P3.13 OBSERVATIONS AND MODELING OF EVAPOTRANSPIRATION AND LATENT HEAT FLUX AT VARIOUS SITES IN NORTH CAROLINA

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Abstract

Evapotranspiration measurements were taken at 14 locations across North Carolina using an ETgage that allows distilled water to evaporate through a waterproof surface. Equivalent surface turbulent latent heat fluxes were derived from evapotranspiration values. Variations in latent heat flux and evapotranspiration were analyzed across North Carolina to investigate its dependence on soil type, land use and initial soil moisture. The Sandhills region experiences the largest amount of evapotranspiration in the state with the mountain region having the least. Estimations of latent heat flux using Priestley-Taylor and Penman-Monteith methods are compared with observations.

A mesoscale numerical simulation was performed for the period, 00Z August 14, 2003 to 00Z August 16, 2003. Penman-Monteith and Priestley-Taylor methods of obtaining latent heat flux were applied using simulated atmospheric parameters and compared with observations. Priestley-Taylor method appears to have a higher degree of accuracy as compared to Penman-Monteith method at the selected locations across the state.

1. INTRODUCTION

Accurate estimates of evapotranspiration are essential for computing water and energy balances. Agriculture and land surface models are dominated by this exchange of water. It is also fundamental to water resource management, with the majority of precipitation lost through evapotranspiration. The Southeastern United States has the highest amounts of evapotranspiration in the country due to the high amounts of both precipitation and incoming solar radiation (U.S. Geological Survey, 1990). This creates a significant sink in the water supply in this area and makes evapotranspiration estimates essential.

Observations of evapotranspiration (ET) are not widespread. There are only 14 locations in North Carolina that take these measurements, which creates a need for estimations. Latent heat flux, which is directly related to ET, can be estimated two ways: numerical simulations and empirical methods, which use routine observations from each station.

Two of the more commonly used empirical methods are Penman-Monteith and Priestley-Taylor. Penman (1948) was the first to derive an equation for latent heat flux. Monteith (1965) adjusted this equation by incorporating stomatal resistance. The Penman-Monteith equation for latent heat flux includes a correction term for advection, which can affect evapotranspiration. Priestley and Taylor (1972) simplified Penman's original equation and parameterized advection.

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2. METHODOLOGY

The State Climate Office of North Carolina's NC ECONet (Environmental and Climate Observing Network) system consists of 25 stations statewide. Fourteen of these stations take hourly measurements of evapotranspiration using an ETgage. This instrument allows distilled water to evaporate through a waterproof surface that acts as an agricultural crop. These stations, shown in Figure 1, are distributed throughout the three main regions of North Carolina: the coastal plain, Piedmont and the mountains. Six stations are located in the coastal plain. Five are in the Piedmont, and three are in the mountains.

Measurements of ET were taken from May 1 to August 4, 2004 for evaluation of temporal and spatial trends related to soil type, temperature, relative humidity, soil moisture and precipitation.

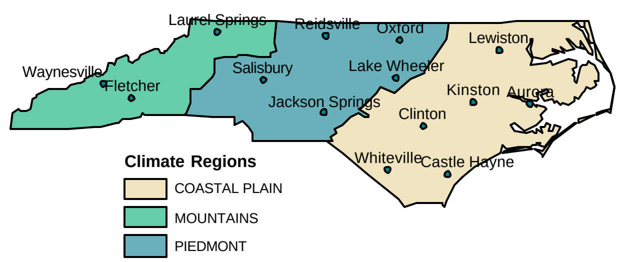

Figure 1. A map of climate regions and stations measuring evapotranspiration in the State Climate Office of North Carolina's NC ECONet system.

Empirical methods were used to calculate latent heat flux according to Stull (1988) using 1-hour data from the Lake Wheeler ECONet station from July 14, 2003 to November 10, 2003. In the Priestley-Taylor equation for potential evaoparation, the parameter α is related to the Bowen ratio is approximately unity for saturated surfaces. Priestley and Taylor suggested that α would be less than unity for unsaturated surfaces

(1972). In this study, α is set to equal 0.60, which is similar to the work of Shuttleworth and Calder (1979).

Estimates of latent heat flux were also used from the State Climate Office's real-time agricultural weather forecasting system. The Pennsylvania State University – National Center for Atmospheric Research Mesoscale Model (MM5) Version 3.6 was run with a dom ain centered over North Carolina and 12 km grid spacing. The model physics included Reisner 2, Grell, Eta Mellor-Yamada and Advanced Cloud Radiation schemes and the NOAH land-surface model. It was run from 00 UTC August 14, 2003 to 00 UTC August 16, 2003. Penman-Monteith and Priestley-Taylor methods were then applied to simulated atmospheric parameters for comparison with observations and model latent heat flux.

3. RESULTS

The observed spatial trends in evapotranspiration, precipitation, soil moisture and temperature are discussed in section 3.1. Section 3.2 includes estimates from the empirical method, and numerical simulations are discussed in section 3.3.

3.1 OBSERVATIONS

Observations of precipitation and evapotranspiration at Lake Wheeler from May 12, 2004 to August 4, 2004 are shown in Figure 2. This demonstrates the dependence of ET on precipitation. On the majority of days when precipitation occurs, ET decreases significantly. This is expected due to the increase in relative humidity, which would cause the evaporation to be less. On the days after precipitation has occurred, ET steadily increases. When ET does not decrease on a day with precipitation, it is due to the precipitation occurring in the evening hours after the peak in ET observations in the afternoon hours.

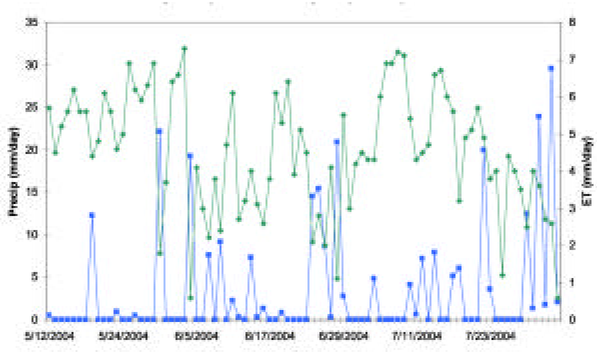

Figure 2. Observations of precipitation (blue) in mm/day and evapotranspiration (green) in mm/day at Lake Wheeler from May 12, 2004 to August 4, 2004.

During the period from May 1 to August 4, 2004, the average daily evapotranspiration totals were highest in the coastal plain region of North Carolina with a regional average of 4.7 mm/day. This was slightly higher than the Piedmont's average ET of 4.6 mm/day. The lowest values were found in the mountains with a regional average of 3.6 mm/day. This could be due to the expected lower air temperatures in the mountains than the coastal plain. More evaporation should occur where there are higher air temperatures. Figure 3 shows shaded contours of average daily evapotranspiration totals across the state with the pinks being higher values and greens lower values. The highest values are located near Kinston in the coastal plain and north of Oxford in the Piedmont. The average daily evapotranspiration generally decreases moving westward across the state.

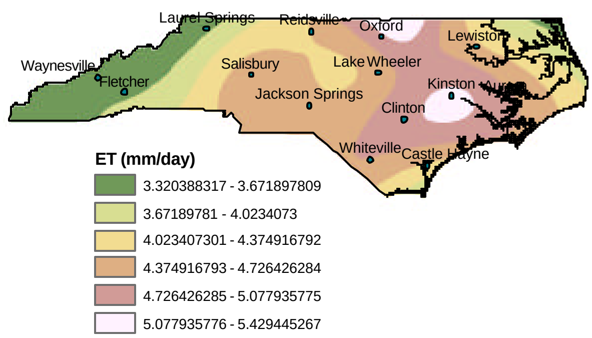

Figure 3. Shaded contours of average daily evapotranspiration totals across the state (in mm/day).

The average daily precipitation totals were highest in the mountain region with a regional average of 3.8 mm/day. This was 0.2 mm/day larger than the regional average for the coastal plain at 3.6 mm/day. The Piedmont had the lowest regional average at 3.0 mm/day. Figure 4 shows shaded contours of average daily precipitation totals across the state with blues being higher values and greens lower values. The lowest values are located in the southern central part of the state. The highest values were observed in the southern coastal plain near Castle Hayne.

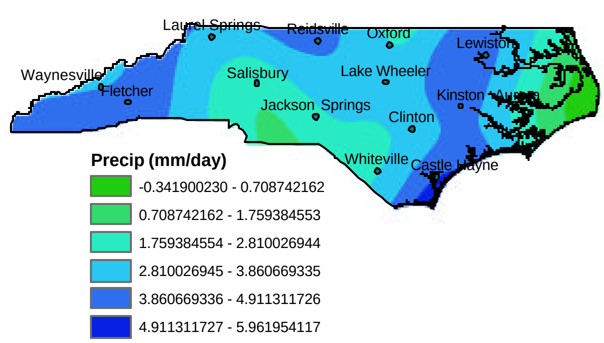

Figure 4. Shaded contours of average daily precipitation totals in mm/day.

Soil moisture values at midnight were used as the daily value. This allows the soil moisture to take into account any precipitation or evapotranspiration that had occurred each day. The highest average midnight soil moisture values were found in the mountains with a regional average of 0.311 m^3/m^3. This corresponds well with the average precipitation and evapotranspiration in the mountains. This high amount of soil moisture compensates for the lack of evapotranspiration and high amount of precipitation. Figure 5 shows the shaded contours of average midnight soil moisture values across the state with the higher values in blue and lower values in yellow. The lowest values are located in the central area of the Piedmont and in the central part of the coastal plain around Clinton and Kinston.

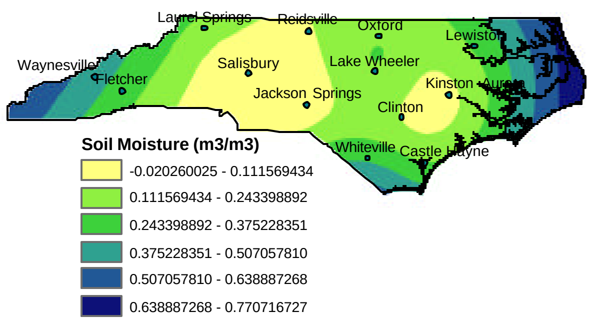

Figure 5. Shaded contours of average midnight soil moisture in $m^3 m^{-3}$.

Figure 6 shows shaded contours of average daily temperature across the state with higher values in red and lower values in green. The warmest average temperatures are observed in the central coastal plain and southern Piedmont. The regional average temperature in the mountains was 19.6°C. The regional average in the coastal plain was significantly higher at 24.1°C. This is expected due to the elevations differences in each region of the state. The average elevation of the stations in the coastal plain is approximately is 20m, while the average elevation of the stations in the mountains is approximately 770 m. The Piedmont stations have an average elevation of 200 m.

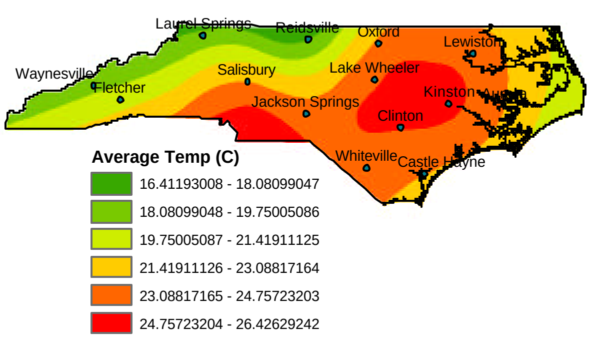

Figure 6. Shaded contours of average daily temperature in °C.

3.2 EMPIRICAL METHODS

Daily observations of ET at the Lake Wheeler ECONet station from July 14, 2003 to November 9, 2003 are compared with the Priestley-Taylor and Penman-Monteith methods. Each of these methods uses routine observations from this station to estimate potential evapotranspiration totals.

These daily observations are shown with the Penman-Monteith estimates in Figure 7. During the beginning of this period, Penman-Monteith method consistently overestimates the ET totals. As the observed values slowly decrease during the autumn months, the estimates approach the observations.

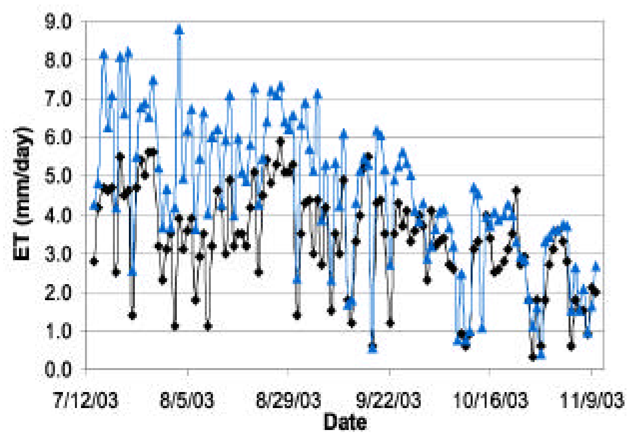

Figure 7. Daily observations of evapotranspiration (black) in mm/day at Lake Wheeler compared with Penman-Monteith estimates (green).

Daily observations of ET are compared with the Priestley-Taylor method in Figure 8. These estimates more closely match the observations than the Penman-Monteith method. During the late summer and autumn, the Priestley-Taylor method tends to underestimate some of the peaks in observations.

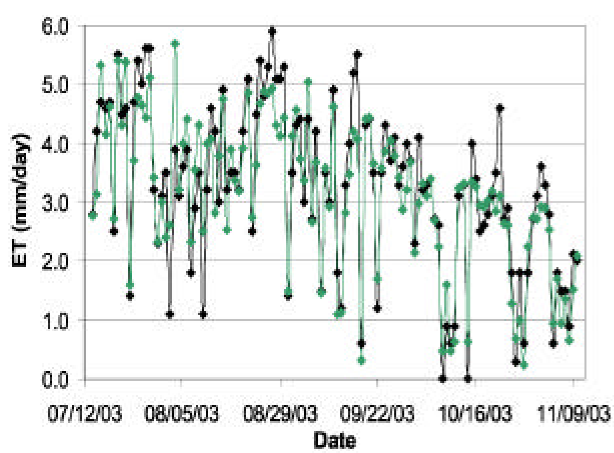

Figure 7. Daily observations of evapotranspiration (black) in mm/day at Lake Wheeler compared with Priestley-Taylor estimates (green).

3.3 NUMERICAL SIMULATION

Observations of evapotranspiration were used to calculate the latent heat flux at Lake Wheeler from 00 UTC August 14, 2003 to 00 UTC August 16, 2003. A numerical simulation using MM5 was performed for comparison, along with latent heat flux estimations using Priestley-Taylor and Penman-Monteith methods.

The diurnal variations in observed latent heat flux (LHF) from evapotranspiration observations are shown in Figure 8 with model output of latent heat flux and the Priestley-Taylor method. The observations show the highest values of LHF during the daylight hours on both days with little to no LHF observed during the night. Both the model LHF and the Priestley-Taylor LHF also demonstrate these variations. The Priestley-Taylor estimate more closely matched the observations at 15 UTC on the first day. The model overestimated this peak by approximately 60 Wm-2. On August 15, the model LHF was better at estimating the afternoon peak in LHF. The Priestley-Taylor LHF was nearly 100 Wm^{-2} less than the observations, while the model LHF was only 50 Wm^{-2} less.

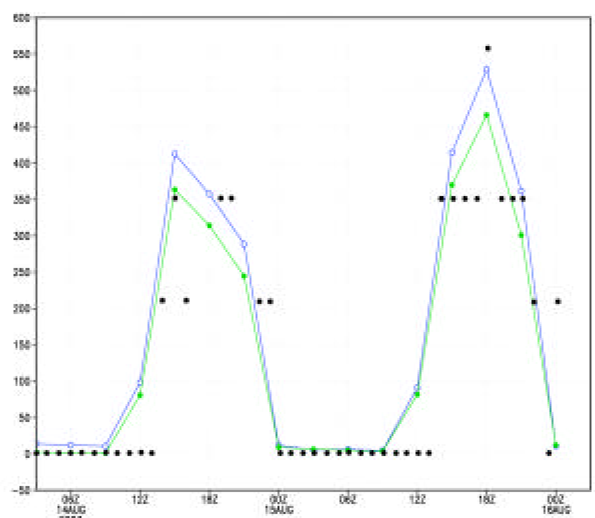

Figure 8. Diurnal variations of observations of latent heat flux in Wm-2 from 3 UTC August 14, 2003 to 00 UTC August, 16, 2003 compared with model latent heat flux and estimations using Priestley-Taylor method. Observations are in black. Model latent heat flux is in blue, and Priestley-Taylor is in green.

Figure 9 shows the diurnal variations of observed LHF with the model LHF and Penman-Monteith LHF for the same time period. The observations and model LHF are the same as in Figure 8. For both days, the model LHF more closely compared with the observations. The Priestley-Taylor LHF overestimated the afternoon peak on August 14 by nearly 400 Wm^{-2}. The second day's peak was overestimated by over 350 Wm^{-2}.

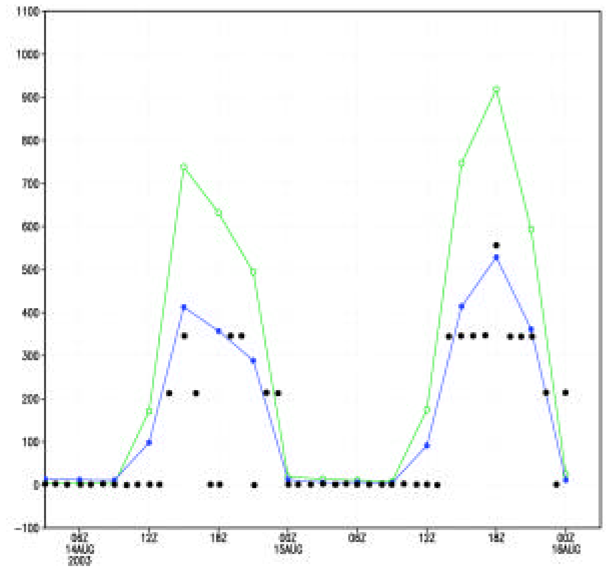

Figure 9. Diurnal variations of observations of latent heat flux (black) in Wm-2 from 3 UTC on August 14, 2003 to 00 UTC August 16, 2003 compared with model latent heat flux (blue) and estimations using Penman-Monteith method (green).

4. CONCLUSIONS

Evapotranspiration is essential for water resource management and agriculture. The lack of observations creates a need for estimations. Observations were evaluated for spatial and temporal trends relating to soil moisture, temperature, relative humidity and precipitation. Estimations from Penman-Monteith and Priestley-Taylor methods using observations and simulated parameters were compared with observations and MM5 model output. Priestley-Taylor method appears to do better for this data set.

5. ACKNOWLEDGEMENTS

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6. References

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