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Assimilation of latent and sensible heat flux data into a land surface model

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In the science of numerical weather prediction, land surface models coupled with climate and weather forecast models are now commonplace. Sensible and latent heat flux predictions from land surface models provide valuable atmospheric feedback for climate and weather forecast models to achieve optimal predictions. This research will focus on the assimilation of sensible and latent heat flux data into a stand-alone land surface model to test how this might improve modelled sensible and latent heat fluxes compared with traditional approaches of assimilating soil moisture and/or screen level temperature and relative humidity data. Since soil moisture and screen level temperature and humidity states are weakly related to heat fluxes, this research is motivated by the assumption that assimilating sensible and latent heat flux data may yield better predictions. The investigation will be carried out using both synthetically generated sensible and latent heat flux and soil moisture data, in addition to measured sensible and latent heat flux and soil moisture data from three study sites in south eastern Australia. Of the measured data, ground based point measurements will be used, in addition to measurements from airborne sensors and derived from remotely sensed satellite estimates.

Introduction It has long been established that weather and climate forecast accuracy is improved when a coupled land surface model accurately represents the latent and sensible heat flux feedback to the atmosphere (*Pathmathevan et al.*, 2003; *Pitman*, 2003; *Entekhabi et al.*, 1996). In this context, data assimilation research has focussed on improving land surface prediction of latent and sensible heat fluxes by improving soil moisture prediction through the assimilation of remotely sensed near surface soil moisture (e.g., *Walker and Houser*, 2001) or screen level humidity and temperature observations (e.g., *Margulis and Entekhabi*, 2003; *Seuffert et al.*, 2003; *Bouttier et al.*, 1993; *Mahfouf*, 1991). However, screen level humidity and temperature are indirectly and sometimes weakly related to evapotranspiration (*Qu et al.*, 1998). Moreover, most land surface models coupled to atmospheric models use soil moisture primarily as a tuning variable to achieve the correct latent and sensible heat flux prediction. Thus, there is no guarantee that assimilation of these variables (particularly a physical soil moisture content observation) into these models will improve the model prediction of latent and sensible heat flux (*Richter et al.*, 2004). Therefore, this research aims to assimilate observed sensible and latent heat flux data into a land surface model, to correct the model's prediction of latent and sensible heat flux by modifying the model's prediction of soil moisture and temperature. The impact of assimilation on these states can then be compared with observations. This is an approach that has received little attention to date, with *Schuurmans et al.* (2003) representing one of the few published examples of this approach. In the study presented by *Schuurmans et al.* (2003), only remotely sensed latent heat flux estimates were used as observed data. These data were treated as truth and used to evaluate the values output from the land surface model. The latent heat flux data derived from remotely sensed data were assimilated into the land surface model to improve modelled latent heat flux values. However, no ground based validation of the remotely sensed fluxes was presented, or validation of the model

Figure 4.9: Map of Australia with close up showing approximate locations of study sites at Kyeamba Creek, Kyabram and the 25 km $\times$ 25 km study region near Rochester.

predictions after assimilation using ground based latent heat flux or soil moisture data in between assimilation time steps.

Method The assimilation will be performed using both synthetic and real datasets. The synthetic data assimilation approach will be similar to that of Walker and Houser (2001) for soil moisture assimilation. First, a one-dimensional soil column model will be spun-up for a fixed time period using forcing data that represents realistic meteorological conditions. Using the spin-up initial condition the model will be used to generate "true" land surface observation and evaluation data. Second, degraded simulations will be made representing the same period; one by setting the initial soil moisture variables to extreme wet values, and another by setting the soil moisture to extreme dry values. Typical errors in forcing data and model parameters will also be applied. Finally, simulations will be made whereby the "true" latent and sensible heat flux values from the original model simulation will be treated as observations and assimilated into each of the degraded simulations. The aim is to develop the assimilation algorithm and test the ability of the assimilation to improve the latent and sensible heat flux prediction from the degraded simulations as compared to the "true" values from the original simulation. At the same time, we aim to positively impact on the soil moisture and temperature profile predictions.

To test the performance of the assimilation approaches developed under real conditions, two one dimensional field sites will be investigated, each using latent and sensible heat flux data recorded via eddy correlation systems, along with soil moisture and temperature profiles. For these sites, the land surface model will be forced using measured meteorological and radiation data collected at the sites. The measured latent and sensible heat fluxes will be assimilated into the model. Measured values of soil temperature, soil moisture and latent and sensible heat flux between assimilation time steps will be used to test the assimilation performance. A 25 km $\times$ 25 km study region will also be investigated using spatial latent and sensible heat flux data from an airborne eddy correlation system, satellite remotely sensed data and ground based point measurements of soil moisture and of latent and sensible heat flux from eddy correlation systems. Forcing data for modelling in this region will be sourced from available point meteorological and radiation measurements, and from the nearest Australian Bureau of Meteorology station. A spatial study will first involve the assimilation of airborne eddy correlation data, using ground based point latent and sensible heat flux measurements, and soil moisture data to validate the modelled results. Then

Figure 4.10: False colour (near infra red) Landsat image covering the 25 km × 25 km study region in Victoria. Blue dots represent soil moisture monitoring sites.

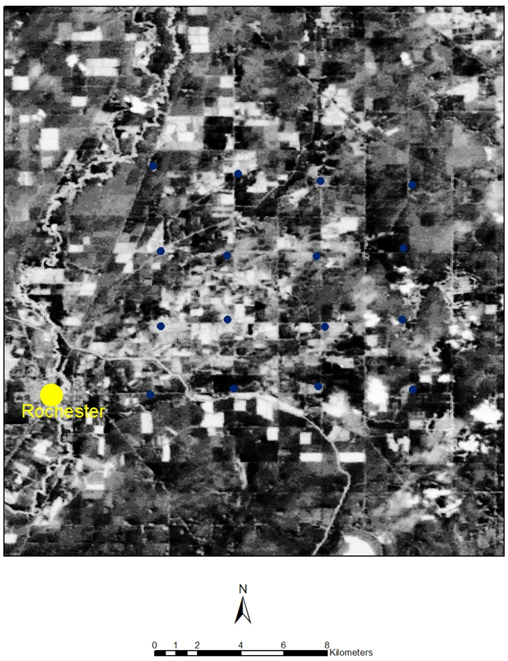

Figure 4.11: Remotely sensed thermal infra red image of the 25 km × 25 km study region shown above. Darker shades represent a higher thermal signature.

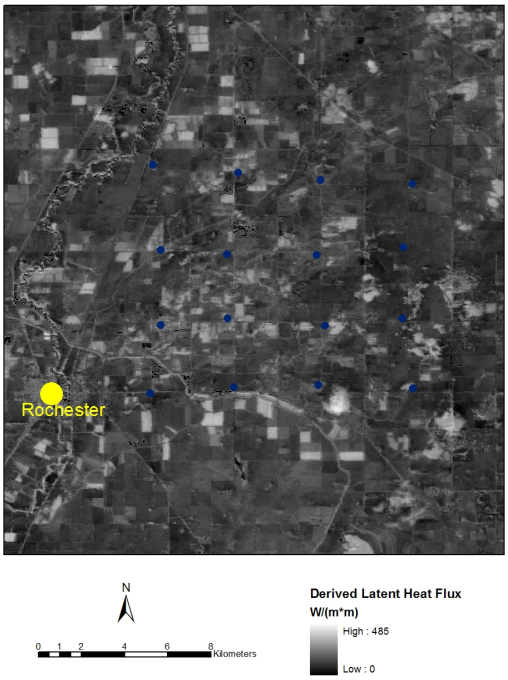

Figure 4.12: Image of latent heat flux values for the 25 km × 25 km study region, derived from satellite imagery shown above using the SEBAL algorithm.

using satellite remotely sensed data, assimilations will be made both with observed surface temperature data and with latent and sensible heat flux values derived using the SEBAL algorithm (*Bastiaanssen et al.*, 1998). The performance of these two remote sensing based approaches will be compared, again with ground based latent and sensible heat flux and soil moisture measurements used as testing data sets.

Models A Kalman filtering approach will be used to assimilate the observed latent and sensible heat flux data into the European Center for Medium range Weather Forecasting land surface scheme used by the Australian Bureau of Meteorology. This land surface model was developed by *Viterbo and Beljaars* (1995), and is referred to herein as VB95. It consists of four prognostic layers for soil moisture and soil temperature, including a skin temperature and surface interception reservoir. The thickness of the four layers are 7 cm, 21 cm, 72 cm and 189 cm, from top to bottom respectively, with the penetration of roots from vegetation allowed in the three top layers. Vertical movement of water between the layers is governed by the diffusion form of Richard's equation, and vertical energy fluxes are governed by a soil heat diffusion equation. The lower boundary condition is characterised by a free drainage condition and zero heat flux. Net heat flux, computed from a surface energy balance calculation, and net water infiltration, which is the difference between incoming precipitation and a combination of interception, bare soil evaporation and surface runoff from the incoming precipitation, represent the upper boundary condition. Evapotranspiration in VB95 can occur from the interception reservoir, bare soil in the top soil layer and through transpiration from vegetation having roots in the top three soil layers (the root zone). Latent and sensible heat flux data and/or skin temperature data will be assimilated into the VB95 model using the Ensemble Kalman Filter, which is discussed in detail by *Evensen* (2003).

Data Sets The field data will be from three study sites in south eastern Australia (figure 4.9).

These data consist of (1) two one dimensional sites measuring eddy correlation, soil temperature and soil moisture data in different landscapes, and (2) a 25 km $\times$ 25 km region with sixteen soil moisture monitoring sites, and remotely sensed (airborne and satellite) latent and sensible heat flux data.

At the one dimensional sites, continuous measurements of soil and atmospheric data are made over a 12 month period. One of the one dimensional sites is situated at Kyeamba Creek within the Murrumbidgee catchment, approximately 30km south east of the city of Wagga Wagga in New South Wales, and is located in a flat area of non irrigated grass pasture. The other is located near the town of Kyabram in Victoria on irrigated grass pasture land. The 25 km $\times$ 25 km monitoring region is located in northern Victoria near the town of Rochester and has one week of aircraft (January 2003) and nine months of satellite remote sensing measurements during periods from 2002 to 2004 that are being analysed for latent and sensible heat flux. Figure 4.10 is a false colour (near infra red) Landsat satellite image of the area which was used for analysis, with figure 4.11 showing the thermal infra red image of the same area. Figure 4.12 illustrates latent heat flux coverage in the area that was derived from the Landsat data using the SEBAL algorithm (*Bastiaanssen et al.*, 1998). In addition there are 16 ground point measurements of neutron probe soil moisture data collected at 4 depths (15 cm, 45 cm, 75 cm and 105 cm), these were collected fortnightly to coincide with the satellite overpass for the summer months of 2003 and 2004. The blue dots in figures 4.10 through 4.12 show their spatial distribution throughout the area. Also from the area are point measurements of atmospheric, radiation and latent and sensible heat flux data from 1D eddy correlation and Bowen ratio systems for the beginning of the irrigation season (October 2002) until January 2003. Continuous 3D eddy correlation, atmospheric and radiation data from the opening of the 2003 irrigation season (October 2003) until January 2004 are also available.

Summary This project aims to analyse the improvements in predictions of latent and sensible heat flux, together with soil moisture and temperature by a land surface model resulting from assimilating estimates of some or all of latent and sensible heat fluxes and surface temperature. Further, it aims to determine the best approaches to this assimilation problem. An assumption is made that assimilating latent and sensible heat flux into a land surface model, as opposed to soil moisture data, may lead to better model estimates of the surface energy balance as the process will bypass the dependency on soil parameterisation errors inherent in land surface models. These errors can lead to poor heat flux predictions when assimilating soil moisture.

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