspects of land use change that are of the most interest. For example, loss of vegetative cover may be the primary interest in watershed areas, whereas conversion of residential to commercial land may be the interest in other parts of the region.

Air Quality Modeling

A major objective of Project ATLANTA is to better understand the cause-and-effect relationships between urbanization and trends in climatology and air quality. Numerical modeling techniques will be used to produce results from a variety of scenarios that will improve our understanding of urbanization and local and regional climate impacts. Model scenarios can be developed in response to particular user interests in ground level ozone, air quality concerns relating to Atlanta's present non-attainment status, heat island mitigation using tree planting strategies, etc.

Thermal Maps

Thermal maps depicting temperature differentials in the Atlanta region will be produced. The potential exists to integrate these data with land use changes and/or air quality models to produce unique data products for use in analysis of how specific urban surfaces (e.g., asphalt, building rooftops) effect the overall heat regime of the city.

Cost-Benefit Analysis

Cost-benefit analysis can be performed on selected mitigation strategies as desired.

Project Atlanta Applications Working Group

C.P. Lo	Univ. of Georgia/Geography
Brian Stone	Georgia Tech City Planning
Jim Durrett	Georgia Conservancy
Steven Haubner	Atlanta Regional Commission
Nick Faust	Georgia Tech
Richard Schneider	Georgia Department of Transportation
Ingrid Sather	USDA Forest Service
Blake Burgess	Georgia Department of Natural Resources
Dale Kemmerick	Georgia Environmental Protection Division
Liz Kramer	University of Georgia Institute of Ecology
Terrence Campbell	U.S. Forest Service
Rick Durbrow	US EPA, Region 4
Ron Ritschard	UAH/GHCC
Marcia Bansley	Trees Atlanta
Joe Burgess	U.S. Department of Agriculture
Cindy Haygood	U.S. Department of Agriculture
Michael E. Chang	Georgia Tech and Ga. Env. Protection Branch
Dale Quattrochi	NASA/GHCC
Jeff Luvall	NASA/GHCC
Maury Estes	USRA/GHCC