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THE ATMOSPHERE-LAND EXCHANGE INVERSE (ALEXI) MODEL: REGIONAL-SCALE FLUX VALIDATIONS, CLIMATOLOGIES AND AVAILABLE SOIL WATER DERIVED FROM REMOTE SENSING INPUTS

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1. INTRODUCTION

In Anderson et al. (1997) and Mecikalski et al. (1999), we detailed a method for evaluating fluxes of sensible and latent heat at the land surface using an Atmosphere-Land EXchange Inverse (ALEXI) model. 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.[1]

ALEXI is a so-called "two-source" model, the two sources being soil and vegetated components of a scene. Each of these scene subcomponents contributes 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.

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.

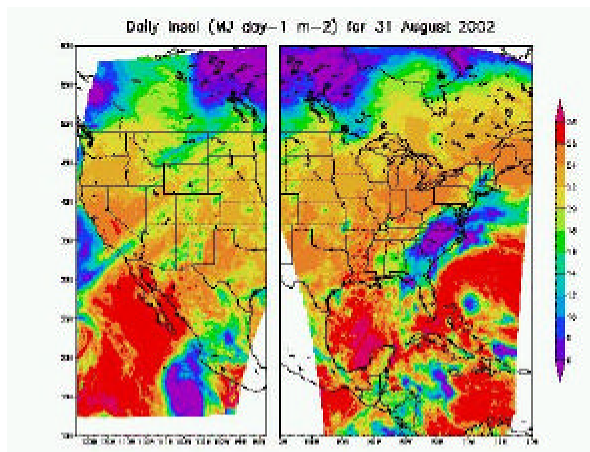

Figure 1: GOES-08 and –10 derived solar insolation as used in the real time ALEXI routine to help formulate net radiation as an input to the ALEXI algorithm.

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. To ameliorate this problem, we have adapted the forecast model component of CIMSS Regional Assimilation System (CRAS, Diak et al.,

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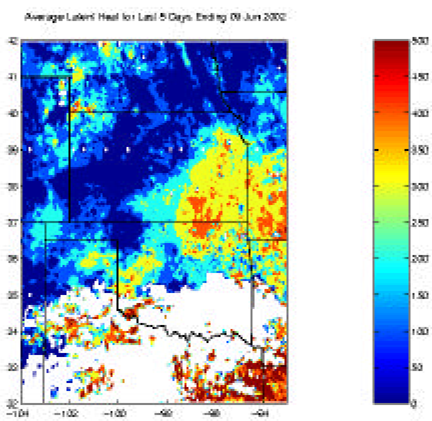
1998) to provide all the required atmospheric and selected other inputs to ALEXI. These inputs are vertical profiles of atmospheric temperature over the ALEXI region at the initial time, as well as wind speed, incident flux of clear-air solar radiation and net thermal radiation at both GOES observation times.

Two similar versions of ALEXI are being tested in real time. The first is identical to that described in Anderson et al. (1997). The second follows the mathematics of so-called "statistical interpolation" (see for example Diak et al. 1995) for a description of these principles applied to remote sensing of the surface energy balance). It has an advantage of being able to easily incorporate other "signals" of the surface energy flux balance, however none have been incorporated to date, and the results of the two methods are thus nearly identical.

a)



b)

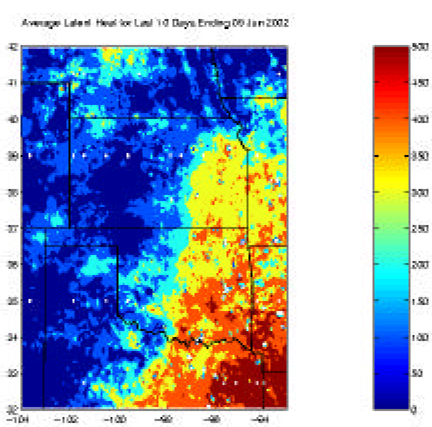


Figure 2: ALEXI-derived 5- and 10-day flux climatologies of latent heat ending on 9 June 2002 over the IHOP_2002 domain. White areas in a) represents regions that were never clear over the five days of this climatology.

2. NEW COMPONENTS OF THE ALEXI MODEL

a) Flux Climatology Work

As of autumn 2002, the ALEXI model is being run in real time over the continental U.S., the Intenational H_2O Project (IHOP_2002) domain of the south-central Great Plains, and the Soil Moisture EXperiment (SMEX) region centered on Iowa. ALEXI estimates four surface flux components (sensible, latent, and ground heats, and net radiation). For the IHOP_2002 and SMEX regions, field-experiment-specific 0.05 x 0.05-degree resolution (~5 x 5 km) fluxes are generated; for the U.S. domain, fluxes on a 0.1 x 0.1-degree grid (~10 x 10 km) are generated. These fluxes are computed at the end of a given day once GOES observations of surface radiometric temperature are available 1.5 hours before local noon across a domain. The ALEXI flux estimates, along with all input variables, are displayed daily on the web at: *kang.ssec.wisc.edu/~alexi/USAlexi_home.html*. The methodology for these flux estimates is outlined in Mecikalski et al. (1999), with new work on the validation of these techniques presented in Mecikalski et al. (2002a,b).

Beginning in the summer of 2002, software development progress, increased computational capabilities, and general improvements to the ALEXI method have allowed us to utilize data from both the GOES-08 and GOES-10 satellite platforms within ALEXI. In particular, ALEXI uses solar insolation computed from both GOES-08 and –10 (Fig. 1), GOES Imager or Sounder data to compute the brightness temperature changes (Imager data to compute 0.05 degree resolution ΔTb's for IHOP_2002 and SMEX, and Sounder data for the U.S. domain at 0.1 degree resolution), and GOES Sounder data for cloud clearing. Diak et al. (2002) outlines the use of all three types of GOES data (1 km, 4 km and 10 km) in ALEXI.

Plans for early 2003 are to make daily 0.1-degree flux estimates for both clear *and* cloud sky regions across the domain; currently, all our methods are limited to clear-sky conditions. An algorithm has been developed to estimate fluxes on cloudy days, when GOES-based surface temperatures are cloud-contaminated, and ALEXI cannot be used. On clear days, it is possible from ALEXI flux estimates to compute an "available water" for a region (described simply as the ratio of actual to potential evapotranspiration, ET). For cloudy days, it is assumed that this available water (estimated separately for the top 5 cm of soil and in the plant root zone) is depleted by an amount consistent with the previous day's available water fraction, also taking into account the cloudy net radiation. A modified Priestley-Taylor algorithm is used for the estimation of ET under cloudy conditions. The sequence continues until the scene again is clear, and ALEXI can once again be used to calculate available water. Such updates correct errors in depletion and any rainfall/drainage that may have occurred during the intervening cloudy period.

This algorithm is currently being tested using flux and surface temperature observations collected at several sites in Oklahoma during the Southern Great Plains (SGP) '97 field experiment, and during the SMEX 2002 campaign in Iowa during June-July 2002. Preliminary results to estimate soil water availability are encouraging.

The overall goal of this portion of the ALEXI project, the first phase to be completed by early 2004, will be to generate a two-year climatology of fluxes across the U.S. Using these data, we may provide to numerical forecast models (like CRAS) estimates of soil moisture, as well as flux partitioning in the form these models require.

Figure 2 illustrates and example of some simple 5- and 10-day flux "climatologies" of latent heat, ending on 9 June 2002 over the IHOP_2002 domain.

b) Oklahoma Mesonet Flux Validation

Collaboration with the University of Oklahoma and the researchers who collect and maintain the Oklahoma Mesonet has provided this project an excellent validation data set for ALEXI flux estimates. For the 2000 and 2001 growing seasons, Mesonet fluxes for 24 clear days across Oklahoma region are being directly compared with ALEXI 0.05-degree flux estimates.

The results to date are generally agree within with the 15-50% errors typical of in-situ surface flux measurements.

c) Flux Disaggregation to 30-m Scales

While the scale of ALEXI flux estimates is limited by the 4- to 5-km scale of the GOES thermal measurements required to compute time-changes of radiometric temperatures, there are many uses for surface fluxes/ET estimates at finer spatial scales. Our ALEXI 0.05 degree-resolution flux-to-Mesonet station comparison work demonstrates suggests there is a need to identify how well we can estimate land surface fluxes on the scales measured by the Oklahoma Mesonet stations, specifically, on scales from 30-100 m.

Ongoing experiments are being conducted "disaggregating" the 0.05 and 0.1-degree fluxes output from ALEXI to the 30-meter scale. This procedure, termed "Disaggregated-ALEXI", or "DisALEXI", has been outlined by Norman et al. (2002), and incorporates inputs from high-resolution remote sensing instruments, as flown on LandSat or aircraft. The motivation for the DisALEXI approach is to attain accurate ET estimates on scales representing individual farm fields and native ecosystems. In addition, the DisALEXI approach relinquishes the need for direct surface measurements while taking advantage of single-instrument remote sensing technologies.

The DisALEXI method is described as follows: 1) use ~5-km values of radiometric temperatures from GOES, atmospheric information (the temperature profile at the initial time and humidity and wind at two times), and vegetation cover observations from AVHRR (also averaged to 5 km) are used in ALEXI to estimate fluxes and 50-m air temperature (T_a) at this 5-km scale, 2) LandSat 30-m-resolution fraction vegetation cover and 60-m resolution radiometric temperature information (T_{radL}), are used a "two-source" (Norman et al. 1995) model of turbulent heat and moisture exchange. The 5-km output of ALEXI atmospheric quantities (wind, temperature, humindity) are used as top boundary conditions in this model, the outputs of which are sensible heat, latent energy, net radiation, and soil heat flux for each LandSat pixel resolution.

These 30-meter fluxes are approximately at the same scale as measurements from the Oklahoma Mesonet stations. Aircraft flux data collected during the SGP '97 experiments is also being used to validate our ALEXI estimates and the DisALEXI procedures. As a final check, the 30-meter DisALEXI fluxes are re-aggregated back to 0.05-degree ALEXI estimates and these flux results compared.

Figure 3 displays the resolution DisALEXI processing with images of LandSat-ETM+ derived fraction vegetation cover at 30-m resolution over a 5-km x 5-km (the size of an ALEXI pixel) area. Figure 4 shows latent heat flux derived from DisALEXI at 30-m resolution on 12 August 2000. One Mesonet station is located within this 5-km x 5-km box, as shown in Fig. 3. Our flux validation via of DisALEXI method is limited by the requirement of obtaining LandSat images on a clear day in Oklahoma when Mesonet data is also available. On a given LandSat image, a maximum of only 10-15 Mesonet stations can be directly compared with DisALEXI flux estimates.

To date, the DisALEXI approach has been applied to four Mesonet "SuperSite" stations in Oklahoma during 2000. Figure 5 shows these component flux results. Processing to perform similar DisALEXI work will occur for four other Mesonet sites during 2001. Analysis using the four stations was performed on 29 May and 12 August, and in southeast and west central Oklahoma. Hence, this analysis shows that the DisALEXI (and ALEXI) procedures are land-cover independent, performing very well in wet and dry conditions with widely varying soil and cover characteristics.

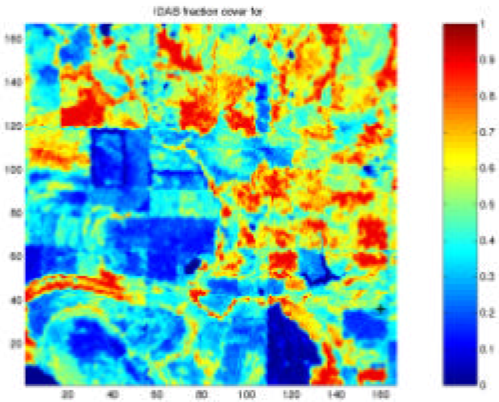


Figure 3: LandSat-ETM+ derived fraction vegetation covers for a 5 km x 5 km (ALEXI pixel) region on 12 August 2000 surrounding the Mesonet station near Idabelle, Oklahoma.

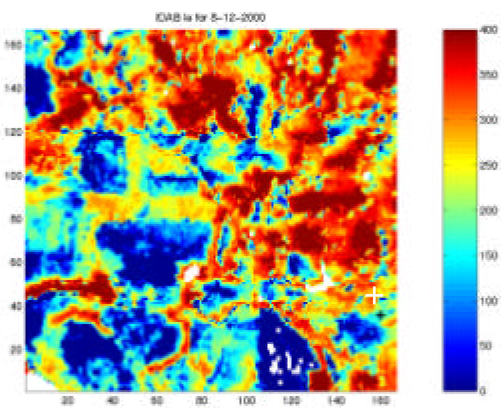


Figure 4: DisALEXI simulated latent heat fluxes for the 5 km x 5 km box above for 12 August 2000. The "+" in the lower right of this image denotes the location of the Idabelle, Oklahoma (IDAB) Mesonet station.

Figure 5 shows that for net radiation, ground heat and sensible heat, absolute errors are approximately 5-8%, while for latent heat (the residual in the ALEXI method; Anderson et al. 1997), error are nearer 8-10 %. These results are within the limits of many past remote sensing flux estimation procedures (see Diak et al. 2002).

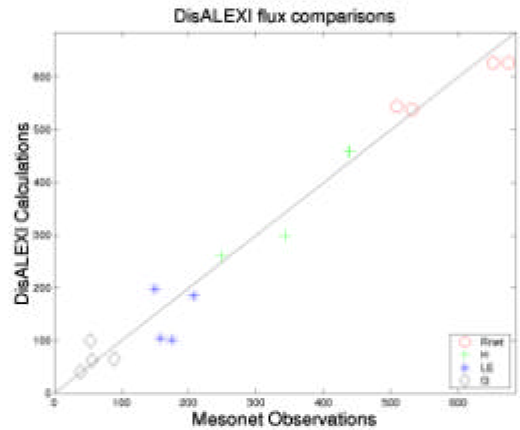


Figure 5: Component flux results comparing DisALEXI simulated fluxes against those from four Mesonet sites during 2000 (IDAB and STIG for 12 August, and BESS and ALV2 for 29 May). These reults show that the 0.05 x 0.05 degree box-averaged fluxes can be used with LandSat-ETM+ data to provide 30-meter resolution fluxes, applicable in this case to these individual Mesonet sites. Corrections for the flux "footprint" for all days studied have not been performed.

3. ONGOING WORK

Work with the ALEXI model continues in earnest. Through 2002, we plan on having ALEXI fluxes for the entire US, with the construction of the flux climatology now well underway. Formal reporting of the ALEXI-Oklahoma Mesonet flux validation and DisALEXI procedures is forthcoming. We also plan to explore the incorporation of our daily flux and soil moisture estimates as boundary conditions in numerical weather forecast model at CIMSS, as well as explore the use of MODIS data (imagery and products) within the ALEXI and DisALEXI systems.

New work on this subject has been submitted (Diak et al. 2002), and is in progress (Mecikalski et al. 2002a,b; Norman et al. 2002). Norman et al. (2002) outlines the DisALEXI procedure as applied to the LandSat-ETM+ image processing as described above.

4. ACKNOWLEDGEMENTS

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