P1.5 NUMERICAL SIMULATION OF CONVECTION DURING IHOP_2002 USING THE FLUX-ADJUSTING SURFACE DATA ASSIMILATION SYSTEM (FASDAS)

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1. INTRODUCTION

With increasing reliance on numerical weather prediction models by the operational forecasting community, more accurate and detailed data assimilation systems are essential. Data assimilation is based on the concept of combining current and past meteorological data in an explicit dynamical model. Four-dimensional data assimilation (FDDA) is the time dependent dynamical coupling of various numerical fields with the model's prognostic equations. FDDA provides a logical extension between objective analysis methods and dynamic relationships of atmospheric variables. One major method of FDDA uses a continuous (i.e., every time step) dynamical assimilation where forcing functions are added to the governing equations to "nudge" the model state toward the observations. This type of FDDA is often used in the research community to study various mesoscale features. Users of the MM5 modeling system frequently use continuous nudging FDDA. Nudging was initially developed and tested by Kistler (1974) and by Anthes (1974). Refer to Stauffer and Seaman (1990) for a more detailed review of these techniques.

FASDAS (Flux-Adjusting Surface Data Assimilation System) closely follows the works of Mahfouf (1991) and Bouttier et al. (1993). FASDAS was developed in order to address the errors in both the soil moisture and temperature parameters, both of which are important variables in the development of deep moist convection. It also includes direct and indirect assimilation components utilizing the FDDA methodology employed by Stauffer and Seaman (1990).

In FASDAS, surface temperature and dew point temperature are directly assimilated by using the analyzed surface observations. FASDAS calculates the difference between the observations and model predictions and adjusts surface heat fluxes to account for these differences. These adjustments are added to the surface heat fluxes simulated by the model. The updated heat fluxes are then used in the prognostic ground temperature and soil moisture equations, which in turn affect the simulated surface heat fluxes in the subsequent time step.

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The indirect assimilation of soil temperature and soil moisture is applied simultaneously with the direct assimilation of observed/analyzed temperature and dew point in the lowest layer of the model. This helps to maintain consistency between the soil temperature and moisture, and the surface layer mass variables. For further details refer to Alapaty et al. (2001a, 2001b, 2001c).

The primary goal of this research is to study the effects of FASDAS on numerical simulations of convective initiation over the Southern Great Plains (SGP) of the United States during the International H_2O Project (IHOP_2002). FASDAS is used to obtain realistic soil moisture and temperature fields over the IHOP_2002 region. All surface observations used for FASDAS were obtained from the IHOP_2002 Hourly Surface Meteorological Composite dataset (available on the IHOP_2002 data archive website http://www.joss.ucar.edu/ihop/dm/archive). Over 250 locations provided meteorological data, including observations of temperature, wind, and moisture.

Two 72-hr numerical simulations were performed. A Control Simulation was run that assimilated all available IHOP_2002 data into the standard MM5 Four-Dimensional Data Assimilation. An Experimental Simulation was completed that assimilated all available IHOP_2002 data into the FASDAS version of MM5. With the dense observational network during the IHOP_2002 study, local surface fields should be accurately defined, leading to the inclusion of feedback between soil moisture heterogeneity and convection in this region. The study period is from 0000 UTC 17 June 2002 through 0000 UTC 20 June 2002. This period was selected because large scale and intense convection occurred along various boundaries over portions of the IHOP_2002 region.

2. METHODOLOGY

The Control and Experimental Simulations were completed using version 3.6.2 of the MM5 modeling system. The simulations were identical with the exception of the FASDAS scheme being used in the Experimental Simulation. The fifth-generation NCAR/Penn State Mesoscale Model (MM5) is the latest version of a mesoscale model first used and developed at The Pennsylvania State University in the early 1970's. MM5 is a primitive equation model that uses a non-dimensional terrain-following σ-vertical coordinate system. Eta model analyses, produced by the National Center for Environmental Prediction (NCEP) and archived by the National Center for Atmospheric Research (NCAR) were used to prescribe initial conditions. The resolution of the archived data is approximately 40 km. The above data are interpolated onto the model grid to serve as initial values and to provide lateral boundary conditions for the simulation. The analysis corresponding to 0000 UTC 17 June 2002 was utilized as the initial condition. The model was integrated up to a period of 72h ending 0000 UTC 20 June 2002.

The following MM5 physics configuration was used in this study. The model simulation for this research uses surface layer similarity for the constant flux layer and the Eta Mellor-Yamada (Eta M-Y) planetary boundary layer (PBL) parameterization scheme for the mixed layer (Betts and Chen 1997). MM5 uses explicit equations for cloud water, rainwater, ice and water vapor. In order to account for ice phase processes, the Simple Ice scheme was used. The outer (12 km) domain used the Kain-Fritsch cumulus parameterization scheme to account for the sub-grid water cycle (Kain, 2004), while the inner (4 km) domain used only explicit moisture physics to account for precipitation processes. The Dudhia cloud-radiation scheme was used to account for the interaction of shortwave and longwave radiation with clouds and the clear air. The Noah Land Surface Model (LSM) was used to represent land surface processes (Ek et al. 2003).

For the Experimental Simulation described here, MM5 was altered to allow for the full implementation of the FASDAS scheme. The code was modified to allow for observational nudging of the mass fields, and to allow for direct interaction between atmospheric variables and related surface fluxes. Observational nudging was prescribed at an interval of 180 minutes throughout the 72-hr model integration.

3. RESULTS AND DISCUSSION

The main goal of this paper is to investigate the effect of using FASDAS on simulated convective initiation over the Southern Great Plains (SGP) during the IHOP_2002 experiment. The MM5 domain configuration used in this study is illustrated in Figure 1. The outer domain, D1 has a horizontal grid spacing of 12 km, while the inner domain D2 has a horizontal grid spacing of 4 km. Elevation data in meters is shaded, and ranges from less than 250 m over Kansas and Oklahoma to nearly 3750 m over Colorado. Locations of interest in this study are indicated on Figure 1. These were the locations where convective activity occurred during the study period.

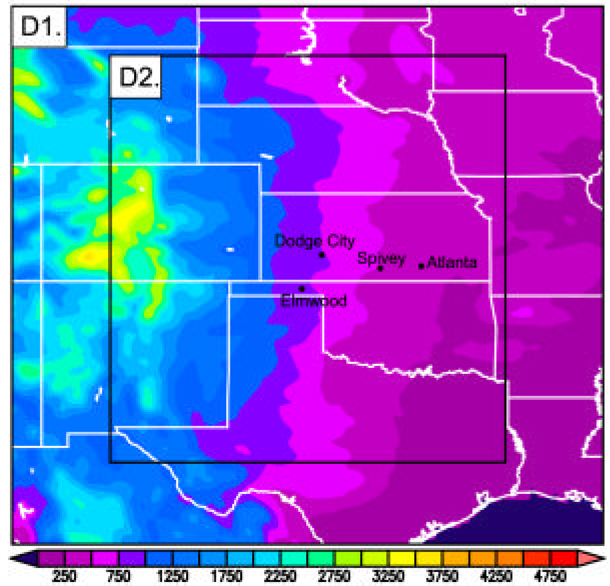

Figure 1 MM5 domain configuration used in this study. The outer domain, D1, has a horizontal grid spacing of 12 km while the inner domain, D2, has a horizontal grid spacing of 4 km. Elevation data is shaded in m. Locations of interest are shown in black.

Precipitation reflectivity (dBZ) valid 0000 UTC 18 June 2002 is presented in Figure 2. Control simulated reflectivity is shown in Figure 2A, while the Experimental simulated reflectivity is shown in Figure 2B. National Weather Service Doppler Radar reflectivity is shown in Figure 2C. With the exception of eastern Nebraska, the Control Simulation did not predict any precipitation over the entire domain. The Experimental Simulation predicted two regions of significant precipitation: northern Texas and southeastern Nebraska into eastern Kansas. Reflectivity data from National Weather Service Doppler Radar shows intense precipitation (>55 dBZ) over Northern Texas and Central Kansas, with lighter precipitation detected over northeastern Kansas and southeastern Nebraska. Neither simulation resolved the intense precipitation over central Kansas, although the Experimental Simulation accurately predicted strong convection over north Texas and lighter precipitation over northeastern Kansas. Both simulations over predicted precipitation in eastern Nebraska. High boundary layer relative humidity (greater than 90%) and enhanced vertical motion (1.8 m s^{-1}) over northern Texas (not shown) likely contributed to the enhanced convection simulated in the Experimental model. This region corresponds closely with the observed reflectivity data from the National Weather Service Doppler Radar.

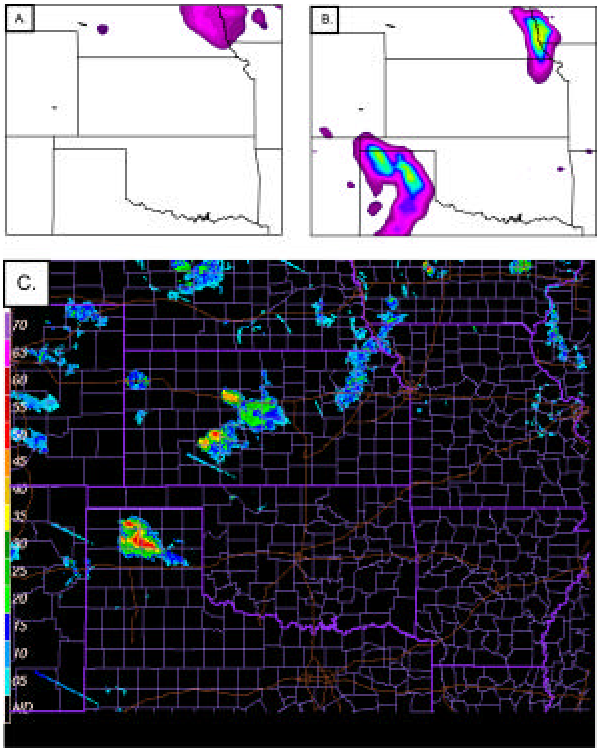

Figure 2 Control simulated reflectivity (dBZ) valid 0000 UTC 18 June 2002 is shown in Figure 2A. Experimental simulated reflectivity (dBZ) valid 0000 UTC 18 June 2002 is shown in Figure 2B. National Weather Service Doppler Radar reflectivity (dBZ) valid 0000 UTC 18 June 2002 is shown in Figure 2C.

Figure 3A shows Multisensor Precipitation Estimate (MPE) data (cm) valid 0000 UTC 17 June through 0000 UTC 20 June 2002 over the study region. MPE corrects radar precipitation estimates with observations from surface gages. 72-hr total precipitation (cm) from the Control Simulation is depicted in Figure 3B. The Control Simulation predicted less than 1.25 cm of precipitation over much of the region, with the exception of western Iowa, where 2.5 to 5 cm of precipitation was simulated. MPE data shows several regions of enhanced precipitation (greater than 4 cm), including northern Texas, western Oklahoma, central and Western Kansas, eastern Colorado and portions of Central Nebraska, respectively. The Control Simulation predicted light precipitation (less than 1.25 cm) over much of central Kansas and portions of New Mexico, but simulated less than 0.50 cm elsewhere.

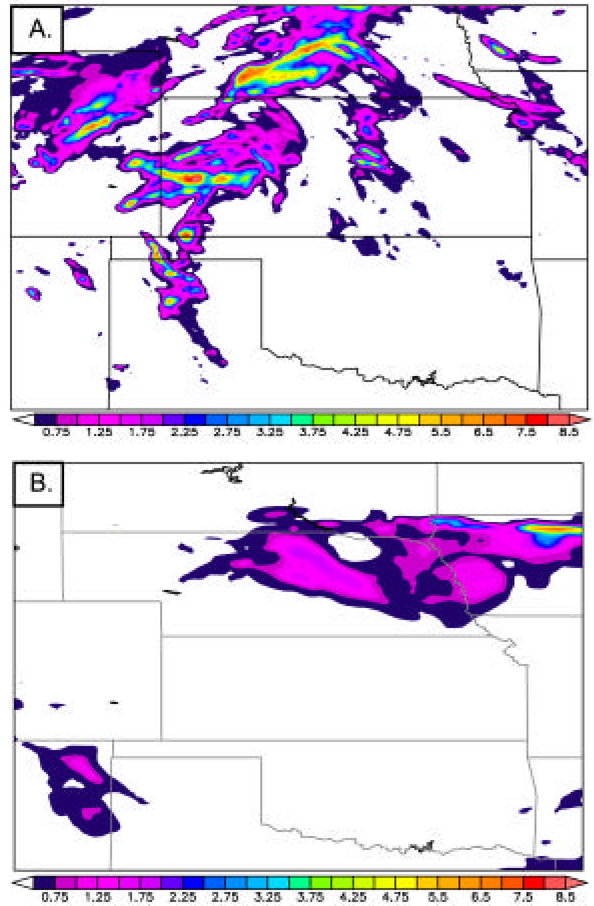

Figure 3 Multisensor Precipitation Estimation (MPE) data (cm) valid 0000 UTC 17 June through 0000 UTC 20 June 2002 is shown in Figure 3A. Control simulated precipitation (cm) valid 0000 UTC 17 June through 0000 UTC 20 June is shown in Figure 3B.

Figure 4A shows MPE data (cm) valid 0000 UTC 17 June through 0000 UTC 20 June 2002 over the study region, while 72-hr total precipitation (cm) from the Experimental Simulation is presented in Figure 4B. The Experimental Simulation predicted several regions of precipitation greater than 4 cm, including northern Texas, northeastern Oklahoma, eastern Kansas and portions of western Kansas. MPE data shows several region of enhanced precipitation (greater than 4 cm), including northern Texas, western Oklahoma, central and Western Kansas, eastern Colorado and portions of Central Nebraska. The Experimental Simulation over predicted precipitation coverage over parts of northern Texas and northeastern Oklahoma. However, the simulated precipitation amounts and distribution from the Experimental Simulation agreed more closely with MPE precipitation data than the Control Simulation. This is likely a result of the enhanced surface heat flux gradients in the Experimental Simulation driving more boundary layer moisture convergence, enhancing vertical motion, and inducing moist convection.

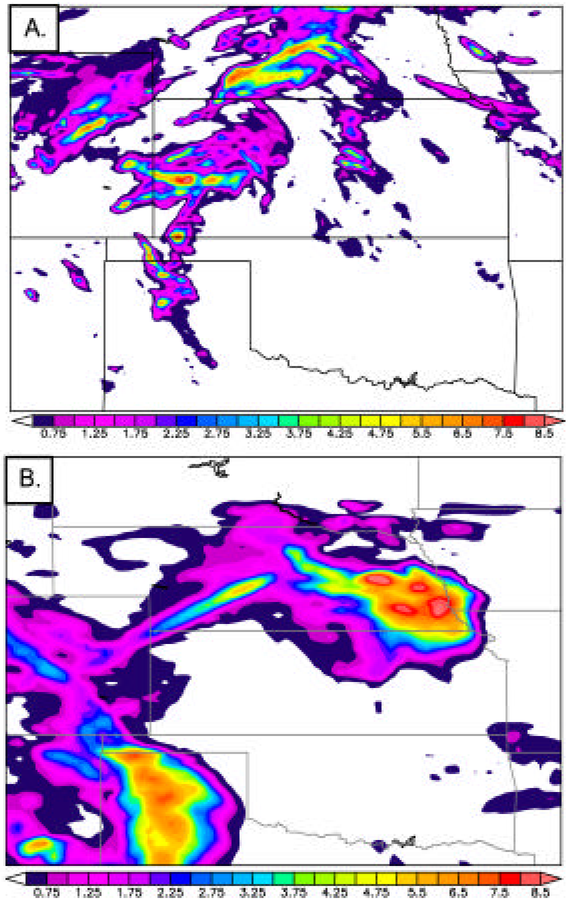

Figure 4 Multisensor Precipitation Estimation (MPE) data (cm) valid 0000 UTC 17 June through 0000 UTC 20 June 2002 is shown in Figure 4A. Experimental simulated precipitation (cm) valid 0000 UTC 17 June through 0000 UTC 20 June is shown in Figure 4B.

Surface heat fluxes for Elmwood, OK, one of the surface flux sites in the IHOP_2002 domain, are presented in Figure 5. These sites are part of the NCAR Integrated Surface Flux Facility (ISFF), which is comprised of nine surface flux sites located in KS, OK and TX. ISFF towers are equipped with sensors to measure fluxes of momentum, sensible and latent heat, trace gases, and radiation in addition to standard surface and atmospheric variables. Observations of surface sensible and latent heat fluxes were used for the comparison purposes in this study. More information on ISFF, including instrumentation and specific variables measured, can be found at http://www.atd.ucar.edu/rtf/projects/ihop_2002/isff/report.shtml.

Surface sensible heat fluxes (W m^{-2}) from the Control (red) and Experimental (blue) simulations, as well as observations (black) for Elmwood, Oklahoma are shown in Figure 5A. The Control Simulation under predicted sensible heat fluxes by 100 to 200 W m^{-2} throughout the simulation. The Experimental Simulation underestimated surface sensible heat fluxes on 17 June 2002, but closely matched observations between 0000 UTC 18 June and 0000 UTC 20 June. For example, the Control Simulation predicted a sensible heat flux of about 190 W m^{2} at 1800 UTC 18 June, while the Experimental Simulation predicted sensible heat flux of 320 W m^{-2}. Observations from this period show a sensible heat flux of 310 W m^{-2}. Surface latent heat fluxes (W m^{-2}) for this site are depicted in Figure 5B. The Control Simulation over estimated the latent heat fluxes over Elmwood throughout the entire 72-hr integration. The Experimental Simulation slightly under predicted latent heat flux values on 17 June over Elmwood, and slightly over estimated latent heat flux values between 1200 UTC 18 June through 0000 UTC 20 June. For example, the Control Simulation predicted a latent heat flux of 550 W m^{-2} at 1800 UTC 18 June, while the Experimental Simulation predicted a latent heat flux of 350 W m^{-2}. Observations showed a latent heat flux of 200 W m^{-2} during this period.

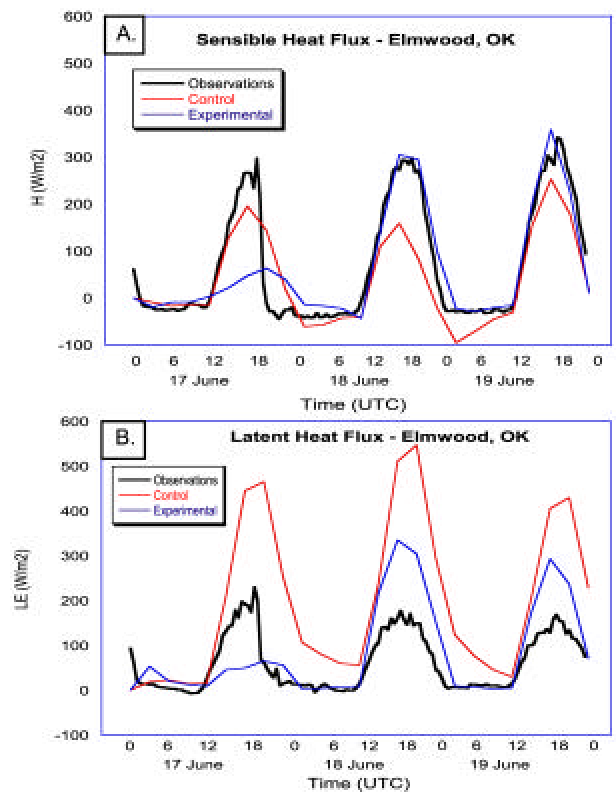

Figure 5 Simulated surface sensible heat fluxes (W m^{-2}) valid 0000 UTC 17 June through 0000 UTC 20 June 2002 for Elmwood, OK are shown in Figure 5A. Simulated surface latent heat fluxes (W m^{-2}) valid 0000 UTC 17 June through 0000 UTC 20 June 2002 for Elmwood, OK are shown in Figure 5B. The Control Simulation is shown in red, while the Experimental Simulation is shown in blue. Observations are shown in black.

Model simulated surface sensible heat fluxes (W m^{-2}) valid 0000 UTC 18 June 2002 are shown in Figure 6. Simulated sensible heat fluxes from the Control Simulation are shown in Figure 6A, while simulated surface heat fluxes from the Experimental Simulation are shown in Figure 6B. Sensible heat flux values are fairly uniform over much of the IHOP_2002 region in the Control Simulation, with values between 250 and 350 W m^{-2} predicted over much of the region. Significant spatial variability is evident in the Experimental Simulation at this time, with sensible heat flux values ranging between 25 and 400 W m^{-2} over the region. Sensible heat flux gradients of 300 W m^{-2} were simulated over northern Texas in the Experimental Simulation.

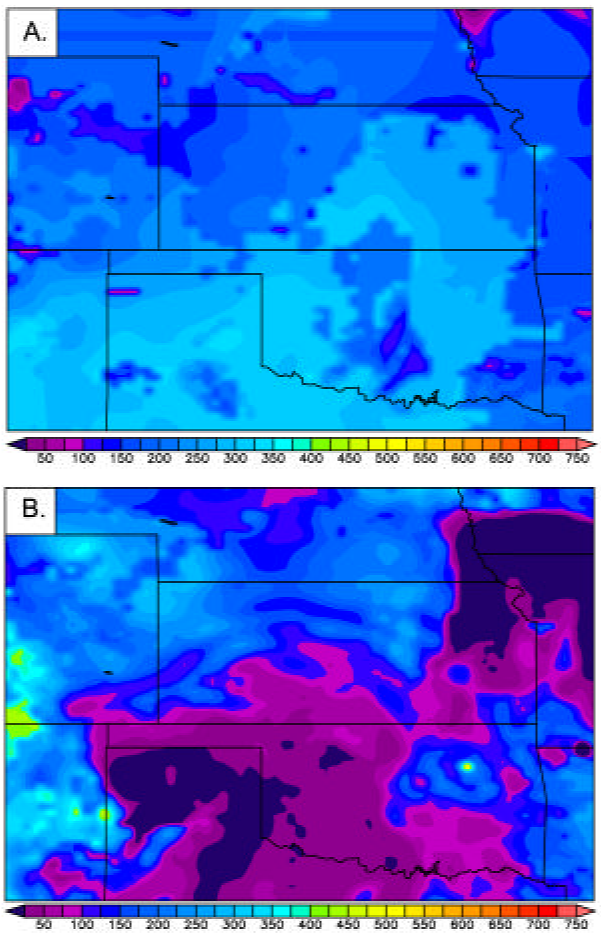

Figure 6 Control simulated surface sensible heat fluxes (W m^{-2}) valid 0000 UTC 18 June 2002 are shown in Figure 6A. Experimental simulated surface sensible heat fluxes (W m^{-2}) valid 0000 UTC 18 June 2002 are shown in Figure 6B.

Model simulated surface latent heat flux (W m^{-2}) values valid 0000 UTC 18 June 2002 are presented in Figure 7. Simulated latent heat fluxes from the Control Simulation are shown in Figure 7A, while simulated latent heat fluxes from the Experimental Simulation are shown in Figure 7B. Latent heat flux values between 300 and 500 W m^{-2} are simulated by the Control experiment with little variation. The Experimental Simulation, however, predicted latent heat flux values between 100 and 500 W m^{-2} over the region. Latent heat flux gradients of 400 W m^{-2} were simulated over portions northern Texas in the Experimental Simulation.

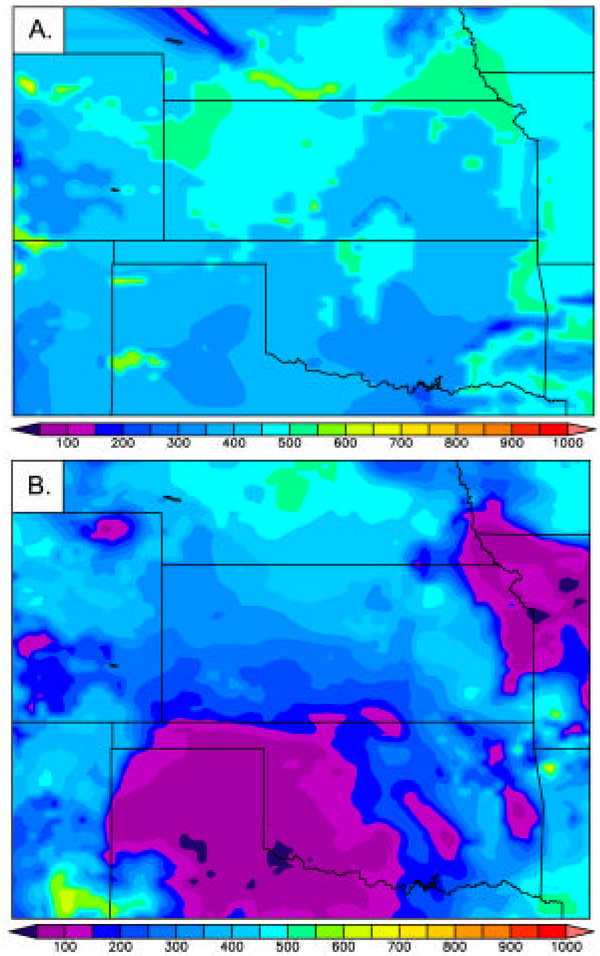

Figure 7 Control simulated surface latent heat fluxes (W m^{-2}) valid 0000 UTC 18 June 2002 are shown in Figure 7A. Experimental simulated surface latent heat fluxes (W m^{-2}) valid 0000 UTC 18 June 2002 are shown in Figure 7B.

4. CONCLUSIONS

The main goal of this research is to study the effects of using FASDAS on numerical simulations of convective initiation during the International H2O Project (IHOP_2002) over the Southern Great Plains (SGP) of the United States during June 2002. Two 72-hr numerical simulations were performed. A Control Simulation was run that assimilated all available IHOP_2002 data into the standard MM5 Four-Dimensional Data Assimilation program. An Experimental Simulation was performed that assimilated all available IHOP_2002 data into the FASDAS version of the MM5.

Surface heat fluxes from the Experimental Simulation agreed more closely with observations from Kansas and Oklahoma as compared to the Control Simulation. Intense surface heat flux gradients (greater than 400 W m^{-2}) over portions of northern Texas and western Oklahoma were simulated by the Experimental Simulation. The Control Simulation predicted more uniform surface heat flux patterns over the region. Surface heat flux gradients in the Experimental Simulation likely enhanced simulated boundary layer moisture convergence. Enhanced moisture convergence increased boundary layer relative humidity and vertical motion, which led to the development of deep, moist convection. The Control experiment simulated much weaker surface heat flux gradients, which likely resulted in the lack of simulated deep convection over the region during this study period. Future research would include a more detailed statistical evaluation of the FASDAS scheme, including several simulations over the southeastern United States.

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References

Alapaty, K., N.L. Seaman, D.S. Niyogi, and A.F. Hanna, 2001a: Assimilating Surface Data to Improve the Accuracy of Atmospheric Boundary Layer Simulations. *Journal of Applied Meteorology, 40,* 2068-2082.

Alapaty, K., N.L. Seaman, D.S. Niyogi, M. Alapaty, G. Hunter, and D. Stauffer, 2001b: Evaluation of a Surface Data Assimilation technique using the MM5. *The 11th Penn State/NCAR MM5 Users' workshop, 25-27 June 2001, Boulder, Colorado, USA.*

Alapaty, K., D.S. Niyogi, and M. Alapaty, 2001c: Indirect Assimilation of soil moisture availability in the MM5. *The 11th Penn State/NCAR MM5 Users' workshop, 25-27 June 2001, Boulder, Colorado, USA.*

Anthes, R., 1974: Data Assimilation and initialization of hurricane prediction models. *J. Atmos. Sci*., **31**, 702-718.

Betts, A. K., F. Chen, K. E. Mitchell, and Z. Janjic, 1997: Assessment of the land surface and boundary layer models in two operational versions of the NCEP Eta model using FIFE data. *Mon. Wea. Rev.,* **125**, 2896-2916.

Bouttier, F., J. –F. Mahfouf, and J. Noilhan, 1993: Sequential assimilation of soil moisture from low-level atmospheric parameters. Part II: Implementations in a mesoscale model. *J. Appl. Meteor*., **32**, 1352-1364.

Chen, F. and J. Dudhia, 2001: Coupling an Advanced Land Surface-Hydrology Model with the Penn State-NCAR MM5 Modeling System. Part I: Model Implementation and Sensitivity. *Mon. Wea. Rev*., **129**, 569.

Michael Ek, NOAA/NWS/NCEP, Suitland, MD; and K. Mitchell, E. Rogers, T. Black, G. Gayno, F. Chen, and J. Kim. Upgrades to the unified Noah land-surface model in the operational NCEP mesoscale Eta model. AMS 17th Conference on Hydrology, Long Beach, Ca, February 9-13, 2002.

Kain, John S., 2004: The Kain-Fritsch Convective Parameterization: An Update. *Journal of Applied Meteorology*, Vol **43**, No 1, pp170-181.

Kistler, (1974): " A study of data assimilation techniques in an autobarotropic primitive equation channel model." M.S. Thesis, The Pennsylvania State University, 84 pp.

Mahfouf, J.F., (1991): Analysis of soil moisture from near surface parameters: A feasibility study. *J. Appl. Meteor*., **30**, 1534-1547.

Stauffer, D.R. and N.L. Seaman, 1990: Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. *Mon. Wea. Rev*., **118**, 1250-1277.

_________, N.R, Seaman, and F.S. Binkowski, 1991: Use of four-dimensional data assimilation in a limited-area mesoscale model. Part II: Experiments with synoptic-scale data. *Mon. Wea. Rev*., **119**, 734-754