8.2 PROJECT ATLANTA (ATLANTA LAND USE ANALYSIS: TEMPERATURE AND AIR QUALITY) – A STUDY OF HOW THE URBAN LANDSCAPE AFFECTS METEOROLOGY AND AIR QUALITY THROUGH TIME

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1. Background

Project ATLANTA (ATlanta Land-use ANalysis: Temperature and Air-quality) is a NASA Earth Observing System (EOS) Interdisciplinary Science investigation that 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 through 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

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changes in 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. Science and Applications Tasks

The science and applications approach we are using in relating land cover changes with modifications in the local and regional climate and in air quality in Project ATLANTA are being executed via a number of separate, but highly interlinked, tasks. These tasks are:

1. Land use/land cover change mapping for the Atlanta metropolitan area using satellite and airborne remote sensing data;
2. Analysis of urban surface energy fluxes from high spatial resolution multispectral thermal IR data;
3. Linking the remote sensing data with temporal changes in urban land cover and observed climatic data;
4. Meteorological and air quality modeling;
5. Analysis of cloud effects on the urban Climate; and
6. Applications strategy assessment.

The research and application activities associated with each of the above tasks are briefly described below.

3.1 *Land Use/Land Cover Mapping from Remote Sensing Data*

Land use/cover maps of the Atlanta Metropolitan Region for the years 1973, 1979, 1983, 1988, and 1992 have been produced using Landsat MSS data. From these maps, land use/cover and land use/cover change statistics have been generated By examining the land use/cover maps of 1973, 1979, 1983, 1988, and 1992, 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. Both forest land and grassland/cropland have decreased in absolute area across the Atlanta metropolitan region. 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% 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 density residential use has increased from 20.29% in 1973 to 32.14% in 1992.

3.2 Analysis of Surface Energy Fluxes from Aircraft Remote Sensing Data

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 (Lo et al., 1997). 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.

High spatial resolution multispectral thermal infrared airborne data have been 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. 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. Examples of the ATLAS data collected over Atlanta are shown on the Project ATLANTA Web page at http://wwwghcc.msfc.nasa.gov/atlanta/.

3.3 Linking Remote Sensing Data with Temporal Urban Land Cover Changes and Climatic Data

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.

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, 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.

Approximately a dozen weather observation stations within a 50 mile radius of Atlanta have been identified that will be used to assess differences and trends in temperatures during the past 20-25 years. Maximum and minimum temperatures 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.

3.4 Meteorological and Air Quality Modeling

The modeling of how land cover conditions and landscape change influence meteorology and ultimately, air quality, is a key focus of Project ATLANTA. As a preliminary analysis, 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°C and a nighttime heat island of about 2-3°C over the Atlanta area. A base case model performance evaluation process was initiated following the establishment of a meteorological base case for each episode. For validation purposes, mesonet data from the Georgia Automated Environmental Monitoring Network were obtained. Fifteen-minute meteorological data for the summers of 1996 and 1997 were obtained from weather stations in Georgia for use in testing the model performance. The tests suggest that the mesoscale model performs well (i.e., simulates more accurately) for clear days during the selected episodes. During overcast days, the model simulations diverged to a certain extent from observed mesoscale conditions. This was expected since the initial model run did not have cloud physics or parameterization capabilities.

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 using satellite and aircraft data incorporated from the other tasks in the project, as well as regional land use plans that have been 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°C following the increases in urban surface albedo. Using an improved version of the model now under analysis, the simulated daytime heat island reaches 2.5°C and the temperature reduction due to increased surface albedo reached some 1.6°C. These findings are preliminary and should change as more updated surface characterization information becomes available from the remote sensing data collected for the project.

3.5 Analysis of Cloud Effects on Urban Climate

Clouds are significant intermediaries in the land cover–climate connection. Changes in land cover will change the cloud cover, which will change the solar insolation, the outgoing infrared radiation, and thus, climate and the air quality. This research initiative as part of Project ATLANTA 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;
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 that is prevalent around Atlanta in the summer. A comparison of the clouds produced in the model with the clouds deduced from GOES 8 data will be made to determine what effects changes in land use/land cover would have on the modeled cloud field.

Atlanta, in the summer, is a very cloudy place. In our 63-day period that has been analyzed to date (5 July–5 September 1996), there were zero days that were clear for the entire daylight period. Days that are cloud-free in the morning become partly cloudy in the afternoon in response to solar heating. Days that are clear in the morning have higher ozone than those that are cloudy in the morning.

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 where the urban parameters are replaced with rural parameters. Similarly, the cloud effect can be studied as the difference between two model runs, one with microphysics turned on (with clouds) and the other with microphysics turned off (no clouds). The UHI effect warms the city, while clouds definitely cool the city.

The effect of land use/land cover on clouds is also being studied. The urban area produces more clouds in the morning, but the rural area has more clouds in the afternoon.

3.6 Applications Strategy Assessment

An effort is being made 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 project's science tasks produce results that can be effectively used to make the Atlanta metropolitan area a better place in which to work and live. This application strategy assessment as part of Project ATLANTA focuses on 3 tasks:

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, the 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;
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; and
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 through the Internet as a distribution vehicle via the Project ATLANTA home page as a way to enhance feedback from the broader user community on the utility of Project ATLANTA data products.

4.0 References

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.

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. *Inter. Jour. Remote Sensing* **18,** 287-304.

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.

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.