Role of Land Surface Processes and Boundary Layer Clouds on Convection

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Introduction

Observations and numerical simulations have shown the surface processes to play a significant role in convection initiation. These processes are complex and physics in many weather models do not represent them properly and thus have problems in forecasting convective precipitation. Multiple modeling and observational studies have focused on the impact of soil and vegetation contrasts on convection initiation in many geographical regions. One study speculated that vegetation on the order of a hundred kilometers can create vertical motions up to 10 cm/s up to an altitude of 1km above the surface (Anthes 1984). Similar results were found by Boyles et al. (2007), where soil contrasts and vegetation contrasts were shown to cause convection in the Sandhills region of the Carolinas through a horizontal sensible heat flux gradient at the transition zone. While it is true that differential heating can create flux gradients and subsequent secondary circulations, these circulations can be masked by terrain effects and ambient winds. This makes it difficult for a coarse model to resolve the effect of local circulations (Zhong et al. 1995). These ambient wind conditions can result from synoptic forcing as well as orographic lifting. Zhong et al. (1997) determined through modeling that when ambient conditions and surface flux gradients are present, the ambient conditions have a larger impact on convective initiation.

The study reported in this paper focuses specifically on convective initiation in the absence of synoptic forcing. The first part of this in depth study focuses on the role of surface sensible heat flux gradients on convection initiation using observations from several stations with a spacing of 50 to 100 km in the Southern Great Plains (SGP) region of the United States. The second part of this study focuses on the diurnal variation of precipitation and possible role of the boundary layer cloud – radiation feed back processes during nights in two regions, SGP and Sandhills region of the Carolinas.

A Case Study of Southern Great Plains (July 23, 2004)

To encompass the majority of the region of the Southern Great Plains (SGP), observations from seven automated weather stations in the southern region of the SGP were considered (Fig. 1).

Figure 1) Map of the ARM Southern Great Plains area of research showing the locations of the stations selected for this study.

In this region different types of soils are present, resulting in differences in soil moisture and soil temperature throughout the region that can influence convective initiation. During this particular day in the southern Great Plains, there was no available lifting due to synoptic forcing. However, it is evident from satellite radar images that convection did occur on this day (Fig. 2). By 21Z GOES 8 satellite and radar images indicate the presence of multiple convective lines in the region, in the absence of major synoptic forcing. Occurrence of convection was probably the result of surface sensible heat flux gradients in the region. Comparisons of sensible heat flux and precipitation over time at multiple sites indicate that shortly before convective precipitation amounts occur, there is a sharp gradient in sensible heat flux at the station (Fig. 3). This corresponds to the convection occurring in the region lowering the sensible heat flux. Considering the heat flux gradient against the precipitation at Lamont, we notice that the gradient is from north to south, coinciding with the buildup of convection prior to precipitation in Lamont (Fig. 4).

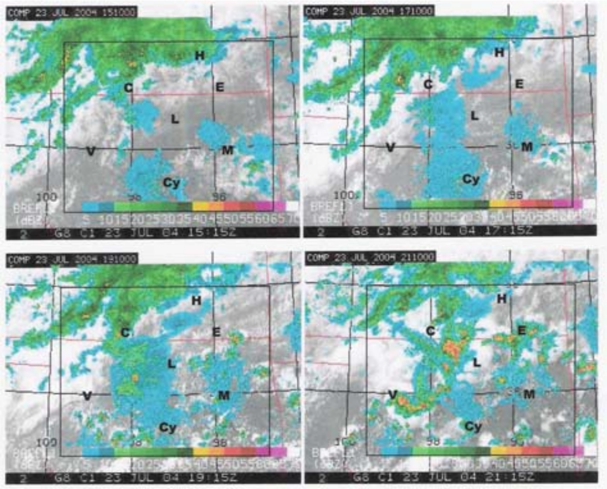

Figure 2. GOES 8 Satellite Radar imagery 7/23/2004 1515-2115Z, overlaid with station locations. C is Coldwater, H is Hillsboro, E is Elk Falls, L is Lamont, V is Vici, Cy is Cyril, M is Morris.

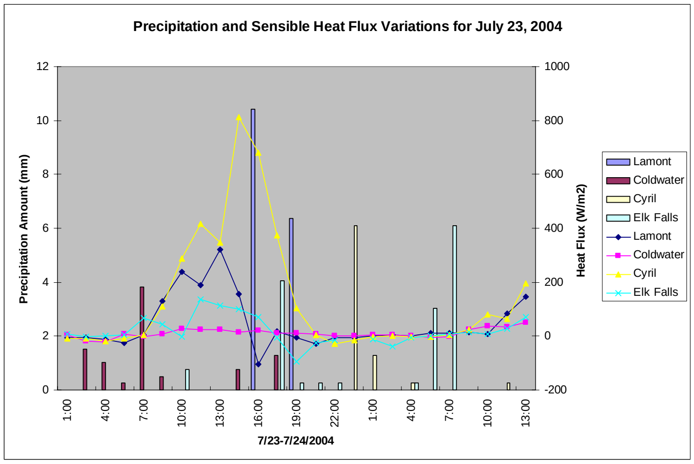

Figure 3. Precipitation (mm) and sensible heat flux (W/m^2) over time for Lamont, Coldwater, Cyril and Elk Falls (from 1CST 7/23/2004 to 13 CST 7/24/2004).

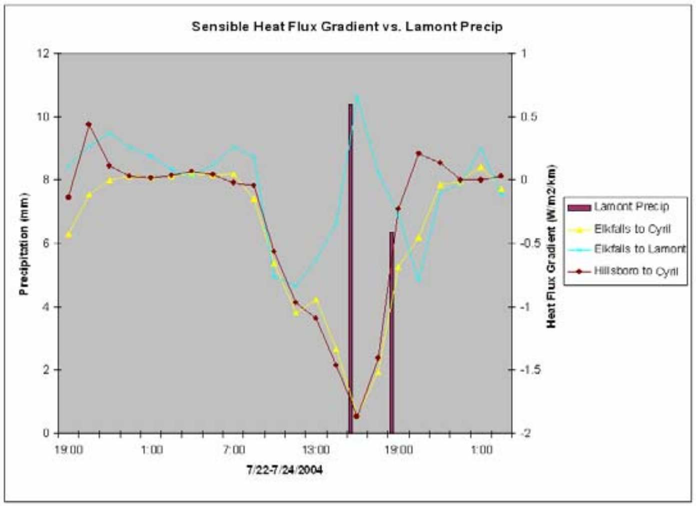

Figure 4. Sensible heat flux gradients (W m^{-2} km^{-1}) and Lamont Precipitation (mm) from 19 CST 7/22/2004 to 1 CST 7/24/2004

Variations in the sensible heat fluxes and the heat flux gradients are consistent with changes in air temperature and soil moisture. The surface heat flux gradient lines up nicely with the north to south pattern of convection in the region on this day, but it also lines up with the changes in the soil type in the region.

Diurnal Variation in Precipitation in the Sandhills and SGP

Statistical Analysis

While multiple case studies support sensible heat flux gradients as being responsible for diurnal patterns in precipitation, statistical analysis of several years of data also suggests similar patterns. Data from the Carolina Sandhills and the SGP were examined for the months of June through August from 2001-2006. Summers were examined in order to avoid the influence of synoptic forcing as the primary influence on convective initiation. A statistical analysis was performed on both datasets to determine if there was statistical significance between the amount of precipitation occurring during the day and during the night. At all of the stations with precipitation data in the SGP, there was more precipitation occurring at night than that occurring during the day, as evident from Figure 5.

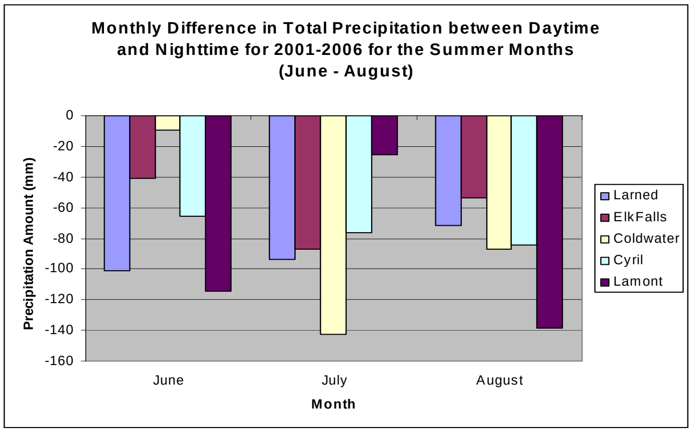

Figure 5. Precipitation difference between day and night precipitation (mm) for Larned, Elk Falls, Coldwater, Cyril and Lamont for June, July and August. A negative bar denotes more precipitation occurring at night.

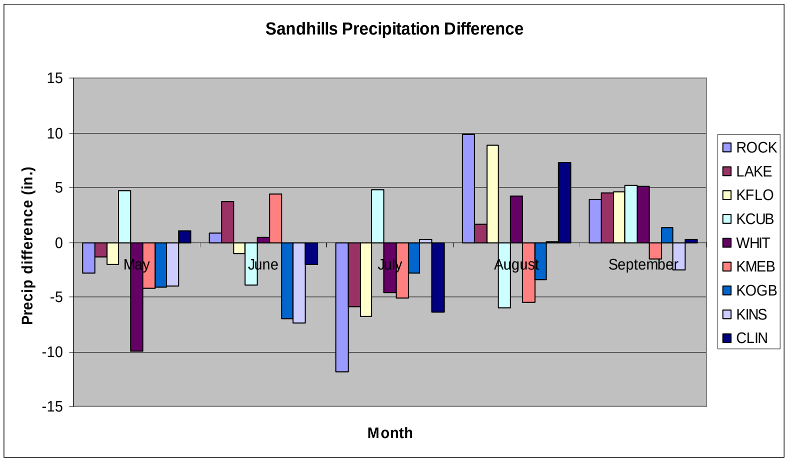

Figure 6. **Difference between day and night precipitation (mm) for 9 stations in the Carolina Sandhills for June, July and August. A negative bar denotes more precipitation occurring at night.**

The largest variations in precipitation were at the Coldwater, Kansas site in this case. Note that the patterns of the monthly difference in precipitation vary between stations. For example, the maximum difference at the Coldwater is in July, while the difference increases steadily at Cyril from June through August and decreases steadily at Larned from June through August. This possibly reflects the subtle differences between each station, even those with the same type of soil. The nine stations used for analysis in the Carolina Sandhills reflected the same trend in diurnal precipitation variation, with the most nocturnal precipitation occurring in July (Fig. 6). In this case, notice that this region has a pattern where most stations in the Sandhills have a peak amount of nocturnal precipitation during July, while most stations have more precipitation occurring during the day in June and August. In both regions, there is evidence in the long term that the sensible heat flux gradients have an impact on convective initiation. Statistical analysis was also performed on the data for both the regions. The level of significance for the analysis was set at 0.05; if the test returned values lower then this level, it was assumed that significant difference between day and night precipitation amounts to exist. For SGP, the analysis returned a significance value of 0.000149, indicating that there is significant difference between day and night precipitation amounts in the summer months. For the Carolina Sandhills, the precipitation difference was only significant in July, with a value of 0.0265. June and August showed no significant difference in day versus night precipitation amounts considering all the stations.

Forecast Validation

As noted previously, most forecast models do not consider directly the sensible heat flux gradients in the generation of convective precipitation although physics related to land surface processes should account for it. This is true for both regions considered in this study. Figure 7 is the percent error of three stations in the SGP. The model used for comparison is the North American Mesoscale model (NAM) with a resolution of 12 X 12 km. In this case Lamont has the largest percent error occurring in the 1200 CST model run, which encompasses sunset in the region.

The statistical analysis for differences between observed and forecast precipitations gave a value of 0.002, showing the difference between model forecast and observed precipitation to be significant in this model run for Lamont

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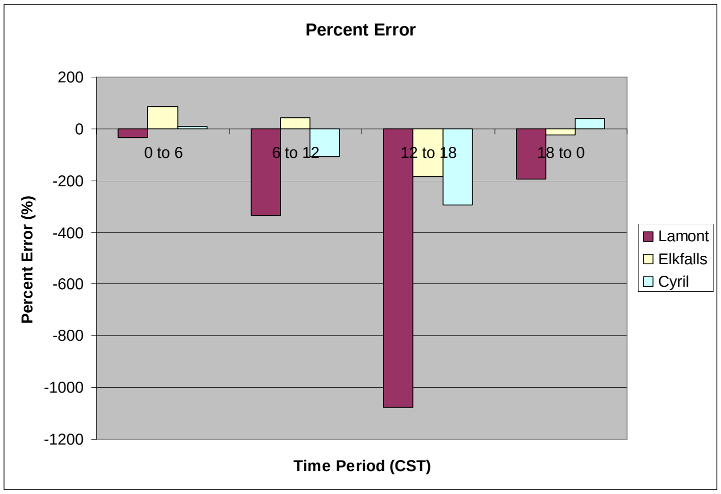

Figure 7. Percent error of the NAM model forecast precipitation for the SGP. A negative bar corresponds to the model over predicting the precipitation. Time periods are in CST.

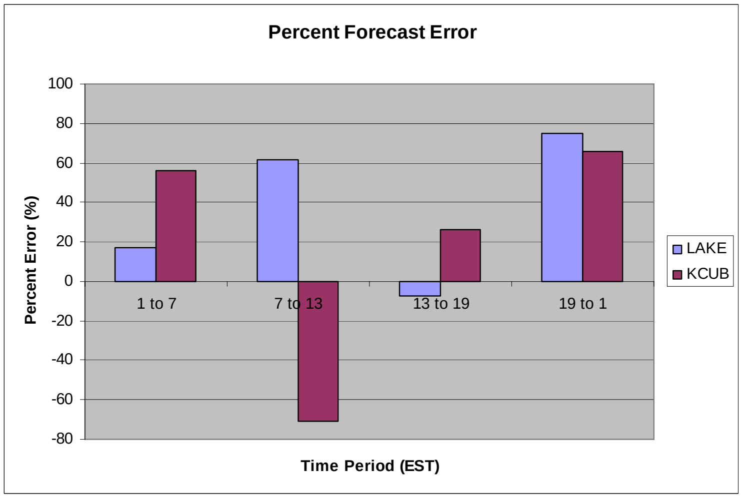

Figure 8. Percent error of the NAM model forecast precipitation for the Carolina Sandhills. A negative bar corresponds to the model over predicting the precipitation. Time periods are in EST.

Similar results were also found for the precipitation at the two stations in the Carolina Sandhills. The percent error chart for the Sandhills shows that the largest percent error at both stations considered for this section occurs after sunset, with the model strongly under predicting precipitation at both stations (Fig. 8). This trend continues for both stations during the entire night from 1900 EST to 0700 EST. However, the statistical analysis of observed versus forecast precipitation reveals that the station in Columbia, SC (KCUB) during the 19 EST model run is the only time and location with a value of 0.042.

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