NASA Earth System Science Fellowship

# The Effects of Remotely Sensed Data on Modeled Land-Surface Atmosphere Interactions: Consequences for Global Carbon Balance Research

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## INTRODUCTION

Most modeling efforts of land-atmosphere interactions at regional and global scales rely to some extent on remotely sensed inputs, either to represent surface processes or to provide state variables. The advantage of using remote sensing in environmental modeling is its ability to provide parameter fields not easily measured, either temporally or spatially, at the ground surface. However, as spatial scales increase from local to regional to global, the modeled interactions between the land surface and the atmosphere may vary because of changing landscape heterogeneity and contrasting surface properties. It is therefore important to understand more fully the contribution of remotely sensed data to modeled results if we are to have confidence in them and use them appropriately. Currently, the relationships between ground measurements and remotely sensed data, and the sensitivity of land surface and atmospheric models to remotely sensed inputs, are not well resolved.

The proposed research was designed to examine the effects of remotely sensed data on the modeled results of land surface and atmospheric models. Two approaches were used. First, the sensitivity of a complex land surface model to its parameters was evaluated through the use of a Monte Carlo style analysis. Second, the sensitivity of modeling results to land surface heterogeneity and the ability of models to capture system dynamics at the reduced spatial resolutions of the remotely sensed inputs was assessed through the use of a coupled land-surface-atmosphere model. In particular, the research reported here focuses on the exchange of $CO_2$ between the land surface and the atmosphere and what the consequences of different representations of land surface heterogeneity might be for regional predictions of net ecosystem exchange (NEE).

## SUMMARY OF ACCOMPLISHMENTS

- The Simple Biosphere Model v.2 was parameterized and run for the WLEF tall tower site in Park Falls, Wisconsin
- The single point version of the model was tested against observations
- The Generalized Likelihood Uncertainty Estimation (GLUE) methodology was used to evaluate the sensitivity of the SiB2 model to its parameterization
- Mesoscale parameter sets were generated for a 1200 x 1200 km area centered on the WLEF tower
- Experiments were conducted using the coupled SiB2-Regional Atmospheric Modeling System (RAMS) model to test the sensitivity of regional predictions of net ecosystem exchange to changes in surface heterogeneity associated with changes in spatial resolution.
- One first author paper has been submitted and two are in preparation
- The investigator was coauthor on two additional papers that have been submitted
- Five first author presentations were given at national and international conferences
- The investigator was coauthor on six additional conference presentations.
- This investigator is now ABD with degree completion expected in 2/02

## STUDY AREA

The modeling domain for this work consists of approximately 1200 x 1200 km in the north-central United States and south-central Canada (Figure 1). It extends from 85W, 50N to 95W, 40N and covers a broad range of vegetation types, from deciduous broadleaf and conifer forests to grasslands and agriculture as well as parts of the great lakes. Located within the Chequamegon National Forest and near the center of the domain is the WLEF-TV tower (90.28W, 45.95N). Micrometeorological, eddy covariance and $CO_2$ concentration measurements have been made since 1995 on this tall tower (a 500 m TV relay tower) (Bakwin *et al*. 1999). The concentration measurements are made at six heights: 11m, 30m, 76m, 122m, 244m, 396m; the eddy covariance measurements are made at three heights: 30m, 122m, 396m. Studies are being undertaken at the tall tower and in the surrounding region to assess the exchange of $CO_2$ and energy between the forest and atmosphere and the processes contributing to these fluxes. Additional studies address questions of scale, measurement of regional surface processes by remote sensing and the role of atmospheric boundary layer dynamics in regulating the carbon dioxide concentration near the ground. Collectively, these studies form the Chequamegon Ecosystem Atmosphere Study (ChEAS) (for details see http://cheas.psu.edu/).

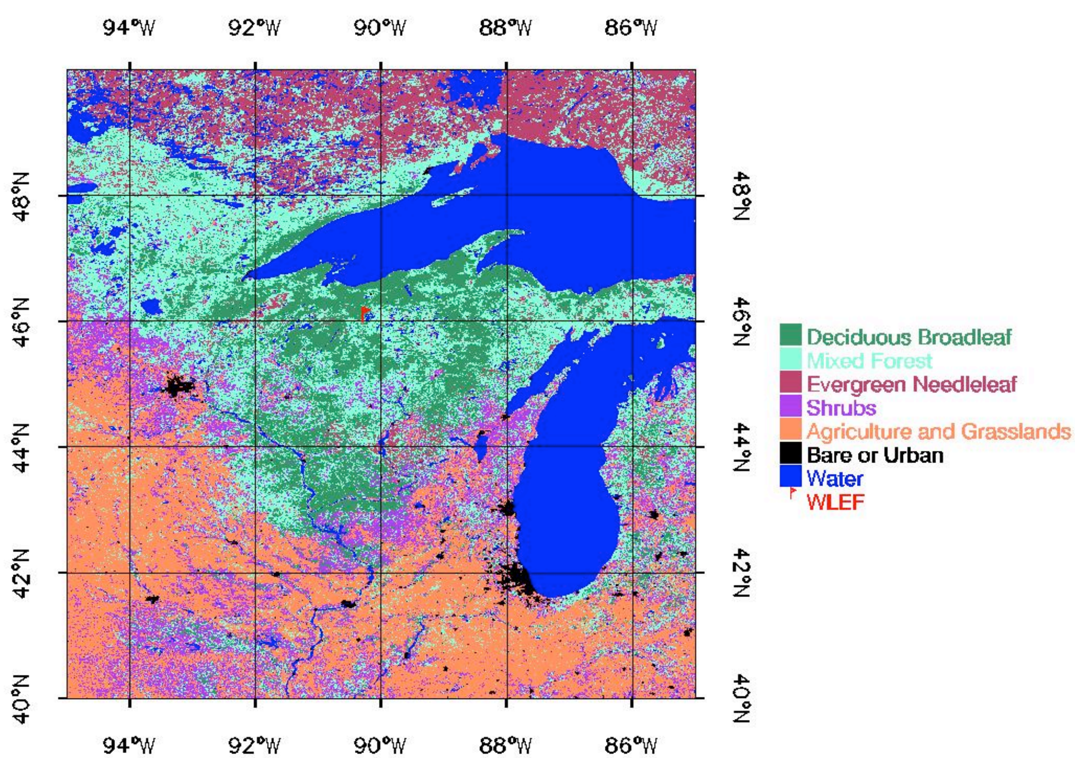


**Figure 1.** Mesoscale modeling domain centered on the WLEF tall tower site in Park Falls, Wisconsin. The vegetation classes were derived from the 1km map produced by Hansen *et al* (2000) remapped to SiB2 classes.

This modeling domain was chosen because of the numerous measurements being made in the area and because the tall tower affords a unique suite of measurements at multiple heights representing multiple spatial scales on the land surface. The results presented in this report focus on the growing season (April - September) of 1997.

## RESULTS

### *Single Point Simulations with the Simple Biosphere Model*

The Simple Biosphere Model v.2 (Sellers *et al* 1996a) is a single canopy layer scheme describing the transfers of heat, water and carbon in the soil-vegetation-atmosphere continuum. It is formulated to be driven with remotely sensed imagery and can be run at a single point or coupled to mesoscale or global atmospheric models. SiB2 was parameterized and run for the WLEF tall tower site in Park Falls, Wisconsin. The model was parameterized using the methodology described in Sellers *et al* (1996b) and Los *et al* (2000) with modifications for the site and input data. Specifically, for soil input data, percentage of sand and clay derived from the STATSGO soil database was used (Soil Survey Staff 1994), for land surface characteristics the 1km land cover type map from Hansen *et al* (2000) and the 1km Advanced Very High Resolution Radiometer (AVHRR) data product described in Teillet *et al* (2000) were used. The satellite data was from 1995/96, however continuous flux measurements (no excessively large gaps) were not achieved at the tall tower site until 1997. While this does not pose a significant problem during the height of the growing season, green-up and leaf-fall are slightly offset.

Soil thermal and hydraulic properties were determined using equations from Clapp and Hornberger (1978) as modified by Bonan (1996). Soil moisture was initialized using a 12-year spin-up of the model, where three years of meteorological data were recycled four times. Soil respiration was parameterized following Raich *et al* 1991 and Denning *et al* 1996. Time varying vegetation parameters and soil respiration were calculated from a representative flux footprint. For WLEF, two sets of boundary conditions were created; one for a typical footprint of flux measurements made at 30m above the surface, one for a typical footprint of flux measurements made at 122m above the surface. These footprints are meant to incorporate the primary source region of the measured fluxes and were based on simulations conducted by Marek Uliasz (Colorado State University, personal communication) and the prevailing wind direction for the site. For the 30m footprint, a 9 $km^2$ region was extracted from the NDVI data. For the 122m footprint a 24 $km^2$ region was extracted from the NDVI data. The model does well simulating the observed pattern of net ecosystem exchange (NEE) at 122 meters for the WLEF site (Figure 2a). The only exception is in the late afternoon where modeled NEE exceeds the measurements. It is not yet clear why this is the case, but one possibility is that late afternoon shadowing is not being properly accounted for. Modeled and measured latent heat fluxes (LE) also compare very well (Figure 2b). For sensible heat flux (H) (Figure 2b), however, the model consistently overestimates H as compared to measurements. It appears this is some combination of measurement and model errors.

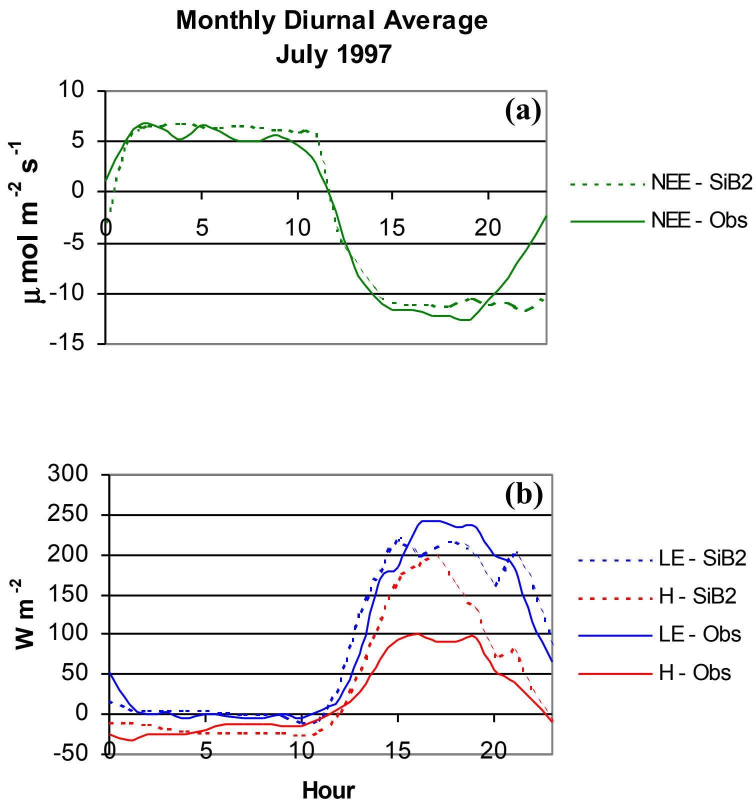


**Figure 2.** Monthly diurnal average plots from July 1997 of observed versus simulated net ecosystem exchange **(a)** and latent and sensible heat flux **(b)** at the WLEF tall tower site.

### *Sensitivity Analysis*

Once the ability of SiB2 to adequately simulate $CO_2$ exchange at the WLEF site was established, the Generalized Likelihood Uncertainty Estimation methodology (GLUE, Beven and Binley, 1992; Freer *et al*, 1996) was used to evaluate the sensitivity of SiB2 to its parameterization. Specifically, the objective was to identify parameters related to remotely sensed data to which SiB2 was particularly sensitive and which would therefore require special consideration. GLUE utilizes a Monte Carlo style methodology to explore the relative worth of parameters and the uncertainty associated with predictions. It can be used to optimize a model or to investigate model sensitivities (as in this case).

Forty-six SiB2 parameters were randomized within physically realistic ranges, including thirty-five related to vegetation and eleven related to soil, to produce 10,000 random parameter sets (Table 1). In certain cases it is not physically realistic to randomize parameters independently. For example canopy base height (Z1) cannot be higher than canopy top height (Z2). Six parameters were consequently made dependent on other parameters (Table 2). Ten thousand 6-month simulations were run and the root mean square difference (RMSD):

$$RMSD = \frac{\sqrt{\sum (obs - est)^2}}{n - 1}$$

was calculated between observations and simulations of NEE, LE and H for the entire six month period and for each individual month. Cumulative frequency and scatter plots were created for each parameter for each predicted quantity for each time period (966 plots). Figures 3 and 4 show an example of the plots and how to interpret them.

**Table 1.** The 46 SiB2 related parameters that were randomized for the GLUE runs. The minimum and maximum values give the range of the parameter; the WLEF value refers to the site-specific values used for the WLEF tall tower site.

| Parameter | Definition | Minimum Value | Maximum Value | WLEF Value |
|---|---|---|---|---|
| **Vegetation** | | | | |
| Z2 | Canopy top height (m) | 15.0 | 30.0 | 20.0 |
| Z1 | Canopy base height (m) | 3.0 | 24.0 | 10.0 |
| ZC | Canopy inflection height (m) | 6.6 | 28.8 | 15.0 |
| VCOVER | Vegetation cover fraction | 0.7 | 1.0 | 0.9875 |
| CHIL | Leaf angle distribution factor | -0.5 | 0.5 | 0.125 |
| ROOTD | Rooting depth (m) | 0.1 | 3.6 | 1.5 |
| PH | ½ critical leaf water potential (m) | -450.0 | -50.0 | -200.0 |
| TRAN11 | Green leaf transmittance (PAR) | 0.0 | 0.1 | 0.05 |
| TRAN21 | Green leaf transmittance (NIR) | 0.05 | 0.3 | 0.15 |
| TRAN12 | Brown leaf transmittance (PAR) | 0.0 | 0.1 | 0.001 |
| TRAN22 | Brown leaf transmittance (NIR) | 0.0 | 0.1 | 0.001 |
| REF11 | Green leaf reflectance (PAR) | 0.02 | 0.2 | 0.07 |
| REF21 | Green leaf reflectance (NIR) | 0.2 | 0.5 | 0.38 |
| REF12 | Brown leaf reflectance (PAR) | 0.05 | 0.25 | 0.16 |
| REF22 | Brown leaf reflectance (NIR) | 0.2 | 0.5 | 0.42 |
| VMAX0 | Rubisco velocity of sun leaf (mol $m^{-2}$ $s^{-1}$) | 2.5E-5 | 15E-5 | 7.5E-5 |
| EFFCON | Quantum efficiency (mol $mol^{-1}$) | 0.03 | 0.13 | 0.08 |
| GRADM | Conductance-photosynthesis slope parameter | 3.0 | 18.0 | 9.0 |
| BINTER | Minimum stomatal conductance (mol $m^{-2}$ $s^{-1}$) | 0.0 | 0.02 | 0.01 |
| ATHETA | Light and rubisco coupling parameter | 0.5 | 1.0 | 0.98 |
| BTHETA | Light, rubisco and CHO sink parameter | 0.5 | 1.0 | 0.95 |
| TRDA | Respiration temperature response ($K^{-1}$) | 0.1 | 1.5 | 1.3 |
| TRDM | Respiration inhibition ½-point temperature (K) | 294.32 | 338.8 | 328.16 |
| TROP | Respiration optimum temperature (K) | 283.0 | 308.0 | 298.16 |
| RESPCP | Leaf respiration fraction of Vmax | 0.01 | 0.1 | 0.015 |
| SLTI | Photosynthesis low temperature response ($K^{-1}$) | 0.1 | 1.5 | 0.2 |
| SHTI | Photosynthesis high temperature response ($K^{-1}$) | 0.1 | 1.5 | 0.3 |
| HLTI | Photosynthesis low temperature inhibition ½-point (K) | 270.0 | 290.0 | 280.66 |
| HHTI | Photosynthesis high temperature inhibition ½-point (K) | 280.8 | 319.0 | 307.16 |
| LWidth | Leaf width (m) | 0.003 | 0.1 | 0.04 |
| Llength | Leaf length (m) | 0.03 | 0.4 | 0.1 |
| LTMAX | Maximum leaf area index | 4.0 | 9.0 | 7.5 |
| STEM | Stem area index | 0.0 | 0.25 | 0.08 |
| ND98 | $98^{th}$ percentile NDVI (over 12 months, by biome) | 0.5 | 1.0 | 0.686 |
| ND02 | $2^{nd}$ percentile NDVI (over 12 months, by biome) | 0.0 | 0.1 | 0.034 |
| **Soil** | | | | |
| BEE | Soil wetness exponent | 4.0 | 8.5 | 5.39 |
| PHSAT | Soil water potential at saturation (m) | -0.05 | -0.35 | -0.15 |
| SATCO | Saturated hydraulic conductivity | 2.5E-6 | 100E-6 | 7.0E-6 |
| POROS | Soil porosity | 0.4 | 0.5 | 0.45 |
| SLOPE | Cosine of mean terrain slope | 0.1 | 0.25 | 0.1736 |
| WOPT | Optimal percent of soil saturation for respiration | 30.0 | 80.0 | 62.7 |
| ZM | Skewness exponent of respiration vs. soil water | -0.2 | 0.5 | 0.359 |
| WSAT | Respiration rate at soil water saturation coefficient | 0.5 | 0.8 | 0.545 |
| SODEP | Soil depth (m) | 0.5 | 4.0 | 2.0 |
| SOREF1 | Soil reflectance (PAR) | 0.01 | 0.4 | 0.0985 |
| SOREF2 | Soil Reflectance (NIR) | 0.011 | 0.6 | 0.2586 |

**Table 2.** Specific parameter dependencies for randomization.

| *Parameter* | *Dependency* | *Where R is randomized between:* |
|---|---|---|
| Z1 | = Z2 * R | 0.2 – 0.8 |
| Rootd | = Sodep * R | 0.2 – 0.9 |
| TRDM | = TROP * R | 1.04 – 1.1 |
| HHTI | = HLTI * R | 1.04 – 1.1 |
| Soref2 | = Soref1 * R | 1.1 – 1.5 |
| ZC | = ((Z2-Z1) * R) + Z1 | 0.3 – 0.8 |

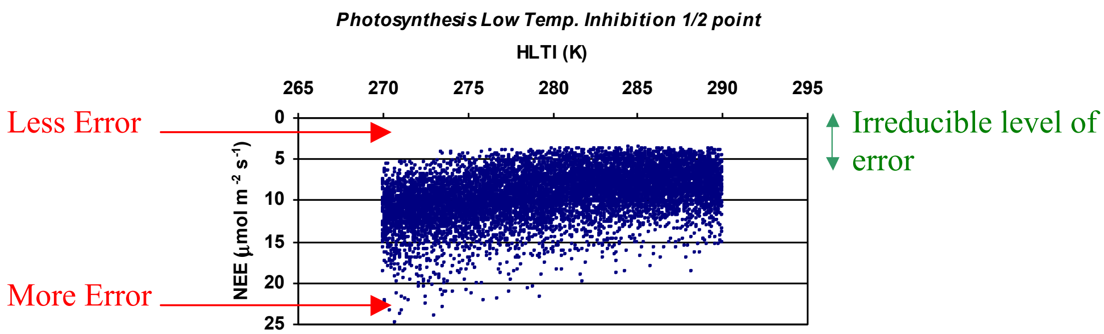


**Figure 3.** Example scatter plot showing the RMSD error in the predicted quantity on the y-axis (NEE) and the parameter range on the x-axis for 10,000 simulations. This scatter plot shows some structure that is more clearly seen in the cumulative frequency plot in figure 4.

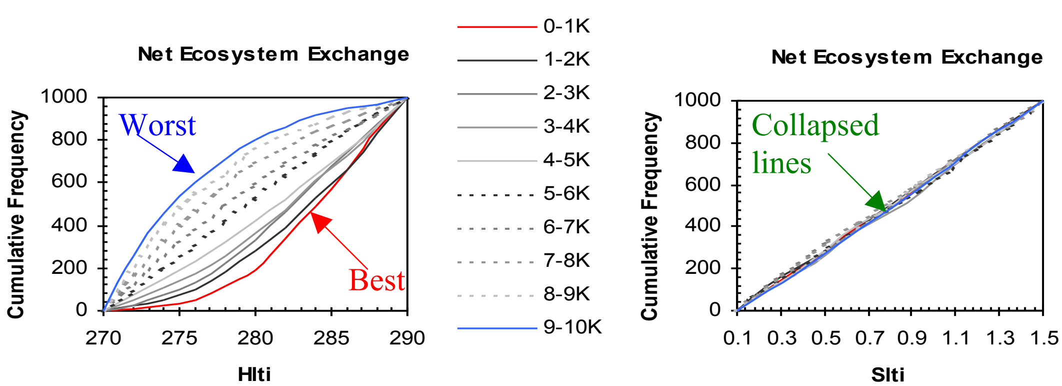


**Figure 4.** Example cumulative frequency plots. The plot on the left shows the scatter plot from figure 3 broken down into ten classes of 1000 simulations each and plotted by cumulative frequency. The best 1000 simulations are denoted by the red line; the worst 100 simulations are denoted by the blue line. The area of the steepest slope on the red line corresponds to the best parameter/parameter range. If all the lines collapse (slope = 1 for all lines), as in the right-hand plot, the model is insensitive to that parameter (here SLTI) in terms of predicting that particular quantity (here NEE).

All of the cumulative frequency plots were evaluated and the overall results show that:

a) Parameter influence varies for NEE, LE and H over the length of the simulation
b) Optimal parameter ranges vary according to the predicted quantity
c) Parameter influence and optimal parameter range can vary by month for any predicted quantity relative to changing environmental conditions

For parameters that are or could be retrieved from remotely sensed data the results show that:

a) All predicted quantities (NEE, LE, H) are sensitive to the parameterization of the fraction of absorbed photsynthetically active radiation (fPAR), particularly during green up and leaf fall. This is evidenced in the parameters ND98 and vcover, which are used in the calculation of fPAR from NDVI.
b) Both LE and H are sensitive to soil reflectance. Currently this is not parameterized with great confidence and is something that might be retrievable via remotely sensed data.
c) Additionally, sensible heat flux is sensitive to reflectance and transmittance of green vegetation in the near infrared wavelengths.

Further, the results indicate particular sensitivity overall to parameters related to photosynthesis and respiration, such as Vmax (maximum rubisco capacity), HLTI/HHTI (Photosynthesis low/high temperature inhibition 1/2 point), GRADm (conductance-photosynthesis slope parameter), and Wopt (optimal percent of soil saturation for respiration), among others, and to hard to obtain parameters such as soil and rooting depth.

There are two generalities that emerge from this work that are important and interesting to consider. There is an irreducible level of error that we encountered between simulated and observed fluxes. This was surprising given the number of simulations performed. In ten thousand simulations the RMSD error between observed NEE and simulated NEE never went below 3.5 $\mu$mol $m^{-2}$ $s^{-1}$ for the six month calculations. This 'irreducible' level of error varied by month from as little as 1 $\mu$mol $m^{-2}$ $s^{-1}$ in April when fluxes of $CO_2$ are relatively small to 4.4 $\mu$mol $m^{-2}$ $s^{-1}$ in August when fluxes are much larger and was also present in the predictions of LE and H. Two possible reasons for this are that models are not always capable of 'going out of the box' and simulating unforeseen combinations of environmental and physical conditions and/or that the observations themselves have an inherent level of noise.

This work also suggests that the simultaneous prediction of NEE, LE and H helps to better constrain the model. Models with large numbers of parameters, such as SiB2, are more likely to exhibit some degree of *equifinality* than are models with fewer parameters. *Equifinality* occurs when compensation between parameters results in physically realistic simulations across a wide range of parameter sets (Franks *et al* 1997; Franks 1998). The additional constraint that the simultaneous prediction of NEE with LE and H adds is demonstrated by the sensitivity of predictions of LE and H to some of the photosynthesis related parameters.  The better constrained a model is the more confidence we have in its predictions.

### *Land Surface Scaling Experiments*

Mesoscale parameters sets were then generated for the whole 1200 x 1200 km area surrounding the WLEF tower (Figure 1). SiB2 parameters were calculated for each individual pixel (see Figure 5 for an example). This procedure was similar to that of generating the boundary conditions for a single point run with a few exceptions.  Soil moisture was not known over the entire grid so as an alternative we used the initial moisture from WLEF and weighted it across the domain by soil type.  Soil respiration was parameterized by biome rather than at each point since the parameterization we use requires an annual simulation and more than one million simulations would have been required.

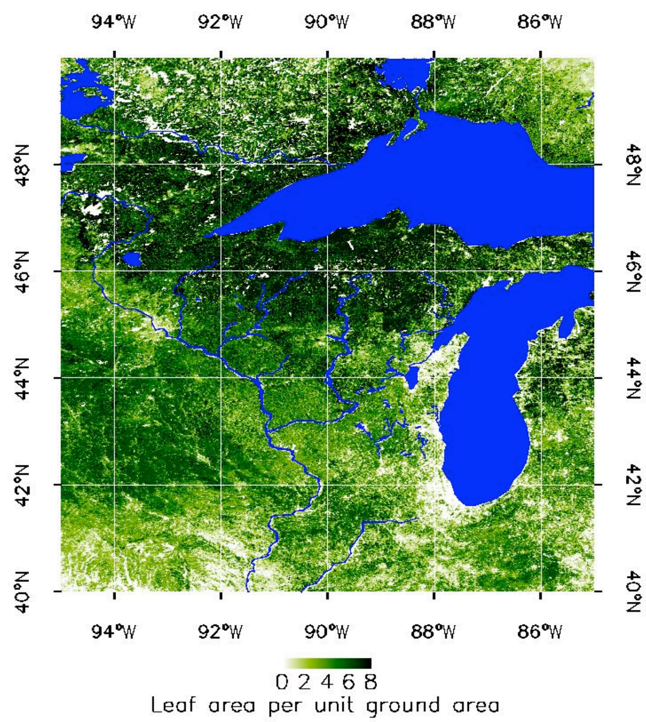


**Figure 5.** Leaf area per unit ground area (LAI) for the mesoscale domain, July 1995.  Leaf area index is one of 8 time-varying parameters required by SiB2.

To address the question of whether regional predictions of net ecosystem exchange are sensitive to changes in surface heterogeneity associated with changes in spatial resolution an additional data set at a coarser resolution was created and regional simulations using a version of the SiB2 model coupled to the Regional Atmospheric Modeling System version 4.29 (RAMS; Pielke *et al*, 1992) were preformed.  RAMS is a general purpose non-hydrostatic atmospheric model with bulk microphysics.  It utilizes a nested grid structure and can be run at resolutions from hemispheres to 100's of meters or less.

‘Effective’ 8km boundary conditions were created from the 1km data. Vegetation type was assigned by the dominant class in an 8 x 8km area (Figure 6). Soil percent sand and clay and monthly maximum NDVI were area averaged to 8km. Boundary conditions for the 8km simulations were calculated at 8km and then disaggregated to 1km. This was done because the resolution of the center grid of the SiB-RAMS simulations was kept 1km for intercomparability of results.


**(a)** **(b)**

**Figure 6.** The 640 x 640 km SiB-RAMS modeling domain vegetation class at **(a)** 1km and **(b)** 8km resolution.

The SiB2-RAMS simulations were set up with 3 nested grids: a 640 x 640km outer grid with 16km resolution, a 160 x 160km middle grid with 4km resolution and a 38 x 38km fine grid with a resolution of 1km. The time steps for each grid are respectively 45,15 and 5 seconds. Twenty-three atmospheric levels were simulated and $CO_2$ concentration was initialized at 360ppm. The coupled model was forced with NCEP reanalysis data for July 26, 1997 through July 31, 1997 and hourly outputs of NEE, LE and H were produced.

Figure 7 shows measured and simulated NEE at the WLEF tall tower site extracted from the coupled simulations. Measured NEE is plotted together with the offline simulations of SiB2 reported above and modeled fluxes from the 1km and 8km SiB2-RAMS simulations. The offline and 8km simulations approximate measurements more closely that the 1km simulation. The tower flux measurements respond to an area of approximately 4-20 $km^2$ (M. Uliasz, personal communication) thus the offline (with boundary conditions corresponding to a 4x6km area and measured meteorology) and 8km simulations may better represent these area-averaged fluxes. An area average NEE corresponding to 8 x 8km calculated from the results of the 1km simulations more closely matches the observations for this same reason. Overall, the results show that the coupled simulations are able to simulate the exchange of $CO_2$ between the surface and atmosphere quite well.

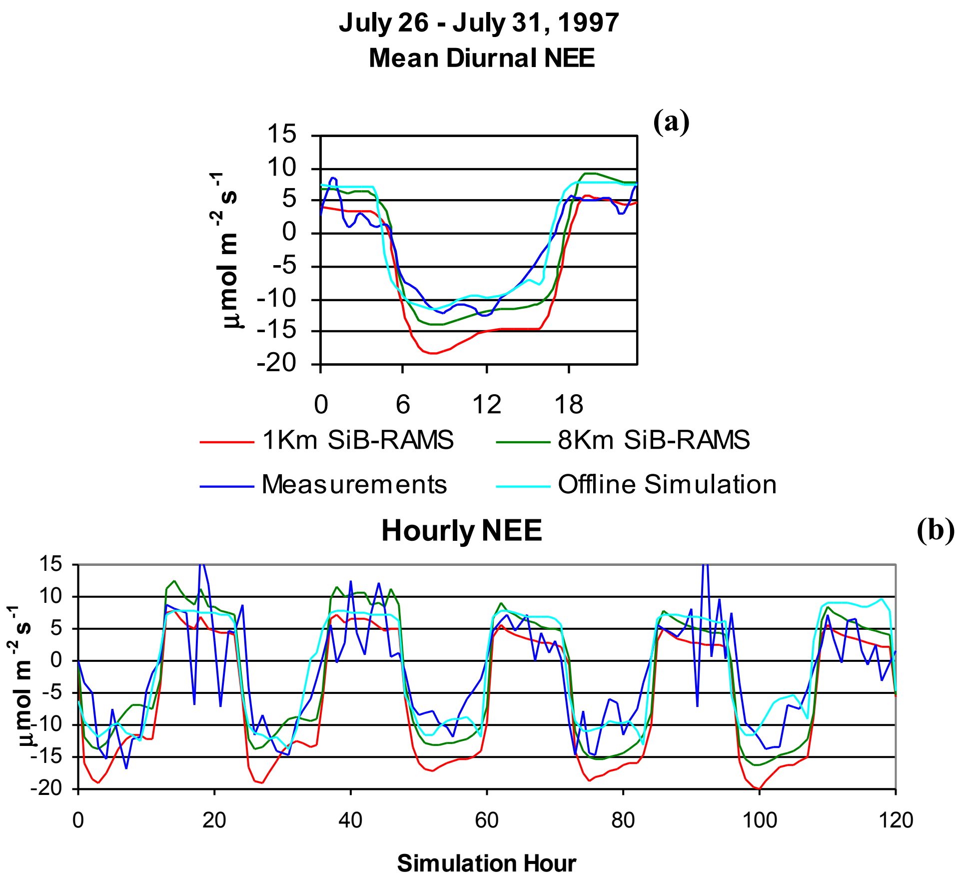


**Figure 7.** Measured and simulated Net Ecosystem Exchange at the WLEF tall tower site. **(a)** Mean diurnal NEE for July 26-31, 1997 **(b)** Hourly NEE for the 5 day simulation.

An example of the SiB2-RAMS simulations for the entire center grid is shown in Figure 8. The 1km data (Figure 8a) show much greater heterogeneity in NEE (shown), LE and H. Water features are poorly represented in the aggregated data (Figure 8b) and consequently the largest differences between the two simulations (8km – 1km, Figure 8c) result from edge effects around lakes, though smaller differences on the order of +/- 5µmol $m^{-2}$ $s^{-1}$ are present throughout the grid.

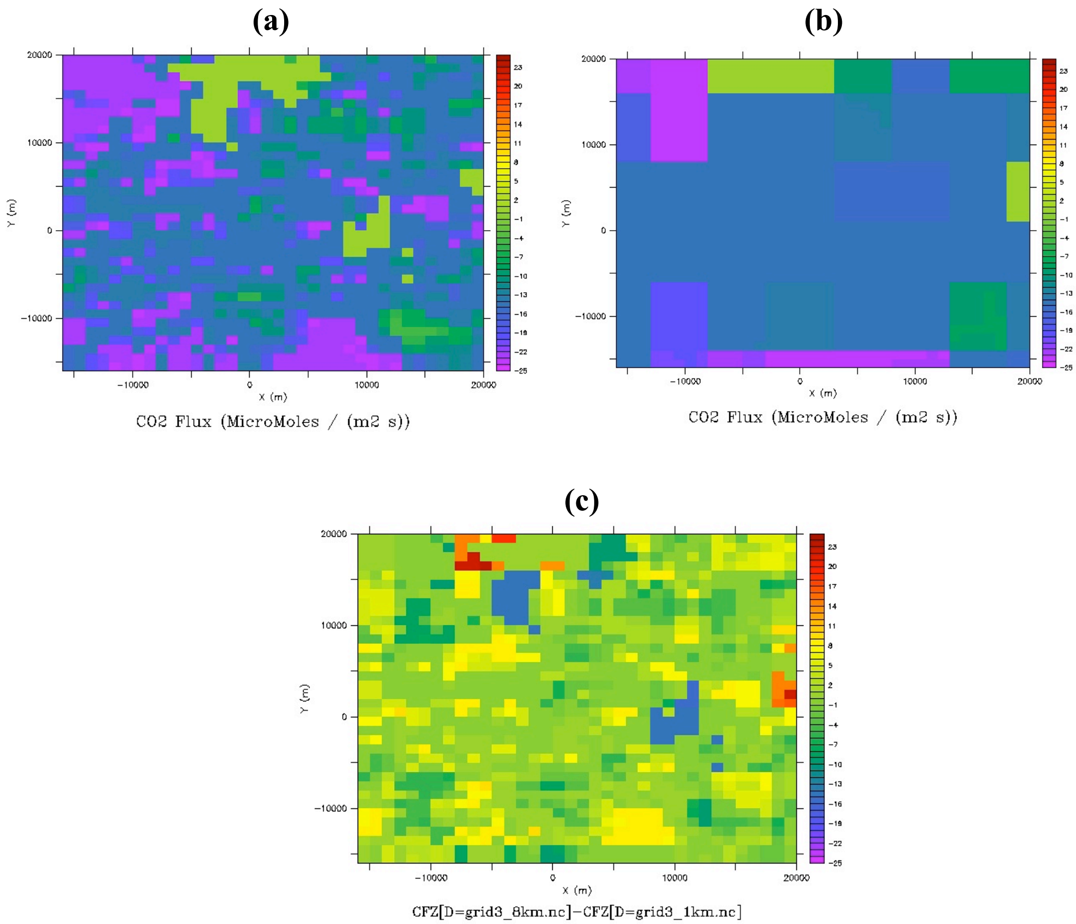


**Figure 8.** SiB2-RAMS simulation results for NEE at 12:00 noon, day 4 of the simulation for the fine grid (38 x 38km). **(a)** 1km simulations **(b)** 8km simulation **(c)** 8km – 1km difference

To better evaluate these differences, the grid mean (for the entire 38 x 38km fine grid) was calculated for NEE, LE and H for both the 1km and 8km simulations. The grid mean NEE shows more difference between the 1km and 8km simulations that the latent and sensible heat flux do (Figure 9a,c,e), though it is quite small ~1µmol $m^{-2}$ $s^{-1}$. However, over time these small differences (more persistent in nighttime respiration) begin to accumulate and lead to a larger divergence of the simulations over time (Figure 10b). Cumulative divergence in LE and H over time appears to be relatively smaller than NEE (Figure 10d,f), perhaps because of direct feedback between land surface temperature and moisture and the fluxes.

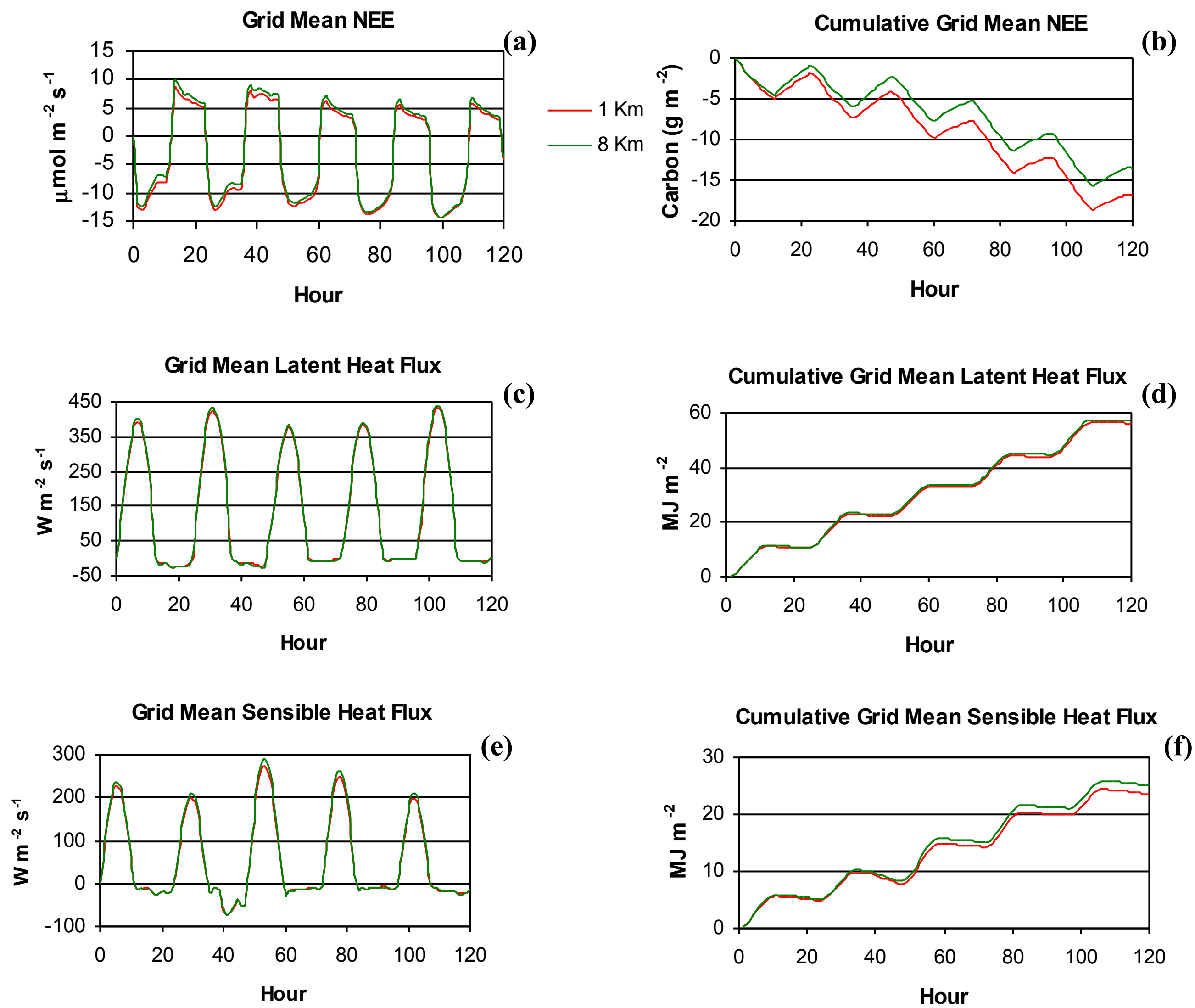


**Figure 10.** SiB2-RAMS simulation results for the entire fine grid (38 x 38km) for the 1km and 8km grids through time. **(a,c,e)** hourly grid means for NEE, LE and H and **(b,d,f)** cumulative grid means for NEE, LE and H.

Because regional fluxes of quantities such as net ecosystem exchange, latent and sensible heat flux are largely unknown, it's not possible to say which result is correct. However, these results do suggest that although grid mean values of NEE over time are not significantly different between the fine and coarse resolution surfaces, cumulative sums of NEE on a regional basis may be sensitive to the level of representation of land surface heterogeneity. Therefore, when regional predictions of NEE are made, particularly if predictions of cumulative NEE are made over time, some accounting should be made for the representativeness of the surface. As aircraft measurements of regional NEE become more available, it should be possible to test the accuracy of simulations such as these.

## CONCLUSIONS

The research reported here was designed to examine the effects of remotely sensed data on the modeled results of land surface and atmospheric models with a particular emphasis on the exchange of $CO_2$ between the land surface and the atmosphere. Single point simulations demonstrated the ability of the SiB2 model to reproduce land surface fluxes of latent and sensible heat as well as net ecosystem exchange at the WLEF tall-tower site in Park Falls, Wisconsin. A detailed sensitivity analysis of SiB2 identified parameters that the model was sensitive to and showed that parameter influence is variable, both in time and depending on the predicted quantity. The sensitivity analysis also revealed that the simultaneous prediction of latent and sensible heat flux along with net ecosystem exchange helped to better constrain the model and the parameter space. Further, there was an irreducible level of error when comparing observations to model results that appears to be due to both model limitations and noise in the observations themselves.

Simulations using the coupled SiB2-RAMS model and varying surface resolutions demonstrated that differences in the representation of the land surface could lead to different results. Grid mean values of net ecosystem exchange over time were not significantly different between the fine and coarse resolution simulations. However, cumulative sums of whole grid net ecosystem exchange were different and the two simulations began to diverge through time. This divergence was attributed to subtle differences in the representation of the land surface, for example the amount of water represented and the amount of land surface covered by the different vegetation types. It is also possible that the loss of the more extreme values of the input data in the coarse resolution simulations led to some of the divergence. The divergence was less clear for sensible and latent heat flux, perhaps because both temperature and water flux are self-regulating and subtle corrections are made at each time step in relation to energy balance. In SiB2, $CO_2$ flux is not physically limited in the same way.

The results of this research indicate that as scales of observation change, how landscape heterogeneity is represented in models can lead to quantitatively different results. Small variations in parameterizations and representations of the land surface can lead to accumulated differences through time. This is seen from the scale of a single point, where one must consider the spatial footprint of the observations, up through regional analyses where large areas of the land surface are considered. Understanding and quantifying these differences is essential because remote sensing is the critical link we use in process modeling to go from local to regional to global scales.

## PEER REVIEWED PUBLICATIONS FROM THIS RESEARCH

**Prihodko, L**., Denning, S., Schaefer, K. and Krebs, T., Creating Mesoscale Land Surface Datasets for Regional Modeling of the WLEF-TV Tower Site, Wisconsin. Submitted to Global Change Biology.

**Prihodko, L.**, Denning, A.S., Hanan, N.P., Davis, K. and Bakwin, P., Parameter sensitivity of a land surface model using Monte Carlo analysis and eddy-covariance measurements at the WLEF-TV tower site, Wisconsin. *In Preparation*.

**Prihodko, L.**, Denning, A.S., Nicholls, M., Baker, I., The influence of land surface heterogeneity on regional predictions of Net Ecosystem Exchange. *In Preparation*.

Denning, M. Nicholls, **L. Prihodko**, I. Baker, P.-L. Vidale, K. Davis, and P. Bakwin. Simulated and observed variations in atmospheric $CO_2$ over a Wisconsin forest. Submitted to Global Change Biology.

Baker, I., A. S. Denning, N. Hanan, **L. Prihodko**, P.-L. Vidale, K. Davis, and P. Bakwin. Simulated and observed fluxes of sensible and latent heat and $CO_2$ at the WLEF-TV tower using SiB2.5. Submitted to Global Change Biology.

## CONFERENCE PRESENTATIONS

**Prihodko, L.,** Denning, A.S., Hanan, N.P., Davis, K. and Bakwin, P., 2001. Parameter sensitivity of a land surface model using Monte Carlo analysis and eddy-covariance measurements at the WLEF-TV tower site, Wisconsin, Presented at the 86$^{th}$ Annual Ecological Society of America Annual Meeting, August 5-10, Madison, Wisconsin.

**Prihodko, L.**, Denning, A.S., Nicholls, M., Baker, I. And Los, S.O., 2001, Are Regional Predictions of NEE Influenced by Land Surface Heterogeneity? Presented at The IGBP Global Change Open Science Conference, July 10-13, Amsterdam, The Netherlands.

**Prihodko, L.**, Denning, A.S., Nicholls, M., 2000, Modelling Surface Fluxes at the WLEF Tall Tower: Parameterization and Scaling of Land Surface Models, NOAA Climate Monitoring & Diagnostics Laboratory Annual Meeting, May 3-4, Boulder, Colorado.

**Prihodko, L.**, A.S. Denning, M.E. Nicholls, P.-L. Vidale, T. Krebs, 1999. The Effects of Spatial Scale on Modeled Surface Fluxes. Presented at the Fall AGU Meeting, December 13-17, San Francisco.

**Prihodko, L.**, A. S. Denning, N. P. Hanan, G. J. Collatz, P. S. Bakwin, and K. Davis, 1998. Simulation and sensitivity analysis of carbon and energy fluxes at the WLEF-TV Tower site in Wisconsin. Presented at the Fall AGU Meeting, December 6-10, San Francisco.

Baker, I.T., A.S. Denning, K. Davis, P. Bakwin, N. Hanan, **L. Prihodko**, 2001,

Modeled and Observed Fluxes at the WLEF-TV Tower in North-Central Wisconsin, AGU Spring Meeting, May 29 – June 2, Boston.

Baker, I.T., A.S. Denning, **L. Prihodko**, N. Hanan, K. Davis, P. Bakwin, Dai,Y., Zeng, X., 2000, Simulation of Soil and Canopy Processes at the WLEF-TV Tower: Comparison of Two Land-Surface Schemes, AGU Spring Meeting, May 30 – June 3, Washington D.C.

Denning, A. S., **L. Prihodko**, N. Suits, M. Uliasz, Melville Nicholls, Niall Hanan, Elicia Inazawa, and Pier-Luigi Vidale, 2000. Estimating the exchange of $CO_2$ and its stable isotopes between Amazonian ecosystems and the atmosphere at multiple spatial scales. First LBA Scientific Conference, June 26-30, Belem, Brazil.

Denning, A. S., N. P. Hanan, P.-L. Vidale, **L. Prihodko**, and N. Zhang, 1998. Regional Integration of Forest-Atmosphere CO2 Flux: a spatial hierarchy of atmospheric data and models. Presented at the First International FluxNet meeting, Polson, Montana, June 3-5.

Denning, A. S., P.-L. Vidale, **L. Prihodko**, N. P. Hanan, K.J. Davis, and P. S. Bakwin, 1998. Simulations and Observations of Forest-Atmosphere Interactions Across Spatial Scales at the WLEF-TV Tower in Wisconsin, presented at Fall AGU Meeting, December 6-10, San Francisco.

Inazawa, E.E., A.S. Denning, M. Nicholls, **L. Prihodko**, 2000. Simulations of physical climate and CO2 exchange in Rondonia and Para (Amazonia). Fall AGU Meeting, December 14-19, 2000, San Francisco, CA.

## REFERENCES CITED


Bakwin P S, Tans PP, Hurst DF, Zhao C (1999) Measurements of carbon dioxide on very tall towers: results of the NOAA/CMDL program. *Tellus,* **50B**: 401-415.

Beven K, Binley A (1992) The future of distributed models: model calibration and uncertainty prediction. *Hydrological Processes*, **6**: 279-298.

Bonan GB (1996) A land surface model (LSM version 1.0) for ecological, hydrological, and atmospheric studies: Technical description and user's guide. NCAR Technical Note NCAR/TN-417+STR, National Center for Atmospheric Research, Boulder, Colorado.

Clapp RB, Hornberger GM (1978) Empirical equations for some soil hydraulic properties. *Water Resources Research*, **14(4)**, 601-604.

Denning AS, Collatz GJ, Zhang C (1996a) Simulations of terrestrial carbon metabolism and atmospheric CO2 in a general circulation model. Part 1: Surface carbon fluxes. *Tellus*, **48B**, 521-542.

Denning AS, Randall DA, Collatz GJ, Sellers PJ (1996b) Simulations of terrestrial carbon metabolism and atmospheric CO2 in a general circulation model. Part 2: Spatial and temporal variations of atmospheric CO2. *Tellus*, **48B**, 543-567.

Franks SW, Beven KJ, Quinn PF, Wright IR (1997) On the sensitivity of soil-vegetation-atmosphere transfer (SVAT) schemes: equifinality and the problem of robust calibration. *Agricultural and Forest Meteorology,* **83**:63-75.

Franks SW (1998) An evaluation of single and multiple objective SVAT model conditioning schemes: parametric, predictive and extrapolative uncertainty. Research Report No. 167.09.1998, The University of Newcastle, New South Wales, Australia.

Freer J, Beven K, Ambroise B (1996) Bayesian estimation of uncertainty in runoff prediction and the value of data: An application of the GLUE approach. *Water Resources Research*, **32**(7):2161-2173.

Hansen MC, DeFries RS, Townshend JRG, Sohlberg R (2000) Global land cover classification at 1 km spatial resolution using a classification tree approach. *International Journal of Remote Sensing*, **21(6)**, 1331-1364.

Los SO, Collatz GJ, Sellers PJ, *et al*. (2000) A global 9-yr biophysical land surface dataset from NOAA AVHRR data. *Journal of Hydrometeorology*, **1(2)**, 183-199.

Pielke RA, Cotton WR, Walko RL, *et al*. (1992) A comprehensive meteorological modeling system – RAMS. *Meteorological and Atmospheric Physics*, **49**, 69-91.

Raich JW, Rastetter EB, Melillo JM, *et al*. (1991) Potential net primary productivity in South America: Application of a global model. *Ecological Applications,* **1**(4), 399-429.

Sellers PJ, Randall DA, Collatz GJ, *et al*. (1996a) A revised land surface parameterization (SiB2) for Atmospheric GCMs. Part I: Model formulation. *Journal of Climate*, **9(4)**, 676-705.

Sellers PJ, Los SO, Tucker CJ, Justice CO, Dazlich DA, Collatz GJ, Randall DA (1996b) A revised land surface parameterization (SiB2) for Atmospheric GCMs. Part II: The generation of global fields of terrestrial biophysical parameters from satellite data. *Journal of Climate*, **9(4)**, 706-737.

Soil Survey Staff (1994) State Soil Geographic Database (STATSGO) U.S. department of Agriculture, Natural Resources Conservation Service, Fort Worth, Texas.

Teillet PM, El Saleous N, Hansen MC, Eidenshink JC, Justice CO, Townshend JRG (2000) An evaluation of the global 1-Km AVHRR land dataset. *International Journal of Remote Sensing*, **21(10)**, 1987-2021.