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Influences of Land Surface / Land Use Characteristics on Precipitation Patterns over the Lower Mississippi Alluvial Plain

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Abstract

The lower Mississippi River alluvial valley in southeast Arkansas, northeast Louisiana, and northwest Mississippi is characterized by widespread agriculture with few urban areas. Land use is predominantly cultivated cropland with minimal topographic variation; however, the eastern edge of the alluvial valley is defined by a rapid, though small, change in elevation into a heavily forested landscape. This change in land use / land cover has been shown to potentially enhance precipitation through generation of a weak mesoscale convective boundary. This project defines the causes and influence of the land surface on associated precipitation processes by simulating a convective rainfall event that was influenced by regional surface features. Analysis was conducted using a high-resolution simulated dataset generated by the Weather Research and Forecasting (WRF) model. Results show that the strongest uplift coincides with an abrupt low-level thermal boundary, developed primarily by a rapid change from sensible to latent heat flux relative to the agricultural and forested areas, respectively. Additionally, surface heating over the cultivated landscape appears to destabilize the boundary layer, with precipitation occurring as air is advected across the land cover boundary and the associated thermal gradient. This information can be used to define and predict surface-influenced convective precipitation along agricultural boundaries in other regions where the synoptic environment is weak.

1. Project Overview

Soil type and vegetation play a key role in determining the dynamics of energy and moisture transport into the atmospheric boundary layer through spatial variations in evapotranspiration, albedo, and surface heat fluxes (Hong et al., 1995; Segal et al., 1988; Ookouchi et al., 1984; Rabin et al., 1990; Mahfouf et al., 1987; Boyles et al., 2007). These effects are well documented, and can occur in various climate zones given benign synoptic forcing. Research has shown that anthropogenic modification of spatial boundaries in land use / land cover through agricultural practices can have an influence on regional weather variability through these processes (Brown and Arnold, 1998). Additionally, agricultural land use can influence the dynamics of the boundary layer through variations in surface roughness over the growing season, effectively modifying existing sub-synoptic and mesoscale flow regimes by varying the intensity of turbulent mixing through the radix layer.

The energy, moisture, and turbulent fluxes all have strong influences on the generation and strength of mesoscale circulations, which can affect precipitation generation. As a result, variations in land use and/or soil type can lead to changes in regional precipitation patterns and associated water resources (Anthes, 1984). Regarding soil-type interfaces, several studies have demonstrated the role of the sand-clay soil boundary in eastern North Carolina (a.k.a., the "Sandhill Effect") on mesoscale surface convergence and convective precipitation (Boyles et al., 2007; Koch and Ray, 1997). Similar soil contrasts, along with distinct vegetation boundaries, exist within the lower Mississippi River alluvial valley in northwest Mississippi (known locally as the Mississippi Delta), and results from Dyer (2008) indicate that precipitation patterns in and around the Mississippi Delta may be influenced by distinct horizontal boundaries in soil type and/or land cover. Additionally, studies have shown that abnormal temperature variations in the region exist as a result of spatial variations in soil and vegetation (Raymond et al., 1994; Brown and Wax, 2007). These temperature effects could be an indicator of possible boundary layer modification through surface influences, resulting in the generation of mesoscale circulations and related localized precipitation.

Although the modification of atmospheric properties through surface characteristics occurs on a diurnal scale, seasonal variations in land cover and synoptic conditions play a role in the strength and extent of the influence. As a result, it is necessary to study the daily evolution of mesoscale convective processes while keeping in context the seasonal conditions of the region of interest. In general, the spatial extent of surface influenced atmospheric processes is of the same scale as the land cover discontinuity driving the circulation, with the advection of atmospheric features (i.e., cloud cover, precipitation, etc.) dependent on the regional synoptic wind field conditions. The modification of rainfall patterns over north Mississippi is on the order of 100 km downwind of the Mississippi Delta boundary (Dyer, 2008), which indicates that local influences play a dominant role in determining the circulation patterns related to the convective development. However, to better define the local variability in surface and atmospheric properties it is necessary to determine the characteristic spatial and temporal scale of the land cover boundary and regional meteorological conditions.

The primary objective of this study is to identify the surface influences on mesoscale convective precipitation generation in northwest Mississippi during the warm season, especially along the eastern boundary of the lower Mississippi River alluvial valley (a.k.a., Mississippi Delta). Due to the highly agricultural characteristic of the landscape in this region and the associated sensitivity to water resources, it is important to identify potential causes for precipitation modification due to land surface characteristics during the warm season when mesoscale processes dominate and water availability is critical. The study employs numerical weather model simulations to identify surface and lower atmospheric processes related to convective precipitation generation. Results of this project provide detailed information regarding precipitation patterns over the Mississippi Delta during the warm season, allowing agriculture and water resource managers to make more accurate local-scale predictions and assessments of water supply and availability.

2. Data and Methods

To better understand the influence of land cover and/or soil boundaries on rainfall distribution in the Mississippi Delta, it is necessary to perform an analysis of convective forcing mechanisms and the associated precipitation generation. Due to the lack of high-resolution observation data in the region, this type of study is best performed through numerical modeling;

therefore, this project utilizes the Weather Research and Forecasting (WRF; Skamarock et al., 2005) model to simulate regional surface and atmospheric mechanisms and processes related to rainfall generation. WRF has been used in various research applications dealing with convective systems and initiation (Done et al., 2004; Schumacher and Johnson, 2005; Trier et al., 2006; Clark et al., 2007; Lim et al., 2008) as well as precipitation distribution and prediction (Miller and Weisman, 2002; Kusaka et al., 2005). Research applications using WRF to simulate heavy precipitation related to flooding have also been conducted in various regions around the world, including Taiwan (Lin et al., 2005) and Texas (Lowrey and Yang, 2008). Additionally, modeling studies have been carried out in various locations to examine the sensitivity of mesoscale circulations to surface characteristics (Mahfouf et al., 1987; Boyles et al., 2007; Hong et al., 1995).

Dyer (2010), using observed and remotely-sensed cloud and precipitation data, showed that precipitation over the southeast US, and the Mississippi Delta in particular, shows a distinct seasonal pattern such that the warm season is dominated by surface-initiated convection driven by small-scale thermodynamic boundaries. The regional variations in precipitation patterns were on the order of 100-km relative to the Mississippi Delta, with convective initiation and rainfall generation occurring on a diurnal temporal scale. However, the surface discontinuity and related convective circulation is on the order of 10-km; therefore, high spatial resolution data is required to assess the influence of surface properties on atmospheric processes.

To analyze the atmospheric mechanisms associated with this pattern, a day was chosen (September 9, 2006) that displayed regional convective precipitation generation and weak synoptic conditions (details on related atmospheric conditions are included in Section 4.1), indicating that the precipitation was a result of near-surface thermodynamic forcing mechanisms. For the study day, WRF was run for a 24-hour period beginning at 0000 LST with 30-minute temporal resolution over a domain centered on the eastern boundary of the Mississippi Delta (Figure 1). The model surface and atmospheric horizontal resolution was set at 3-km with 60 vertical atmospheric levels (logarithmic from 1013 hPa – 100 hPa), which allowed for adequate simulation of convective processes without the need for a convective parameterization scheme. Initial and boundary conditions were provided by the North American Regional Reanalysis (NARR) dataset, which has a 32 km horizontal resolution, 50 hPa vertical resolution, and 3 hour temporal resolution (Mesinger et al., 2005). Subsequent WRF model parameterizations were chosen to best simulate warm-season, surface-based, mesoscale processes. These include the Lin et al. (1983) microphysics scheme, the Mellor-Yamada-Janjic boundary layer scheme, the 4-layer Noah land surface model (Chen and Dudhia, 2001), the rapid radiative transfer model (RRTM) scheme for longwave radiation (Mlawer et al., 1997), and the Dudhia (1989) scheme for shortwave radiation. The time step for the radiation schemes was set at 5 minutes.

Although other parameterizations schemes may lead to different model responses, a sensitivity analysis using various parameterizations was beyond the scope of this study. However, Trier et al. (2010) showed that considerable uncertainty exists in the strength and timing of convective precipitation generation within the WRF model during events influenced by surface-atmosphere energy and moisture exchanges. This uncertainty is based on the turbulent surface exchange strength, which is related to vegetation height and surface roughness; therefore, future research plans include an investigation of WRF using a parameter ensemble approach to verify which schemes and surface exchanges coefficients are most applicable for simulation of convective precipitation in the southeast US.

Verification of the WRF simulations is accomplished using a variety of observed and estimated data sources. Precipitation data are verified against 4x4 km precipitation estimates from the Multi-Sensor Precipitation Estimator (MPE) algorithm, which are derived from hourly WSR-88D data (Weather Surveillance Radar – 1988 Doppler) and hourly surface-based observations from the hydrometeorological automated data system (HADS) network (Fulton, 2002). Simulated cloud cover is compared with visible imagery from the Geostationary Operational Environmental Satellite (GOES) platform, while surface meteorological characteristics and soil properties from Soil Climate Analysis Network (SCAN) stations in and adjacent to the Mississippi Delta are used to verify related WRF-simulated variables (U.S. Department of Agriculture, 2010; Figure 1).

3. Project Results

3.1 Verification of WRF Simulation

Cloud cover patterns over the study area for the morning of September 9, 2006 (1000 LST) initially showed generally clear conditions over Arkansas and northern Louisiana with an increase in convective cloud cover to the south and east (Figure 2a). Additionally, a thin line of convective clouds were apparent along the southeastern boundary of the Mississippi Delta. The WRF simulated cloud cover reflects this pattern well, showing an increase in cloud cover to the southeast of the study area and a line of clouds along the eastern boundary of the Mississippi Delta (Figure 2b).

As the day progresses, observed cloud cover becomes more pronounced along the eastern boundary of the Mississippi Delta and east along the Mississippi/Alabama border, with the extent of the cloud area increasing as convection strengthens (Figure 2c,e). This pattern is maintained through the day, such that by late afternoon (1600 LST; Figure 2g) the most dense cloud cover roughly exists along the eastern edge of the Mississippi Delta and northwestern Alabama. Although the WRF simulated cloud patterns show some variability relative to the observed cloud cover, the same general patterns exist. At 1200 LST (Figure 2d) the most dense cloud cover follows a line roughly parallel to the Mississippi/Alabama border. As the day progresses, a secondary line of convective cloud cover is apparent along the eastern edge of the Mississippi Delta with a definite clear area becoming more defined through the afternoon (Figure 2f,h).

The agreement in the observed and simulated cloud cover over the Mississippi/Alabama border and the eastern edge of the Mississippi Delta indicates that WRF is able to recognize and produce reliable convective cloud patterns over the study period. This is critical due to the importance of the cloud cover in the recognition of a convective mesoscale boundary over the study area, as well as the importance of cloud location and extent in association with the simulated surface heat fluxes.

With regard to precipitation patterns, early in the day on September 9, 2006 both the observed and simulated precipitation patterns agree well, despite the minimal amount and extent of rainfall (Figure 3a-b). Since the rainfall associated with the mesoscale convective boundary initiated along the eastern boundary of the Mississippi Delta is of primary interest in this study, it is critical that the initial timing and location of the precipitation be simulated well. By noon on the study day, the observed precipitation changes little; however, the WRF simulated precipitation patterns begin to show some deviation (Figure 3c-d). Although the rainfall along the Mississippi Delta boundary is maintained, scattered rainfall is generated towards the east that is not mirrored in the observed record. The reason for the region of enhanced rainfall may be associated with false convective initiation in the region of maximum low-level moisture advection, which is reflected in the simulated cloud cover at the same time period (Figure 2d).

As the afternoon progresses the region of enhanced simulated rainfall to the east of the study area is maintained, although the extent continually decreases (Figure 3f,h). More important, however, is the continuation of rainfall along the eastern boundary of the Mississippi Delta and the lack of rainfall to the west of the study area. The multi-sensor precipitation estimates show an enhancement of rainfall intensity and extent along the eastern boundary of the study area through the day, with additional precipitation in northwest Alabama late in the afternoon (Figure 3e,g). Although the WRF simulation indicates a precipitation boundary along the Mississippi Delta boundary, the rainfall in northeastern Mississippi and northwestern Alabama is maintained throughout the day. The exact reasons for this early initiation of precipitation to the east of the study area is likely due to early initiation of convection through enhanced low-level moisture inflow within the model domain. However, the agreement between simulated and observed precipitation patterns along the eastern boundary of the Mississippi Delta is strong enough to accept the WRF simulated atmospheric conditions and continue with further analysis.

Verification of WRF simulated meteorological and surface conditions at select points over the study region using information from SCAN stations shows that near-surface conditions are relatively well resolved (Figure 4a-b). Although the agreement between the observed and modeled time series of temperature and dew point do not match exactly, the relative pattern and magnitude of the variables is maintained over the course of the study period. Specifically, the slightly lower temperature and higher dew point over the forested site relative to the sites within the Mississippi Delta indicate that the simulated surface energy and moisture fluxes are representative of actual conditions.

An examination of soil temperature and moisture shows that although the relative patterns between the simulated and observed data are in agreement, there is some discrepancy in the magnitude (Figure 4c-d). However, it should be noted that the values used for verification are not the same, such that the observed values from the SCAN sites are for soil conditions at 2-cm, while the WRF simulated values reflect average soil conditions from 2 – 10cm. As a result, the general patterns of the time series should match while the magnitudes may be substantially different. The graph of soil temperature (Figure 4c) shows that both the observed and simulated time series show the same relative minimum in the early morning and maximum at sundown, which is reasonable. Additionally, despite the difference in magnitude, neither data source shows much variation in soil moisture over the time period (Figure 4d). These results provide verification that the WRF model is satisfactorily representing soil temperature and moisture patterns over the study period; however, due to the difference in values being compared (2-cm vs. 2-10 cm average), the magnitude of the simulated values cannot be readily verified.

3.2 Synoptic Overview

The day used in this study, September 9, 2006, was previously defined as synoptically benign by Dyer (2010) based on low-level and mid-level wind speeds from regional sounding data. Under conditions where dynamic lifting mechanisms are negligible, convective precipitation is expected to be generated primarily by mesoscale thermodynamic boundaries set up by differential energy and moisture fluxes at the surface. However, the ability for pre-existing boundaries such as outflow boundaries or dry lines to trigger convection can make analysis of surface influences on atmospheric properties difficult. As such, even when synoptic forcing mechanisms are weak the complexity and limited scale of mesoscale convective processes makes it difficult to accurately define the location and timing of precipitation in response to surface energy fluxes.

To verify that the study period was characterized by weak regional dynamic forcing mechanisms with no pre-existing moisture or thermal boundaries, it is necessary to diagnose the general atmospheric conditions over the region. Using the 32-km North American Regional Reanalysis (NARR) dataset, meteorological characteristics at the surface, 850-hPa, and 300-hPa were analyzed to show that conditions on and prior to September 9, 2006 over the lower Mississippi River valley were susceptible to surface energy and moisture influences, especially along the eastern edge of the Mississippi Delta.

Although surface and atmospheric conditions over the study region show considerable variability during the warm season, September 9, 2006 showed minimal influence from synoptic or pre-existing mesoscale forcing mechanisms. Several days prior to the study period an upper-level trough moved across the study region (Figure 5 a-b), followed by a zonal flow pattern over the lower Mississippi river valley on September 8-9 (Figure 5c-d). Near the end of the study period a weak jet max developed to the west of the Mississippi Delta (Figure 5d). Although the dynamic lifting mechanisms associated with this upper-level pattern on September 9, 2006 are not strong enough to generate low-level vertical motion (not shown), the upper-level divergence pattern could help to enhance surface-based convection by helping to remove mass from the atmospheric column. As a result, the upper-level synoptic features during the study period do not appear to be the source of the surface-based convection, but may play a role in the maintenance of convective cells generated through other mechanisms.

Low-level synoptic conditions prior to the study period are roughly barotropic, with flow from the north-east on September 6 (Figure 6a) weakening through September 7 (Figure 6b). Wind and temperature patterns from September 8-9 (Figure 6c-d) show a gradual transition to south-southeasterly flow over the study region, leading to low-level warm air advection over the lower Mississippi River valley. By the evening of September 9 a slight zonal temperature gradient was in place along the eastern edge of the Mississippi Delta (Figure 6d) due to the advection of warm air to the west over Arkansas and northern Louisiana. It is possible that the low-level temperature gradient is the cause of the surface based convection during the study period; however, the orientation of this gradient along the eastern boundary of the Mississippi Delta could be a result of surface energy and/or moisture fluxes influencing atmospheric conditions. Although the cause and effect of this pattern is difficult to define using the 32-km synoptic data, it is necessary to look at regional surface conditions to verify that surface and low-level patterns coincide.

As with the wind field at 850-hPa, surface flow on September 8 – 9 is south-southeasterly across the lower Mississippi River valley (Figure 7). However, despite the southerly flow there is an area of relatively warm, dry air to the northwest of the Mississippi Delta on September 8 (Figure 7a,c) that decreases in extent into September 9 (Figure 7b,d). This area is evident at 850-hPa on September 9 (Figure 6d), where the eastern edge of the moisture and temperature gradient closely follows the edge of the Mississippi Delta at the surface. Interestingly, although the spatial extent of the warm, dry low-level air mass changes considerably from September 8 to 9, the gradient at the surface remains relatively fixed along the eastern boundary of the Mississippi Delta. This implies that surface conditions along the boundary of the Mississippi Delta are influencing atmospheric conditions on and prior to September 9, and that pre-existing synoptic and/or mesoscale boundaries are most likely not responsible for the generation of convective precipitation during the study period.

Precipitation patterns for the days leading up to September 9, 2006 show normal warm-season scattered rainfall over the study region (not shown); however, none of the rainfall appears to be of a high enough magnitude to modify soil moisture conditions along the Mississippi Delta boundary. As a result, the modification of surface soil moisture gradients based on rainfall leading up to September 9, 2006 is considered minimal. It is interesting to note, however, that precipitation patterns for the days leading up to September 9 show a general lack of rainfall over the Mississippi Delta and a regional maximum directly to the east along the Mississippi-Alabama border. This supports the argument that convective boundaries developing due to surface heterogeneities in northwest Mississippi are influencing local precipitation generation.

3.3 Analysis of WRF Simulation

Analysis of meteorological conditions using the 32-km NARR dataset indicates that surface characteristics within the Mississippi Delta may be influencing low-level atmospheric properties; therefore, it is necessary to utilize the 3-km WRF simulation to identify and analyze the local-scale factors causing this influence. Specifically, atmospheric factors related to vertical thermodynamic stability over the study region must be investigated to define the mechanisms responsible for the initiation of convection and precipitation generation.

The first indication of surface influences on lower atmospheric processes over northwest Mississippi on September 9, 2006 occurs as differential surface heating within the lower

Mississippi River valley causes near-surface (1000-hPa) air temperatures to increase relative to adjacent regions in the early afternoon (1400 LST; Figure 8a). At the same time, moisture advection from southeasterly surface winds lead to a relatively tight low-level humidity gradient along the eastern boundary of the Mississippi Delta (Figure 8b). The same general thermal and moisture pattern exists at 850-hPa (Figure 8c-d); however, the area of highest temperatures at this level covers a smaller area over the Mississippi-Louisiana border and west-central Mississippi. As a result, the thermal gradient to the east becomes weaker but is more confined to the central Mississippi Delta. Likewise, the moisture gradient becomes more clearly defined along the eastern border of the Mississippi Delta.

Further aloft at the 700-hPa level the thermal pattern over the study region is reversed, such that there is a temperature minimum over the lower Mississippi River valley with a rapid increase to the east and west (Figure 8e). This change in horizontal temperature gradient, where the relative position of the gradient remains stationary while the direction of the gradient changes with height, implies that there is a surface influence over the region driving the low-level energy flux and associated thermal patterns. If advective processes were the cause of the temperature gradient there would most likely be a change in position with height dependent on the velocity of the horizontal winds, while the relative strength of the gradient would be based on upwind thermal features.

Regarding the moisture patterns over the study region, the gradient at 700-hPa is shifted to the west relative to the lower levels (Figure 8f), being roughly positioned along the western edge of the region of cooler air over the lower Mississippi River valley. In fact, the thermal and moisture gradients at 700-hPa are closely aligned in southeast Arkansas, which could indicate that the strength of the surface influence on lower atmospheric properties is beginning to weaken while the influence of the southeasterly flow and moisture advection is beginning to dominate. It should be noted that convective cloud cover was observed and simulated to the east of the Mississippi Delta by 1400 LST on the study day (Figure 2e-f), indicating that convective processes caused surface moisture to be moved vertically, thereby increasing the lower-level humidity values and horizontal moisture advection over the Mississippi Delta.

The warm, dry conditions at the surface over the Mississippi Delta on September 9, 2006 along with warm, moist air aloft indicates a statically stable atmospheric column; therefore, convective initiation required either an external triggering mechanism or a change in surface and/or low-level atmospheric conditions. For the study period of September 9, 2006, both of these conditions likely come about due to modification of atmospheric properties through surface heat fluxes. In general, the lower Mississippi River alluvial valley is characterized by dark, fertile clay soils and low cropland, while vegetation to the east consists of relatively dense broadleaf and evergreen forests in loamy soils (Figure 1). September is near the end of the growing season in the region; therefore, there is a mix of harvested and non-harvested crops. Additionally, local water resource management requires an end to agricultural irrigation in August (Pennington, 2008). As a result, the amount of evapotranspiration over the Mississippi Delta is much lower than that over the surrounding forested land, leading to considerable variations in the surface heat fluxes.

Figure 9 shows the relatively stark contrast in the sensible and latent heat flux between the lower Mississippi River valley and adjacent regions during the course of the day on September 9, 2006. Even in the morning hours there is a noticeable minimum in the latent heat flux over the valley, which becomes more pronounced through the afternoon. The opposite is true with the sensible heat flux, which shows a general maximum over the lower Mississippi River valley from late morning through early afternoon when solar heating is greatest. The relatively cloud-free conditions over the Mississippi Delta exacerbate this pattern by maximizing the surface heating over the area, thereby strengthening the gradient along the eastern border of the Mississippi Delta where scattered cloud cover exists beginning in the early afternoon.

The ramifications of a higher sensible heat flux in the Mississippi Delta relative to surrounding areas is that surface temperatures will increase faster since there is less evapotranspiration to offset the radiation flux. As a result, lower atmospheric temperatures over the cultivated alluvial valley will increase relative to surrounding areas, causing a dome of warm air to develop due to decreased evapotranspiration over the agricultural surfaces relative to the forested lands to the east. This phenomenon is minimized in the morning when differential surface heating is minimized (Figure 10a), but is easily recognized in the early afternoon once the surface heat fluxes have intensified (Figure 10b).

This dome of warm air can act to destabilize near-surface air advected from outside the region, as is the case for the September 9, 2006 study period where southeasterly flow exists in the lower levels. The relatively warm air over the alluvial valley has a dominant influence during the late morning and early afternoon, as seen by the elevated low-level temperatures (Figure 8a,c). As convection initiates along this boundary, low-level moisture within the boundary layer from the east is utilized for latent heat release and precipitation generation, leading to deeper convection and eventually localized convective rainfall.

In addition to convective uplift due to moisture advection and low-level thermal boundaries, small-scale dynamic forcing is evident along the eastern edge of the Mississippi Delta in the form of near-surface speed confluence (see wind vectors in Figure 8b). The confluence is strongest in late morning, which is likely a result of a deepening of the boundary layer over the Mississippi Delta region through the early afternoon causing a decrease in local winds due to turbulent mixing. However, the combination of the thermodynamic and dynamic factors combines to cause low-level convection to intensify along the eastern Mississippi Delta interface before the initiation of a convective precipitation boundary in the afternoon.

While the southeasterly low-level flow causes near-surface air to become unstable along the eastern boundary of the Mississippi Delta where the positive thermal gradient is strongest, westerly flow aloft acts to advect the convective cells and associated precipitation to the east (Figure 8f). The westerly flow also augments the export of mass from the study area as the convective boundary develops, helping to strengthen and maintain the localized convection and vertical energy and moisture transport. This indirectly leads to an easterly transport of moisture from the study area, which can be considered a source of interbasin water transport.

4. Conclusions

The lower Mississippi River alluvial valley, known regionally as the Mississippi Delta, is characterized by widespread agricultural vegetation and clayey soils, while areas adjacent are heavily forested with loamy soils (Figure 1). The abrupt transition between the surface types leads to high spatial variations in the local energy and moisture balance, which plays a role in the intensity of the sensible and latent heat fluxes due to variations in evapotranspiration and albedo. On days when large-scale synoptic wind speeds are weak, vertical development is largely driven by low-level thermodynamic mechanisms related to these heat fluxes; therefore, the influence of surface conditions on atmospheric processes is substantial.

As shown in this project, local discontinuities in near-surface atmospheric properties during periods of benign synoptic forcing can lead to the development of mesoscale convective boundaries and localized precipitation. However, the specific role of surface conditions in the timing and extent of the convection and convective precipitation over the Mississippi Delta is not well understood. Using the Weather Research and Forecasting (WRF) model, a high resolution simulation was done for September 9, 2006, a day characterized as having weak synoptic conditions and the development of convective precipitation along the eastern boundary of the Mississippi Delta. This information was used to define and describe the surface characteristics responsible for modification of lower atmospheric properties and the associated influence on the development of a mesoscale convective boundary.

Results of the WRF simulation indicate that spatial variations in the sensible and latent heat fluxes relative to areas inside and adjacent to the Mississippi Delta are primarily responsible for atmospheric modification through surface processes. Specifically, a relatively high sensible heat flux inside the Mississippi Delta led to the development of a low-level region of warm air, while high latent heat values to the east over the forested regions helped to maintain a thermal gradient along the boundary of the study area. The thermal gradient was most intense in the early afternoon near the surface (1400 LST), covering most of the lower Mississippi River alluvial valley in northwest Mississippi and southeast Arkansas. The spatial extent of the dome of warm air decreased with height before reversing direction at 700 hPa, at which point the atmospheric temperatures were lower over the Mississippi Delta relative to adjacent regions.

Low-level southeasterly flow interacting with the horizontal thermal gradient near the surface caused a decrease in the vertical static stability over the region, which was augmented by the rapid decrease in atmospheric temperatures with height over the study area. Increased moisture advection along with the development of a mesoscale convergence boundary strengthened the convection along the eastern edge of the Mississippi Delta, leading to deep convection and the generation of convective rainfall. Subsequent westerly flow in the mid-levels during the study period acted to transport the convective cloud cover and associated precipitation to the east, effectively leading to dry conditions over the study area as the moisture was transported eastward.

The direct implications of the surface-based modification of atmospheric properties shown in this study include an indication of regional climate modification due to local anthropogenic causes. The transition from forest to agricultural vegetation over the Mississippi Delta directly affects the energy and moisture fluxes into the lower atmosphere, leading to variations in the patterns of warm season precipitation generation. In essence, the development of a mesoscale convective boundary along the eastern edge of the Mississippi Delta allows for an atmospheric pathway for interbasin water transport. This leads to a net removal of moisture from the agricultural region due to increased evapotranspiration and decreased precipitation. Although the use of a single day to study the influence of surface characteristics on convective rainfall generation does not take into account seasonal or annual variations in land cover or atmospheric properties, the fact that warm season surface conditions can modify local precipitation patterns introduces an area of future research that is critically important to agricultural and water resource managers.

The results of this study show that land surface incongruities, such as soil and vegetation boundaries, can cause horizontal variations in the latent and sensible heat fluxes large enough to influence surface-based atmospheric convection. Such is the case over the lower Mississippi River alluvial plain, where low-level moisture advection from the southeast, combined with an increased sensible heat flux over the Mississippi Delta, leads to convective precipitation initiation. This process is similar to that of the urban heat island, although it is often of a larger extent due to the greater extent of rural and agricultural areas throughout the US. Such precipitation modifications, although minimal relative to mean annual precipitation, could lead to variations in warm-season rainfall distribution. This may potentially lead to water resource issues due to the sensitivity of agriculture to local-scale precipitation patterns during the warm season.

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Figures

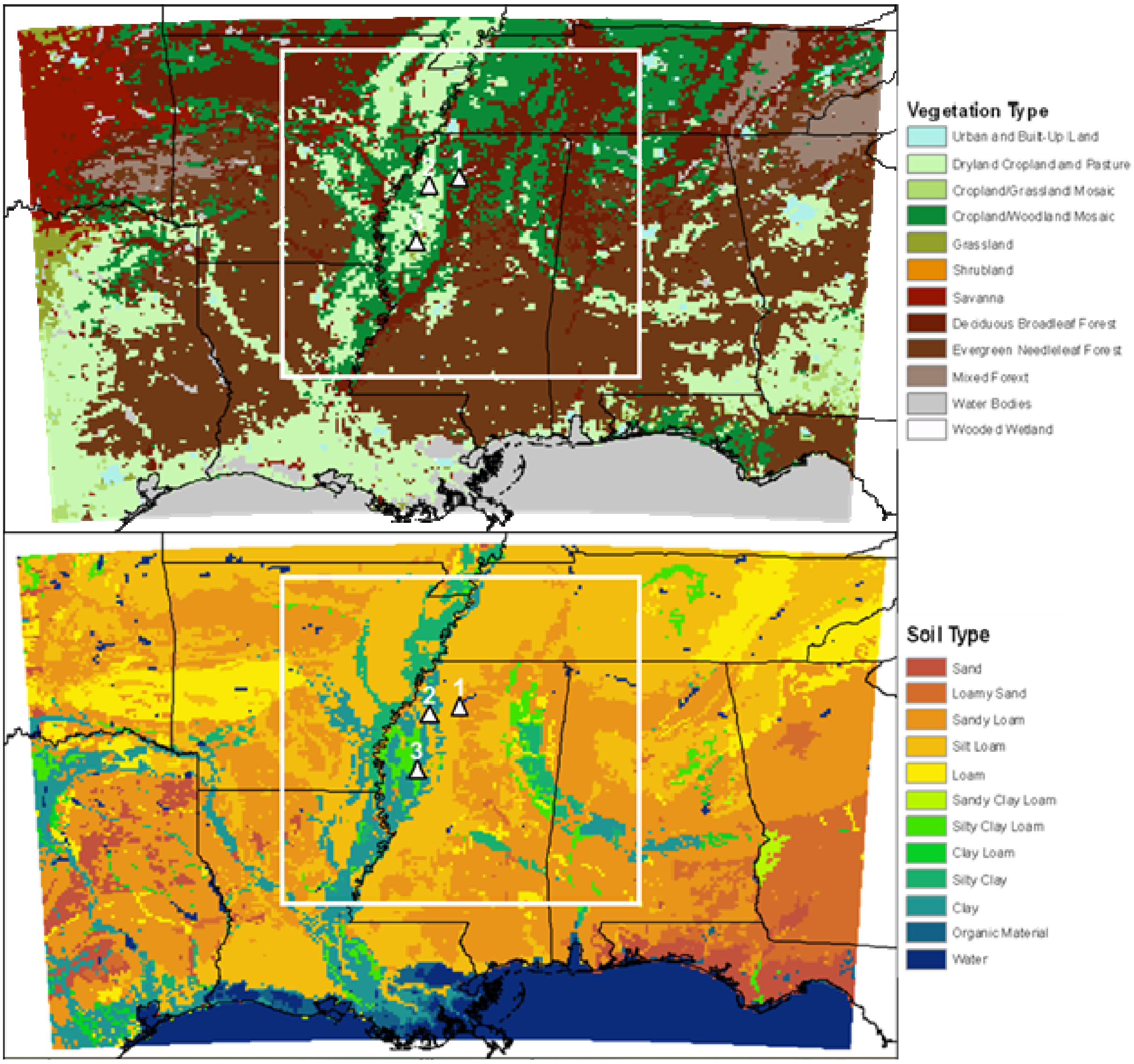


Figure 1. Vegetation and soil type over the southeast US derived from USGS 1-km spatial fields. The white box denotes the extent of the 3-km WRF domain used for analysis. The white triangles denote SCAN sites used for verification, with station labels as follows: 1 – Goodwin Creek Timber, 2 – Vance, and 3 – Beasley Lake.

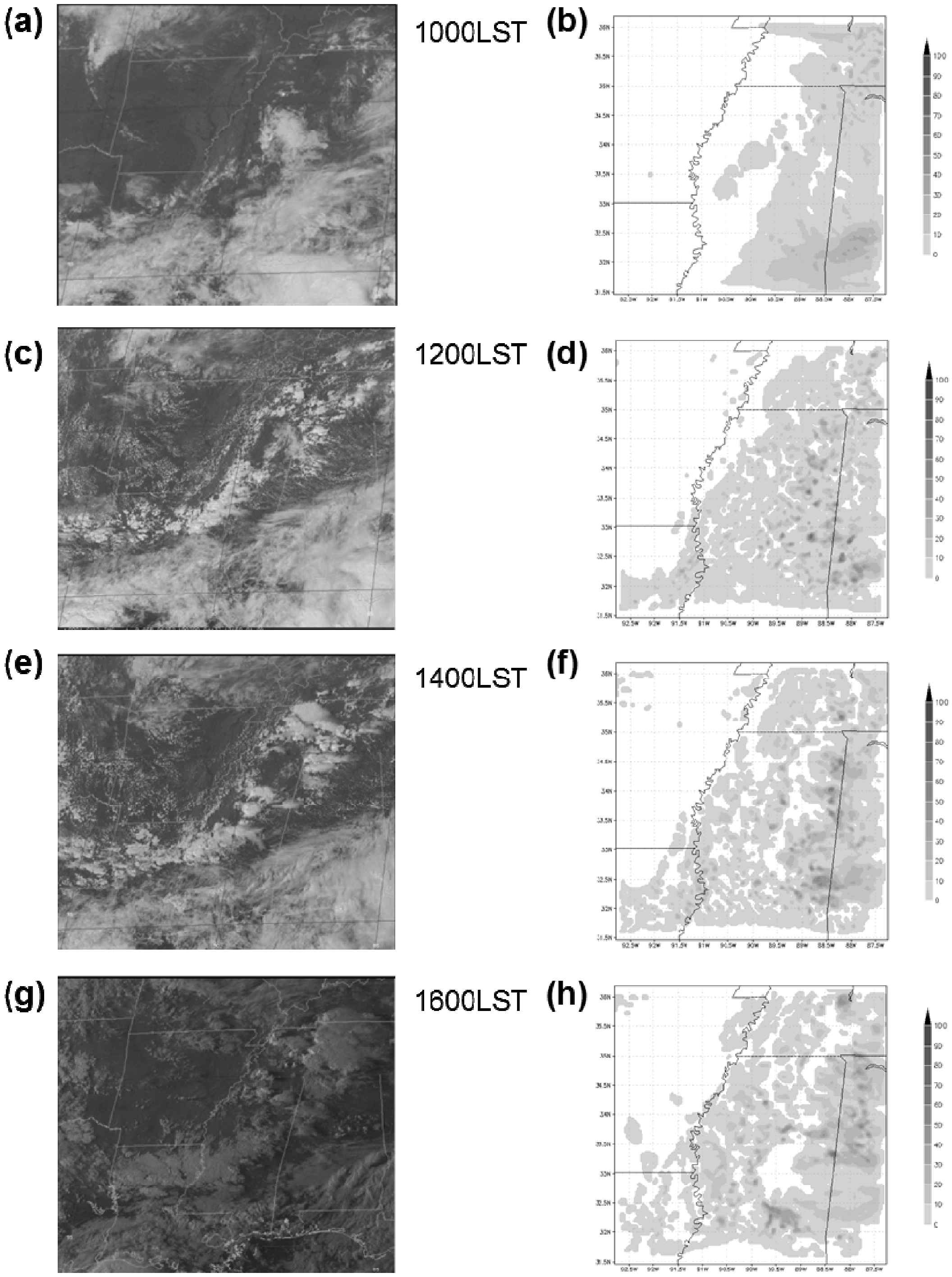


Figure 2. GOES visible imagery and WRF simulated cloud cover (%) at 1000 LST (panels a-b, respectively), 1200 LST (panels c-d, respectively), 1400 LST (panels e-f, respectively), and 1600 LST (panels g-h, respectively).

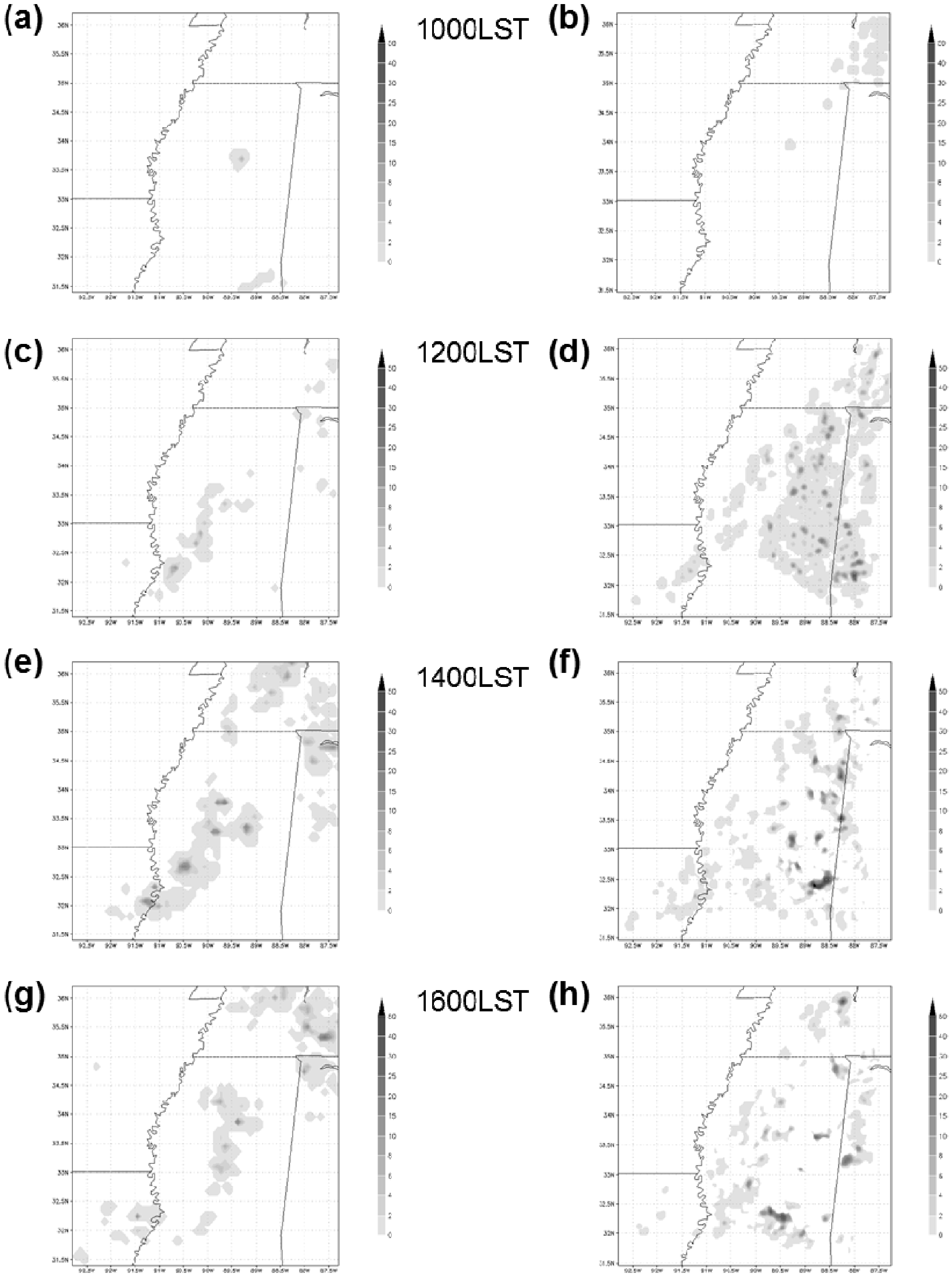


Figure 3. Multi-sensor estimates and WRF simulated values of precipitation (mm) at 1000 LST (panels a-b, respectively), 1200 LST (panels c-d, respectively), 1400 LST (panels e-f, respectively), and 1600 LST (panels g-h, respectively).

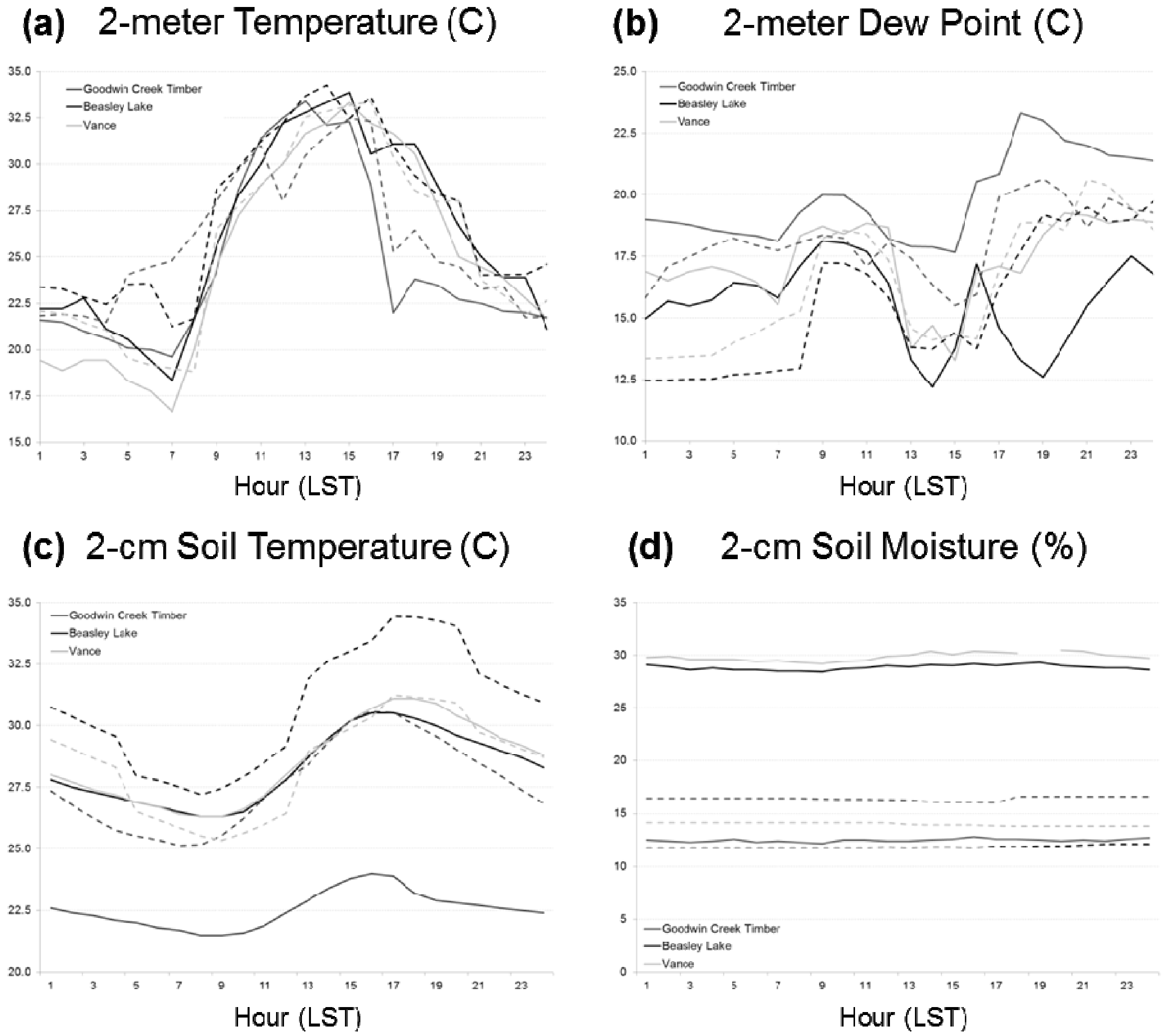
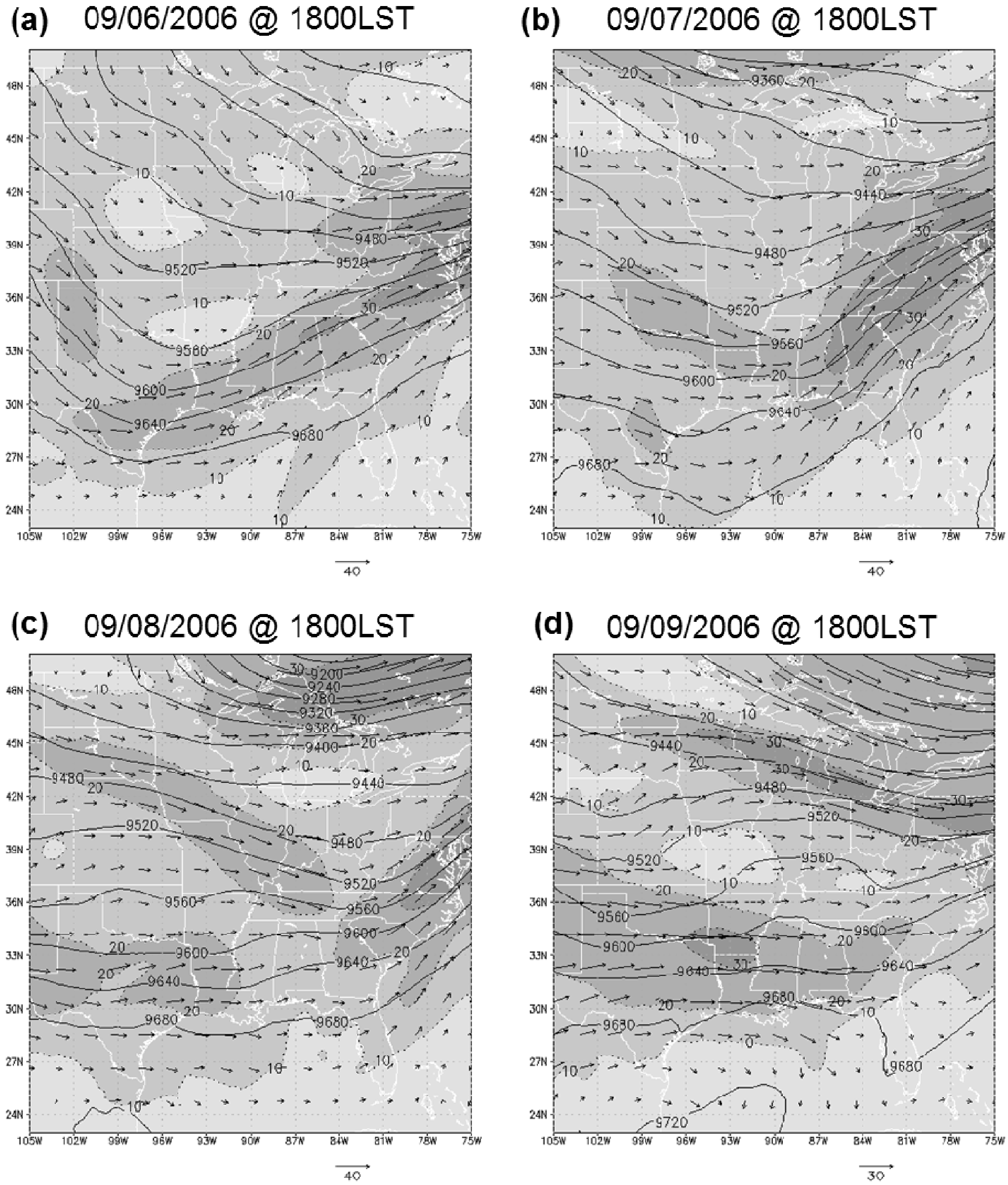


Figure 4. WRF simulated (dashed line) and observations from the SCAN network (solid lines) for (a) 2-meter temperature, (b) 2-meter dewpoint, (c) soil temperature at 2-cm depth (2-10 cm average for simulated values), and (d) soil moisture at 2-cm depth (2-10 cm average for simulated values).



(a) 09/06/2006 @ 1800LST

(b) 09/07/2006 @ 1800LST

(c) 09/08/2006 @ 1800LST

(d) 09/09/2006 @ 1800LST

Figure 5. 300 hPa heights (gpm; solid lines), wind magnitude (m/s; dotted lines and shading) and wind vectors at 1800Z on Sept. 6 – 9, 2006 (panels a – d, respectively).

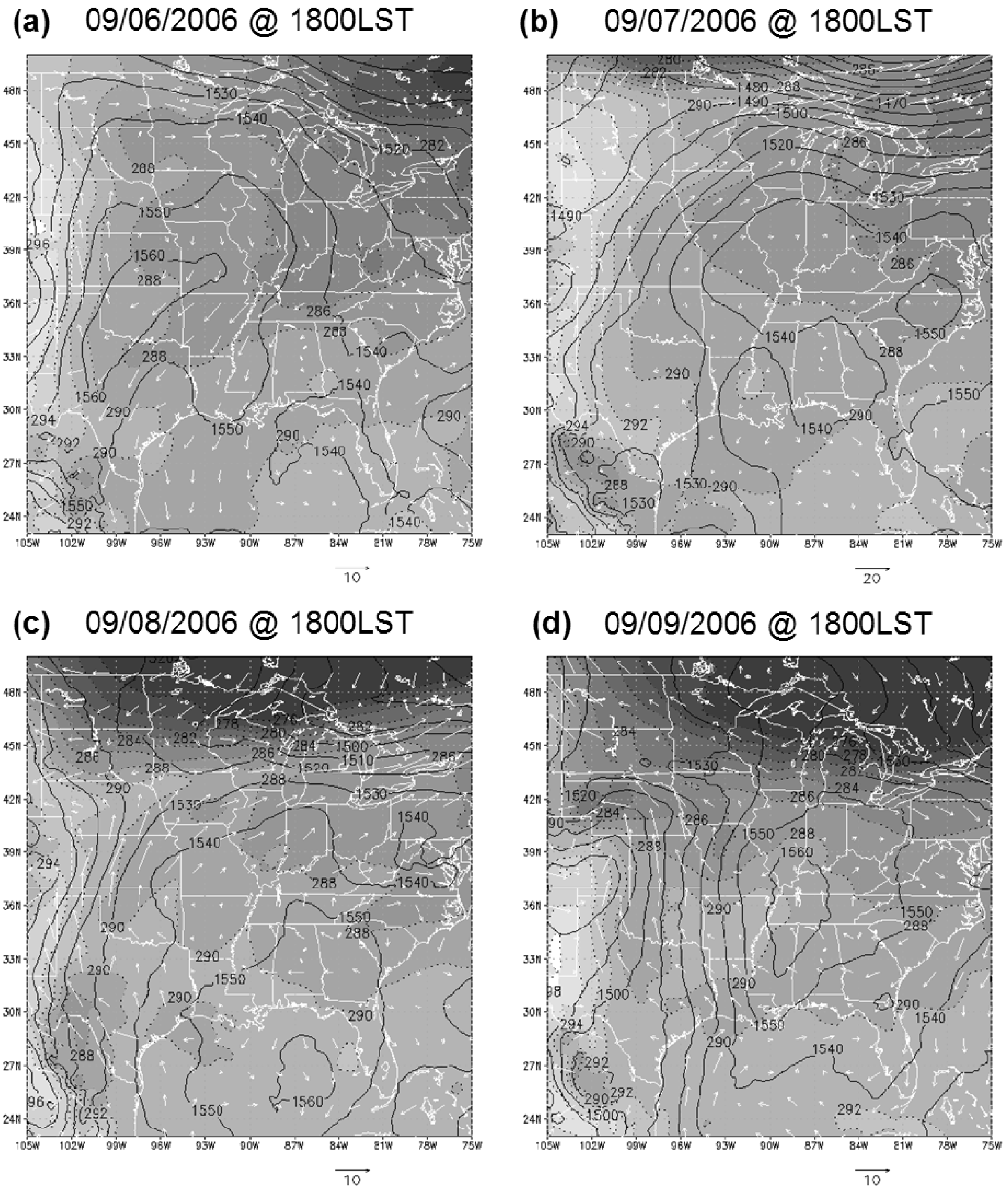
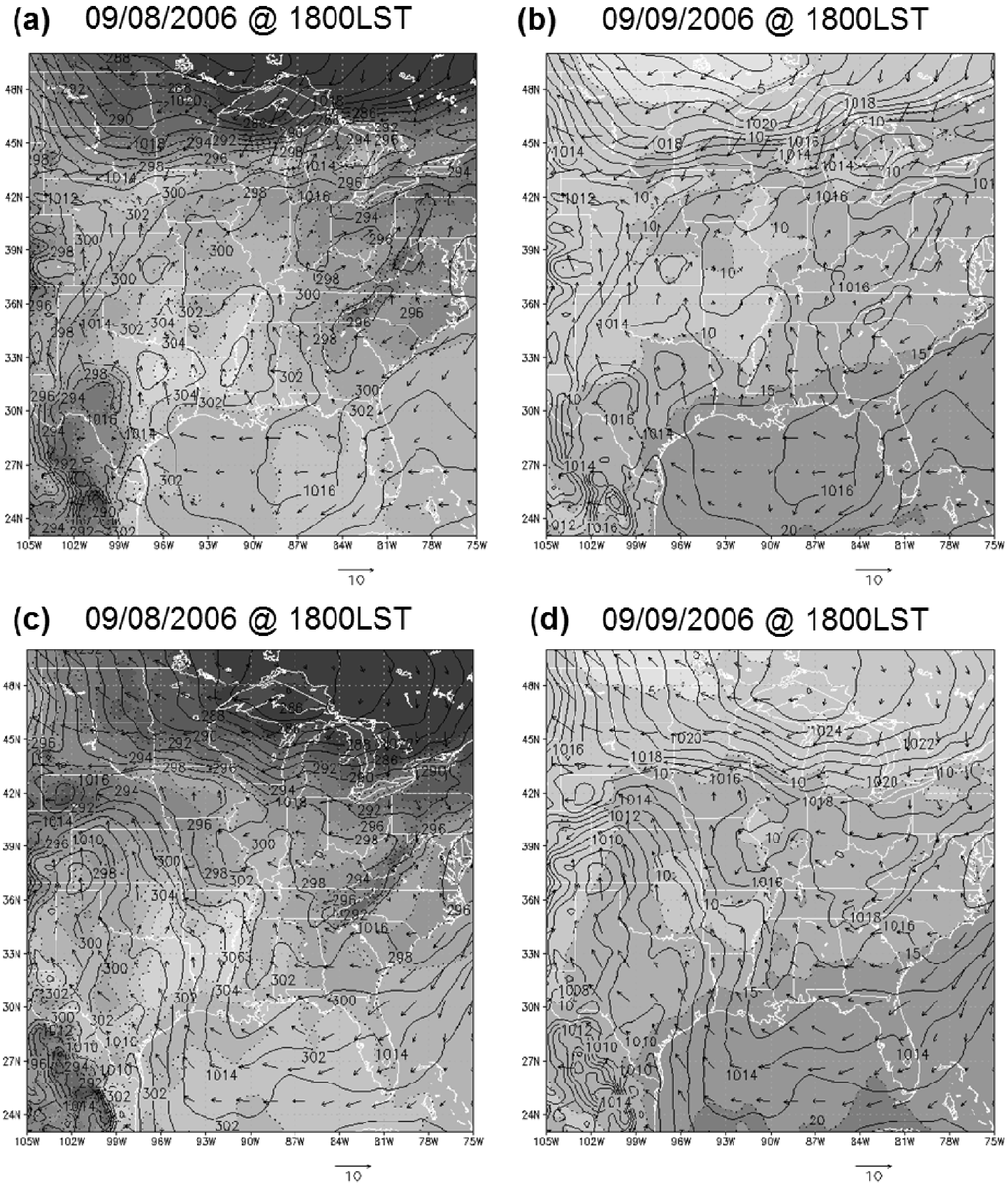


Figure 6. 850 hPa heights (gpm; solid lines), temperature (K; dotted lines and shading), and wind vectors for 1800Z on Sept. 6 – 9, 2006 (panels a – d, respectively).



(a) 09/08/2006 @ 1800LST

(b) 09/09/2006 @ 1800LST

(c) 09/08/2006 @ 1800LST

(d) 09/09/2006 @ 1800LST

Figure 7. Mean sea level pressure (hPa; solid lines), wind vectors (m/s), and temperature (K; dotted lines and shading) [a,c] or specific humidity (g/kg; dotted lines and shading) [b,d] for Sept. 8-9, 2006 at 1800Z.

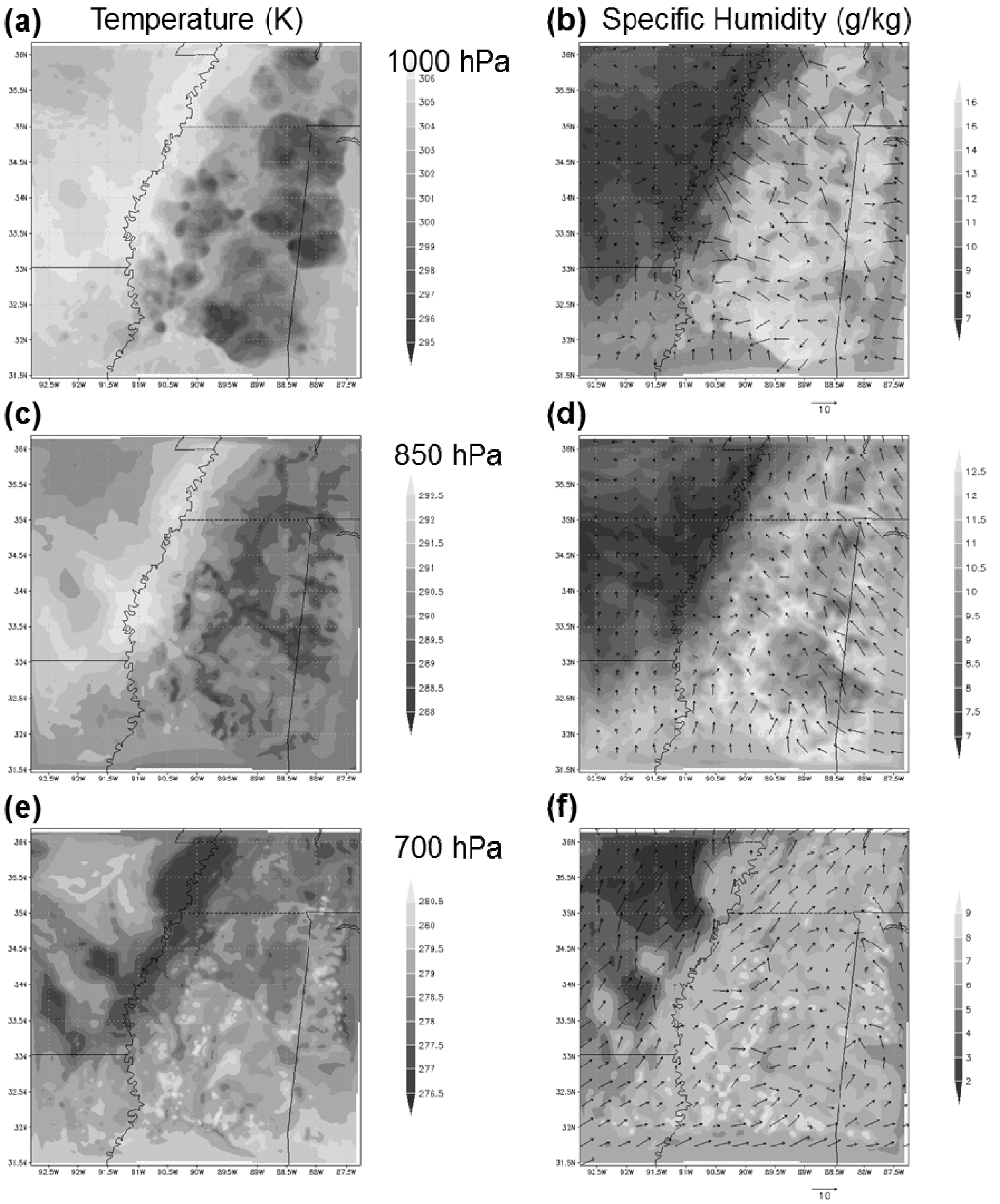


Figure 8. Temperature (K) and specific humidity (g/kg) over the study area for Sept. 9, 2006 at 1400 LST at 1000-hPa (a-b, respectively), 850-hPa (c-d, respectively), and 700-hPa (e-f, respectively).

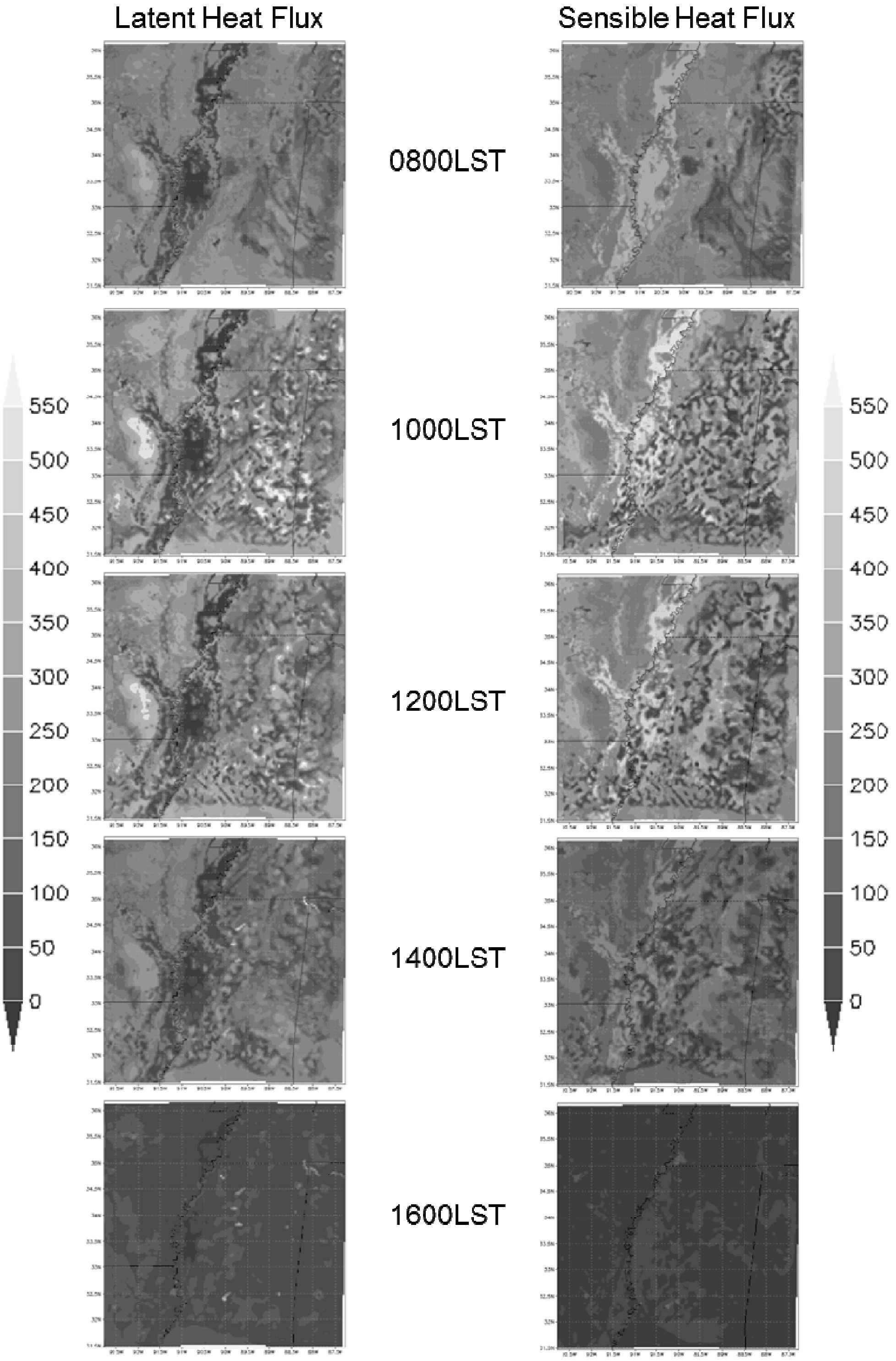


Figure 9. WRF simulated surface sensible and latent fluxes (W/m^2) for 09/09/2006 at 0800 LST (panels a-b, respectively), 1000 LST (panels c-d, respectively), 1200 LST (panels e-f, respectively), and 1400 LST (panels g-h, respectively).

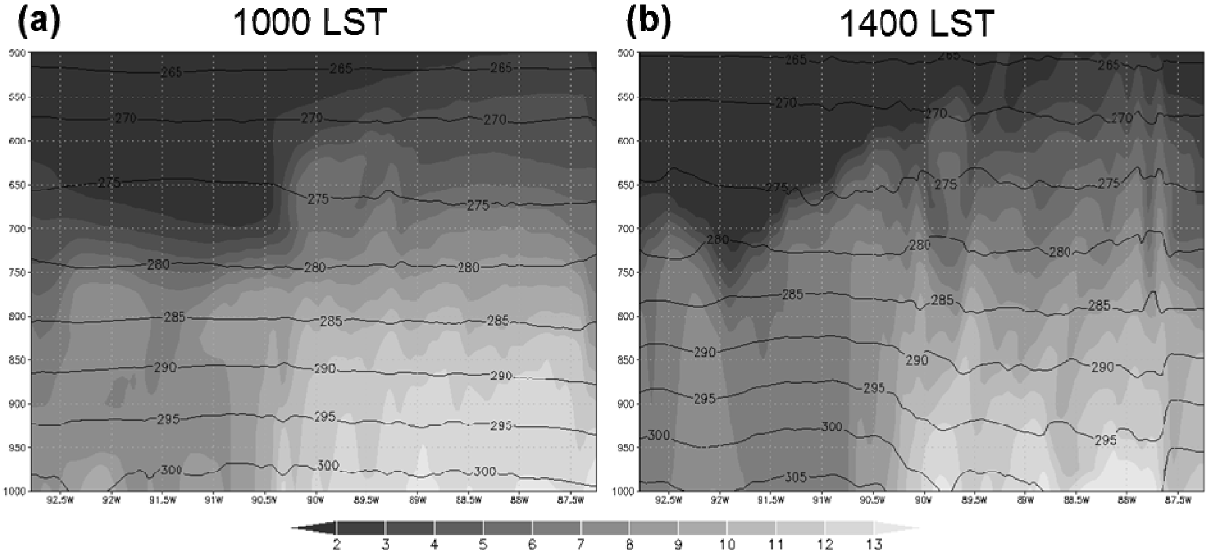


Figure 10. Cross section at 34°N latitude showing specific humidity (g/kg; shaded) and temperature (K; contours) for (a) 1000 LST and (b) 1400 LST.

5. Significant Findings

This project has identified and described the influences of land cover properties, including soil and vegetation conditions, on atmospheric processes over the Mississippi Delta. Specifically, it was found that variations in the energy and moisture fluxes during the warm season along the eastern boundary of the Mississippi Delta were responsible for the generation of a mesoscale convective boundary through processes similar to that found in an urban heat island. This is a direct indication of regional climate change resulting from agricultural practices and the associated anthropogenic modification of the land surface.

Additionally, the development of a convective circulation in the area was responsible for the generation of localized precipitation to the east of the Mississippi Delta. As convection was initiated along the boundary of the land cover discontinuity, prevailing westerly flow caused the cloud cover to advect to the east where the rainfall eventually fell. Under these conditions, it can be said that the atmosphere is acting as a source of interbasin water transport, although the exact volume of moisture removed from the study region has yet to be quantified.

6. Future Research

Based on the findings from this project, future research ideas include quantification of the volume of moisture potentially being transported through atmospheric pathways due to the surface-influenced convective circulation. This would aid in the development and understanding of the sources and releases of moisture over the Mississippi Delta, which could help in local water resource management.

Additionally, using the precipitation patterns outlined through this and previous projects, along with groundwater information from sources such as the Mississippi Department of Environmental Quality and various regional water management districts, a more accurate determination of inputs into the local aquifers can be determined.

Finally, additional research into the variability of the intensity and location of the surface-influenced convective circulation over the Mississippi Delta can be conducted. This would include a sensitivity analysis using the WRF model such that surface and atmospheric conditions could be varied to define the necessary conditions for the circulation to develop. This could help weather and hydrologic forecasters determine when and where the rainfall patterns will be modified due to surface conditions, allowing for a more precise determination of surface precipitation distribution.

7. Information Transfer and Dissemination

The results of the research conducted during the course of this project have been disseminated through peer-reviewed publications and conference presentations. The major results from the project are included in a manuscript that is currently under review in the *Journal of Hydrometeorology*. Additionally, findings were presented at the 2010 Mississippi Water Resources Conference in Bay St. Louis, Mississippi.

8. Student Training

A portion of the research associated with this project was done by Mark Baldwin, a Ph.D. student in the Department of Geosciences at MSU. Although his current research is not directly associated with surface-atmosphere interactions over the Mississippi Delta, he is conducting research related to precipitation prediction and lightning occurrence in the southeast US. Experience while working on this project has helped Mr. Baldwin in the development of the objectives and methodology for his dissertation, and will potentially aid in the development of rainfall prediction and quantification methods over data sparse regions.

9. Financial Summary

Initial budget for funded project:

Cost Category		Percent Time Devoted to Project	Total Salary	Federal Contribution	State Contribution	Matching Contribution	Total
1. Salaries and Wages	PI	15%	$51,665	$3,500	$4,250	$0	$7,750
	GRA	50%	$12,000	$3,000	$3,000	$0	$6,000
	Total			$6,500	$7,250	$0	$13,750
2. Fringe Benefits				$2,048	$2,289	$0	$4,337
3. Materials and Supplies				$100	$200	$0	$300
4. Permanent Equipment				$479	$1,000	$0	$1,479
5. Travel				$987	$1,510	$0	$2,497
6. Other Direct Costs				$990	$1,512	$0	$2,502
Total Direct Costs				$11,104	$13,761	$0	$24,865
8. Indirect Costs				$0	$0	$9,273	$9,273
9. Total Estimated Costs				$11,104	$13,761	$9,273	$34,138

Expenditures during quarterly reporting periods:

1st quarter [3/1/2009 – 6/30/2009]:
Federal:_$3,000.00_, Non-Federal:_$3,701.97_, Cost Share: _$0.00_

2nd quarter [7/1/2009 – 9/30/2009]:
Federal:_$5,765.00_, Non-Federal:_$7,242.00_, Cost Share: _$0.00_

3rd quarter [10/1/2009 – 12/31/2009]:
Federal:_$616.65_, Non-Federal:_$274.75_, Cost Share: _$0.00_

4th quarter [1/1/2010 – 2/28/2010]:
Federal:_$1,700.63_,Non-Federal:_$1,500_, Cost Share: _$9,273.00_

A request for an extension was submitted and approved, leading to expenditures through 11/30/2010 as follows:

Federal:_$21.72__,Non-Federal:_$1,042.28_, Cost Share: _$0.00_