MECHANISTIC MODELLING OF GRASSLAND ENERGY BALANCE

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ABSTRACT

KEYWORDS

Energy balance, soil temperature, canopy temperature, heat flux, evapotranspiration.

INTRODUCTION

Modelling grassland soil temperature is complicated by the sward's mediation of the energy flows between atmosphere and soil, and by the wide diversity of grassland types, from developed to native. This paper describes: 1) models of the surface energy exchanges of grasslands, predicting from weather data both canopy temperature and evapotranspiration, and the soil thermal regime; and 2) model testing at two strongly contrasting sites and grassland types in Canterbury, NZ.

The models extend the bare soil models of Buchan (1982), which are simple *single-layer* models (i.e. analyse energy exchanges only at the soil surface). The grassland models are *two-layer*, adding an equivalent canopy layer (Fig. 1). Key model features include: reductionism (minimum complexity); preferential application of analytical rather than numerical mathematics; and description of the multi-day average diurnal (24-hour) variation, i.e. of thermal 'climate', as opposed to single-day 'weather'.

Previous studies have modelled two surface types. a) Vegetated surfaces. Commonly, models are numerical, and either single- or two-layer (i.e. neglect or include the soil surface, respectively); or even multi-layer, for deeper canopies. However vegetation models commonly focus on the canopy microclimate. b) Mulched surfaces, with greater interest in predicting soil temperature and moisture regimes. Our models combine aspects of both surface types, by focussing on the soil thermal regime, and admitting a mulch-like heat conduction term for dense swards.

MATERIALS AND METHODS

Models. As shown in Fig. 1, the two-layer models partition the grassland into: a soil surface layer; and an equivalent canopy layer, effectively a 'porous sheet' through which the soil exchanges radiation, heat and vapour with the atmosphere. This model converts to a resistance network, with a 'node' for each energy source or sink.

Key canopy characteristics include: the canopy cover fraction, σ_c ($1-\sigma_c$ represents both the canopy's radiation transmissivity, and the fractional contribution of bare soil to the total surface energy budget); aerodynamic characteristics, including roughness length; radiative characteristics, i.e. albedo and emissivity; and (especially for the dense sward at site 2), the thermal conductivity of stems and leaves, providing an additional conduction path for heat flow. We aimed to develop simplified models characterizing 'climate' rather thatn day-to-day 'weather' (e.g. for climate change sutdies). Hence we modelled the multi-day (typically c. 7-day) mean diurnal variation. The models are of two types. The simpler 'non-interacting' model assumes the heat and vapour fluxes from the soil surface transfer directly to the atmosphere, with no interaction with the canopy. The 'interacting' model (Fig. 1) admits mutual influences between the canopy and soil surface via their heat and vapour fluxes. However both models are 'radiatively interacting', i.e. include full solar and longwave exchanges between layers. A further subdivision of model types assumes windspeed is either constant or varying throughout the day.

Measurements were at two contrasting sites: Site 1, a classic, developed pasture on the Canterbury Plains; and Site 2, an inland, hill-country site characterised by a dense, clumpy sward.

Field measurements included the following. Model input data: solar radiation, air temperature and vapour pressure, windspeed; canopy albedo; canopy cover fraction. Other parameters included soil albedo, emissivities, and soil thermal conductivity and heat capacity. A sonic anemometer gave direct measurements of sensible heat flux, enabling canopy resistance to be deduced via energy balance closure. Model output data: soil temperatures to 1m depth; soil heat flux; canopy temperature T_c from infra-red thermometer; evapotranspiration from mini-lysimeters.

For site 2, the more complex canopy was partiioned into two layers: an upper layer of protruding tops; and a lower, dense layer including senescing and dead material. For this lower, mulch-like layer, vertical heat transfer via vegetative conduction was also included.

RESULTS AND DISCUSSION

Fig. 2 shows illustrative results from the interacting model version, for the high-country site, for one 7-day period in late summer 1994.

More generally, our results show that the above mechanistic, two-layer models of grassland energy balance can predict canopy and soil surface temperatures in good agreement (typically within c.± 1.5 K) with measurements. These climatic models can be used to characterize grassland microclimate, and have potential utility in assessing impacts of climate change.

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Figure 1

Network diagram representing the 'interacting' version of the model, with soil surface layer and canopy layer diffusively coupled via the notional canopy airstream node. T,e represent temperature and vapour pressure values. r_{cs} represents heat flow by plant conduction. r_8 if the soil resistance to evaporation.

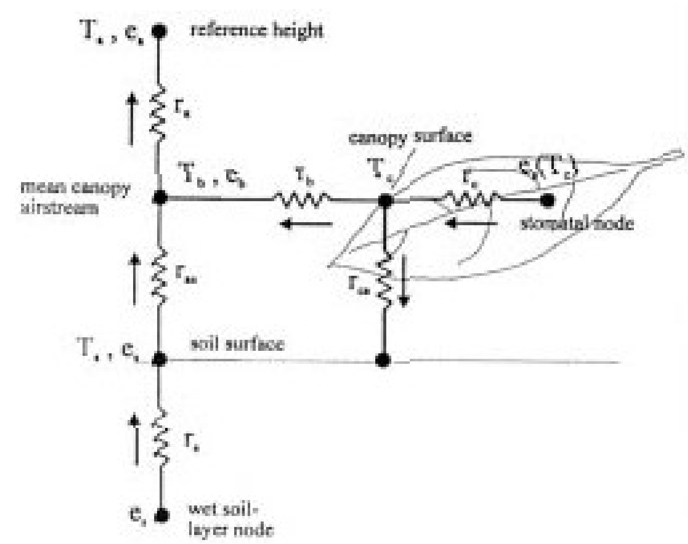

Figure 2

Comparison of predicted and observed 7-day average diurnal variations of soil surface and grass canopy temperatures at the high-country site (site 2). Dtails: days-of-year 38-44 (late summer), 1994: soil surface assumed dry; canopy height c.30 cm; canopy cover fraction = 0.95.