P3.14

EVALUATING THE USE OF THE ATMOSPHERIC LAND EXCHANGE INVERSE (ALEXI) MODEL IN SHORT-TERM PREDICTION AND MESOSCALE DIAGNOSIS

John R. Mecikalski[†], Scott M. Mackaro[†], Martha C. Anderson[§], John M. Norman[§], and Jefrey B. Basara[¶]

[†]Atmospheric Science Department
University of Alabama in Huntsville

[§]Soil Science Department
University of Wisconsin—Madison

[¶]Oklahoma Climatological Survey
University of Oklahoma Norman

1. INTRODUCTION

The purpose of this research is to motivate the use of the ALEXI model's output fields in problems of meso- and regional scale short-term prediction and forecasting. This is being done at the University of Alabama in Huntsville (UAH). This will be done as three distinct components: a) validation of ALEXI fluxes/data fields on regional scales b) 2-6 h convective initiation prediction research, c) ALEXI-estimated soil moisture and evapo-transpiration (ET) assimilation. This presentation focuses on the first two components in particular.

2. ALEXI OVERVIEW

In Anderson et al. (1997) and Mecikalski et al. (1999), a method for evaluating fluxes of sensible and latent heat at the land surface using anAtmosphere-Land EXchange Inverse (ALEXI) model was detailed. Since 1999, this model has been developed for a wide variety of landscape, agricultural and land-surface—atmosphere interactions (Norman et al. 2002; Anderson et al. 2004). The most important inputs to this model are a fraction vegetation cover (obtained from the Normalized Vegetation Difference Index [NDVI] estimated from the AVHRR data or other satellite sources), and the change in radiometric temperature of the land surface over approximately a four-hour time interval in the morning. Currently, this time-change information is only available from the NOAA-GOES geostationary satellites.

Continental scale maps of daily surface energy fluxes are being generated using ALEXI. Sensible, latent and ground heat flux components along with net radiation and soil moisture are estimated on the 5-10 km scale from these inputs. Recent efforts have validated this modeling procedure to within 10-12% of surface- or tower-based instruments. Validation results for ALEXI resolutions of 5-10 km compare to within 30% of ground-based sensors. Figure 1 demonstrates daily-integrated latent heat produced by ALEXI.

Ongoing work with the ALEXI model has developed a 2-3 year climatology of land-surface [*] energy, evapotranspiration (ET) and soil moisture (root zone, 6 cm-1.5 m, and surface layer, 0-6 cm) estimates over the continental U.S (Fig. 2). This climatology will extend from 1 June 2002 to late 2004. As part of this ongoing climatology work, this presentation will highlight the specific details of the ALEXI system that allow us to retrieve the above quantities, validate their quality, and seek new avenues for using ALEXI input/output fields in short-term weather forecasting on mesoscales (2-200 km). The validation of ALEXI is bein conduct ed through the analysis of data collected during the Soil Moisture Atmospheric Coupling EXperiment (SMACEX) field campaign in 2002

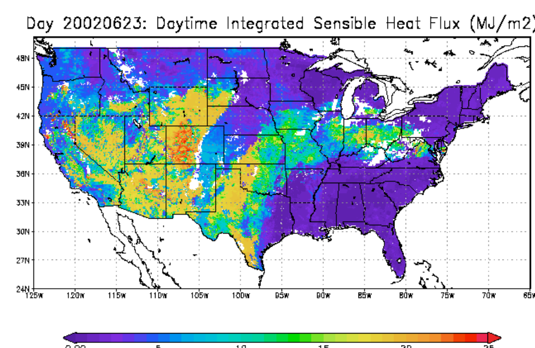

Figure 1: Daily integrated latent heating as produced by ALEXI for 23 June 2002 as recently regenerated as part of the 2-3 year ALEXI climatology. Most of the darkest purple regions were cloudy on this day.

[*] Correponding Author: Prof. John R. Mecikalski, Atmospheric Science Department, University of Alabama in Huntsville, 320 Sparkman Drive, Huntsville, AL 35805-1912. *johnm@nsstc.uah.edu*.

within the state of Iowa, and from the Oklahoma Mesonet.ALEXI is a so-called “two-source” model, the two sources being soil and vegetated components of a scene. Each of these scene subcomponent contribute to the radiometric temperature of the scene, and thus this quantity is influenced by the angle of view of the GOES observation, and thus the relative amount of soil and vegetation viewed.

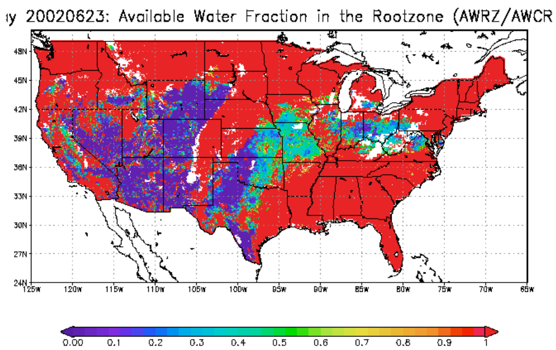

Figure 2: Available water fraction in the root zone for 23 June 2002. Red areas on map could not be retrieved by ALEXI on this day due to cloud cover.

Through resistance formulations for canopy and soil flux exchanges with the atmosphere, surface fluxes are coupled to an atmospheric surface layer model, and ultimately to a simple model of the growth of the atmospheric boundary layer (ABL). This ABL model provides the energy closure needed to solve the ALEXI equation system, and is more robust than using an air temperature measured at shelter lever (2 m) to close the energy balance. In fact, through balancing surface and ABL fluxes, ALEXI is able to *estimate* the air temperature at the top of the atmospheric surface layer, approximately 50 m Using time-changes of radiometric temperature mitigates some of the problems involved with estimating surface emissivity and applying atmospheric corrections to satellite-measured temperature measurements.

ALEXI also requires a modest amount of vegetation, land-use and atmospheric information (detailed in Mecikalski et al. 1999). Sources of the land-use and vegetation data are unchanged from those noted in that publication. The required atmospheric information was originally provided through objective analyses of surface synoptic data for wind speed and rawindsonde information for the atmospheric vertical profiles needed for the ABL energy closure, a data- and computationally-intensive process over regional and continental scales (Mecikalski et al. 1999; Norman et al. 2002; Anderson et al. 2004). To ameliorate this problem, we have adapted the forecast model component of CIMSS Regional Assimilation System (CRAS, Diak et al., 1998, 2004) or MM5/WRF to provide all the required atmospheric and selected other inputs to ALEXI. These inputs are vertical profiles of atmospheric temperature over the ALEXI region at the initial time, as well as wind speed, incident flux of clear-air solar radiation (Fig. 3) and net thermal radiation at both GOES observation times.

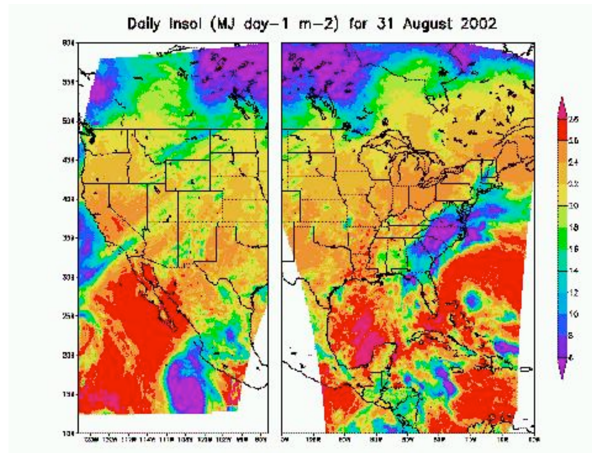

Figure 3: GOES-12 and –10 derived solar insolation as used in the real time ALEXI routine to help formulate net radiation as an input to the ALEXI algorithm.

3. RESEARCH BACKGROUND

a) CONVECTIVE INITIATION

Thunderstorms have long been a focus of study in the meteorology community; the later portion of the last decade has been heavily dedicated to better understanding and forecasting of the initiation of such events. The ability to forecast convective initiation (hereafter referred to as *CI*) is very difficult even when considering very short lead times (Benjamin et al. 2004).

The goal of this component of the ALEXI-related research is to use satellite, land-surface and NWP fields to develop a probability index for CI, constructed at ~10 km resolution.

The Southeast region of the continental United States is a region where CI is observed almost on a daily basis during the spring and summer months. Atmospheric conditions over this region are often largely homogeneous, as moisture, advected from the Gulf of Mexico, produces a widespread, deeply moist, low-CAPE atmosphere, dominated by weak synoptic forcing.

The multitude of preconditioning and triggering processes that can lead to CI make the problem of forecasting it very complex. Contributions from local, advective, and dynamical processes must all be considered for any type of accurate prediction. Locally, CI can result from one or any combination of processes evolving from the boundary layer, from terrain, and/or from the surface. Advective processes leading to CI include those as destabilization of the atmosphere, deepening of the planetary boundary layer, as well as formation of convergence lines. Dynamical effects including large scale synoptic forcing, and mesoscale instabilities and motions such as horizontal convective rolls also may aid in the formation of CI (Doswell 2001).

The specific challenge of this research is to attempt to relate CI in a homogeneous atmosphere to heterogeneity of the land surface. In the absence of convergent boundaries and large scale forcing, CI in a homogeneous atmosphere may be a result of several processes.

Perhaps the most obvious process is that of winds interacting with terrain (i.e. terrain-induced moisture convergence). The right combination of terrain slope, wind speed, and wind direction can lead to condensation rates sufficient for CI to take place (Smith and Barstad 2004). Heating over elevated topography impacts CI through the development of thermals nearer the top of a convective boundary layer (Doswell 2001).

In addition to the effects of topography, the heterogeneity of the land as related to land use and land cover may also have a significant impact on CI. Differential surface heating leading to variations in surface flux have long been known to develop convergence zones such sea breeze and land breezes (Shaw and Doran 2001; Mackaro 2003). Surface inhomogeneities causing gradients in sensible and latent heat fluxes can lead to development of convergent zones (Segal and Arritt 1992) and provided sufficient moisture may lead to CI. Smolarkiewicz and Clark (1985) suggested that inhomogeneities in soil and vegetation characteristics are likely to be important in the early stages of cumulus formation. For these gradients in fluxes to have any impact on CI, however, it is necessary that the winds in the region of potential CI be generally weak. In a study by Avissar and Schmidt (1998) it was found that a moderate ambient wind of 5 ms^{-1} can eliminate all impacts that could potentially be produced by the differential fluxes. Wind speeds of 2.5 ms^{-1} were found to be strong enough to considerably reduce the impact of the heterogeneous land surface.

With these processes in mind, an attempt will be made to develop an index that provides a probability of CI for homogeneous atmospheres over heterogeneous terrain. This index will be based to some extend on what ALEXI provides for land-surface flux and vegetation information, as well as from the CI diagnostic/prdiction algorithm of Mecikalski and Bedka (2005). Figure 4 demonstrates how satellite can be used to assess CI climatology, as in this example, 12 days of afternoon GOES-12 visible images are averaged together to gain a first picture of how local terrain and land-surface heterogeneities influence cumulus cloud development.

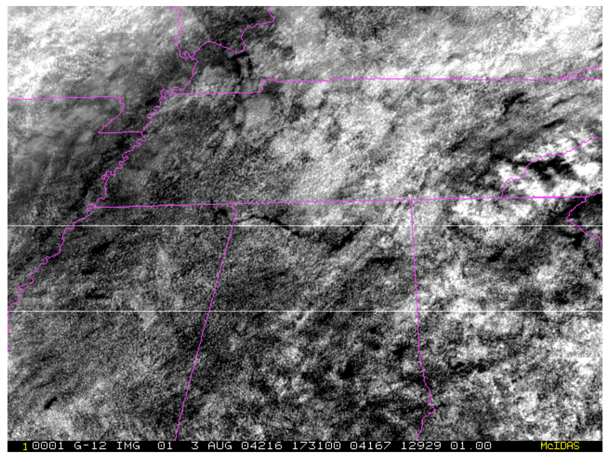

Figure 4: 12-day average of 1830 UTC GOES-12 visible imagery during July-August 2004 over the Tennessee River Valley and adjacent Appalachian mountains. Enhanced (whiter) regions are indicative of locations of cumulus cloud development at this time of day. Weather conditions for all days were similar.

b) SOIL MOISTURE ASSIMILATION

For this aspect of the project, a series of soil moisture assimilation experiments are being undertaken in which ALEXI-derived root zone (6 cm–2 m) and surface layer (0-6 cm) soil moistures are used to update NCEP Eta model soil moisture. This is being performed in the Advanced Regional Prediction Systems (ARPS) Data Analysis System (ADAS) as run at UAH. ALEXI estimates soil moisture using the ratio ETp/ET (ETp is potential ET), which effectively provides a measure of vegetation stress (see Campbell and Norman 2002). As the fraction vegetation cover changes, GOES skin temperature changes during the morning hours (required by ALEXI to assess the evaporative fraction for the day) are used within an empirical relationship to compute the available water in the soil layer most in contact with plant roots (M. C. Anderson, personal communications; Fig. 2). This relationship is therefore a function of vegetation type and plant characteristics, as well as wind, vapor pressure deficits, and previous rainfall/soil moisture conditions.

Plans are to compare the 10 km resolution ALEXI soil moisture within ADAS/ARPS to Eta, and then to field measurements collected during the Soil Moisture Experiment (SMEX) in 2002 in Iowa, in 2003 in North Alabama, and in 2004 in Arizona.

Beyond the ALEXI-Eta comparison and soil moisture validation work, several sensitivity experiments will be run during SMEX days. The working hypothesis is that ALEXI soil moisture at 10 km resolution both improves the initial conditions of a high-resolution NWP simulation (using the ARPS, WRF or MM5 model), and leads to an improved forecast of weather on a given day, especially related to the development of the local ABL, the availability of low-level moisture and in terms of cloud cover and convective development.

Other assimilation experiments will be designed to test the applicability of assimilating ET from ALEXI in a retrospective sense. For this, we will assume that to some extent, yesterday's ET is similar to that for today, allowing ALEXI to provide a "first guess" for ET-related low-level moisture forcing from the land surface.

4. ADDITIONAL RESEARCH

An important component of this ALEXI-related research is toward validating and comparing the energy and water fluxes on regional scales to those from surface networks. In particular, working with the Oklahoma Mesonetwork data, we will perform regional comparisons motivated by the interest of assessing ALEXI accuracies on meso- scales. (Mecikalski et al. 2005).

The ALEXI model provides field on daily timeframes that have the capability of assisting several end-users in the agricultural, energy provider, and even aviation communities. These products include those related to ETp (for irrigation scheduling), daily boundary layer depth and growth, and potential heating (for predicting warming rates during morning hours for electricity load forecasting). Graduate students at UAH will gradually (over the coming 5 years) work to develop such products as interested audiences are found for them.

Viewers of this poster are encouraged to visit P2.3 in the IOAS-AOLS conference portion of this AMS meeting for additional information on how the ALEXI model will be developed to support short-term prediction and data assimilation Testbed activities at UAH.

5. ACKNOWLEDGEMENTS

This research was funded by NASA Research Grant NAG5-12536 and through the NASA Short-term Prediction Research Transition (SPoRT) Center at NASA MSFC.

6. REFERENCES

Anderson, M. C., J. M. Norman, G. R. Diak, W. P. Kustas, and J. R. Mecikalski, 1997: A two-source time-integrated model for estimating surface fluxes using thermal remote sensing. *Remote Sens. Environ.*, **60**, 195-216.

Anderson, M. C., J. M. Norman, J. R. Mecikalski, R. D. Torn, W. P. Kustas, and J. B. Basara, 2004: A multi-scale remote sensing model for disaggregating regional fluxes to micrometeorological scales. *J. Hydrometeor*. **5**, 343-363.

Avissar, R., and T. Schmidt, 1998: An evaluation of the scale at which ground-surface heat flux patchiness affects the convective boundary layer using large-eddy simulations. *J. Atmos. Sci.* **55**, 2666-2689.

Benjamin, Stanley G., Dévényi, Dezsö, Weygandt, Stephen S., Brundage, Kevin J., Brown, John M., Grell, Georg A., Kim, Dongsoo, Schwartz, Barry E., Smirnova, Tatiana G., Smith, Tracy Lorraine, Manikin, Geoffrey S. 2004: An hourly assimilation–forecast cycle: The RUC. *Mon. Wea. Rev.* **132**, 495–518.

Campbell, G. S., and J. M. Norman, 1998: *An Introduction to Environmental Biophysics*, 2nd Ed. Springer, New York, 286 pp.

Diak, G. R., M. C. Anderson, W. L. Bland, J. M. Norman, J. R. Mecikalski, and R. M. Aune, 1998: Agricultural management decision aids driven by real-time satellite data. *Bull. Amer. Meteor. Soc.* 79, 1345-1355.

Diak, G. R., J. R. Mecikalski, M. C. Anderson, J. M. Norman, W, P. Kustas, R. D. Torn and R. L. Dewolf, 2004: Estimating Land-Surface Energy Budgets from Space: Review and Current Efforts at the University of Wisconsin-Madison and USDA/ARS.*Bull. Amer. Meteor. Soc.*, **85**, 65-78.

Doswell, C. A. 2001: *Severe Convective Storms* Edited by C. A. Doswell III (2001) AMS Meteorological Monograph Series, Vol. 28, No. 50.

Mackaro, S. M., 2003: Applications of land surface data assimilation to simulations of sea breeze circulations. Masters Thesis, University of Alabama in Huntsville. 86 pp.

Mecikalski, J. R., and K. M. Bedka, 2005: The evaluation of convective initiation signatures in realtime GOES visible and infrared satellite imagery. In press. *Mon. Wea. Rev.*

Mecikalski, J. R., G. R. Diak, M. C. Anderson, and J. M. Norman, 1999: Estimating fluxes on continental scales using remotely-sensed data in an atmospheric-land exchange model. *J. Appl. Meteor*., **38**, 1352-1369.

Mecikalski, J. R. M. C. Anderson, J. B. Basara, and J. M. Norman, 2005: The Atmospheric Land EXchange–Inverse (ALEXI) Model: Validation of Daily, Regional Land-Surface Flux Estimates. In preparation *J. Hydrometeor*

Norman, J. M., W. P. Kustas, and K. S. Humes. 1995: A two-source approach for estimating soil and vegetation energy fluxes from observations of directional radiometric surface temperature. *Ag. For. Meteorol*., **77**, 153-166.

Norman, J. M., M.C. Anderson, W. P. Kustas, A. N. French, J. R. Mecikalski, R. D. Torn, G. R. Diak, T. J. Schmugge, and B. C. W. Tanner' 2002: Remote sensing of surface energy fluxes at 10^1-m pixel resolution. *Water Resour. Res*. **39**, 1221.

Segal, M., and R. W. Arritt, 1992: Nonclassical Mesoscale Circulations Caused by Surface Sensible Heat-Flux Gradients. *Bulletin of the American Meteorological Society*: Vol. 73, No. 10, pp. 1593–1604.

Shaw, W. J., and C. J. Doran, 2001: Observations of systematic boundary layer divergence patterns and their relationship to land use and topography. *J. Climate*. **14**, 1753-1764.

Smith, R. B., and I. Barstad, 2004: A linear theory of orographic precipitation. *J. Atmos. Sci.,* **61**, 1377-1391.

Smolarkiewicz, P. K., and T. L. Clark,1985: Numerical simulation of the evolution of a three-dimensional field of cumulus clouds. Part I: Model description, comparison with observations and sensitivity studies. *J. Atmos. Sci.,* **42**, 502-521