The effect of landuse, landform and topographic relief on nocturnal land surface temperature

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Summary. The nocturnal surface temperature of the landscape is important information which can be used to improve the management of farming systems. Thermal images prepared from satellite-mounted infrared sensors show that variations in minimum surface temperature can exceed 7?C between different landform units. Studies of these temperature differences in low relief landscape shows that thermal properties of the surface and not elevation is the main determinant of nocturnal temperature. This implies caution if thermal mapping is to be interpreted on the basis of elevation alone.

Introduction

Measurements of landscape temperatures on a broad scale provide accurate information which can be a valuable planning and management tool for agricultural enterprises. Historical temperature data observed in standard meteorological screens over a sparse network of locations does not necessarily give an accurate indication of land surface temperature (LST). Also, existing information networks do not show the simultaneous development of nocturnal minimum temperature patterns over the landscape. For these reasons, such data are often of limited value for farm planning.

Satellite-mounted infrared sensing has been used to measure LST of extensive cropping areas in north-west Victoria. The technique has advantages over traditional methods. It is accurate, fast, cost effective and enables simultaneous observations over large tracts of land (1). Nocturnal measurements made during 1989 and 1990 clearly show that large and repeatable differences occur in LST between landform features. The observed variations in temperature occured in response to a number of characteristics associated with both land use and surface properties. The aim of this study is to show the relative importance of characteristics determining LST and to demonstrate that contour height has little influence on nocturnal temperature minima in complex landscapes with low topographic relief.

Materials and methods

Satellite and map data

Variations in LST were measured using thermal images produced from data collected by the NOAA polar orbiting satellite. Temperature discrimination was 0.1?C and ground resolution was 1000 m or 100 ha for each pixel.

Zones of different temperature and their associated landscape units were located on the ground after inspection and interpretation of LANDSAT 5 MSS and TM images (resolutions of 80 m and 30 m respectively). This information was combined with data from the Victorian Geographic Information System (VGIS) and the Agricultural Management and Production Information System (AMPIS) to identify the vegetation, soils and land use within landscape units.

Changes in height of the land surface were determined by interpolation of contour data from 1:100,000 topographic maps (Series R652). The 20 m contour information published in this series is based on the Australian Height Datum and is accurate to ? 10 m.

Regression relationships

Correlations between LST and height of surface or thermal characteristics were estimated using linear regression techniques. LST and elevation were measured at identifiable points in a study area bounded by the South Australian border (west), Lake Buloke (east), Lake Hindmarsh (north) and Miga Lake (south). This large area of approximately 180 km by l 10 km or 1.98 million ha contains landforms and topographic relief typical of north-west Victoria. In a second linear relationship, the independent variable, a weighted thermal index (TI) was calculated by combining thermal properties for each landscape unit on a volumetric basis for the first metre of the surface. Depending on layer thickness (10 cm equals a 10% contribution), and thermal properties of material in the layer (dry sand, rock etc.) was determined for the average surface metre of each landscape unit. The thermal index for each component layer (Tic) in the surface metre was based on the additive ranking of five thermal properties (heat capacity, thermal conductivity, diffusivity, admittance and absorption) which strongly influence heat flux convergence and resultant surface temperatures. In this additive model, high values for each thermal property (maximum 10) are summed to give high TI which relates directly to LST.

Field validation sites

In 1990, five field sites were selected along a 60 km traverse between Lillimur South and Niniwell for monitoring of soil (10 cm deep), surface (+ 0.5 cm) and air temperature (+ 50 cm) of common landform units. Temperatures were measured every 30 minutes during the period 1 June 1990 to the 30 November 1990 using calibrated electronic sensors (? 0.08?C) and automatic data logging systems. These data were compared with satellite measured LST and expected temperature trends for known thermal properties of the surface volume at each site.

Results and discussion

The effect of land use on nocturnal LST for a typical satellite overpass is given in Table 1. Changes in management of land surfaces causes variation in LST by altering thermal characteristics which dictate the efficiency of energy trapping and rates of flux convergence and divergence.

Deep dry sands of the desert have low energy absorption, heat capacity, thermal conductivity and diffusivity. This leads to rapid, shallow heating during the day and fast cooling of the surface at night because heat cannot be conducted upwards from deeper in the profile. Land clearing of deep desert sands also causes greater heat loss at night because the boundary layer height is reduced, sky exposure is high and the soils have generally drier surfaces.

Land clearing and cultivation of shallow sands over clay often results in higher nocturnal LST because surface albedo is lower, soil water content is increased and heat stored in the subsoil can be more readily transferred to the surface at night.

Table 1. Differences in surface temperature (?C) of landforms determined from infra-red imagery (1.30 am AEST 6.9.89). Mean corrected, relative to zero ?C.

Landform		Average	Range	
			Minimum	Maximum
Desert:	Deep sand, cleared pasture	-3.3	-4.1	-2.7
	Deep sand, short vegetation	-1.4	-1.9	-0.5
	Shallow sand, cleared pasture	+0.2	-0.1	+0.7
	Shallow sand, cleared burnt	-1.7	-1.9	-1.5
Ridges:	Solonetz over stone	+1.8	+1.2	+2.4
	Brown clay and duplex	+1.7	+1.1	+2.9
Plains:	Self mulching grey clay	-1.5	-1.9	-0.8
	River plains	+1.1	+0.9	+1.2
	Lake beds, wet clay	+2.8	+2.7	+2.9
	Lakes:Turbid	+0.9	+0.4	+1.4
	Clear	+3.2	+3.1	+3.2

In cropping zones, cultivated soils with clay surfaces generally have higher nocturnal LST. A notable exception is the friable self mulching grey clay which is of low surface density (0.7 *g/* cm^3), dries quickly and has a high air filled porosity. These factors result in a surface which is characterised by low thermal diffusivity and conductivity. It is therefore expected that diurnal fluctuation will be high with low LST minimum at night. These surface conditions will be maintained irrespective of cultivation because the soils are self mulching.

Landform and thermal properties of the surface exert the greatest influence on nocturnal LST. Data presented in Table 1 show desert regions to be the coldest, followed by grey clay plains, river plains, ridges, lake beds and lakes. Soil surfaces least prone to low temperature at night are those over high density subsurface strata such as sandstone which has particularly high energy admittance, conductivity and diffusivity. Heat is readily stored during the day and released to the surface at night.

The dependence of LST on topographic relief was not significantly correlated in the study area considered (Fig. 1). Additional regression analyes were carried out on a subset of 26 identifiable locations for satellite overpasses on four occasions. The relationships showed a negative trend and coefficients of determination did not exceed 0.15. In a landscape of low relief this result should be expected where only 6% of the surface is above 160 m and over 90% is between 100 m and 160 m. Some cold air drainage effects would occur during radiative heat loss but major effects of elevation would not explain the observed variation of 7.2?C in minimum LST.

Data presented in Table 2 collected at the field sites shows differences in surface and air temperature to be close to that expected for the types of surfaces being investigated. The ridge soils with high thermal indices had generally warmer environments than the grey plains soils. Amplitude in the soil temperature wave was lower for the ridge sites and temperature peaks occurred earlier, as expected for surfaces which allow more rapid heat flux. The variation in elevation between sites did not exceed 70 m.

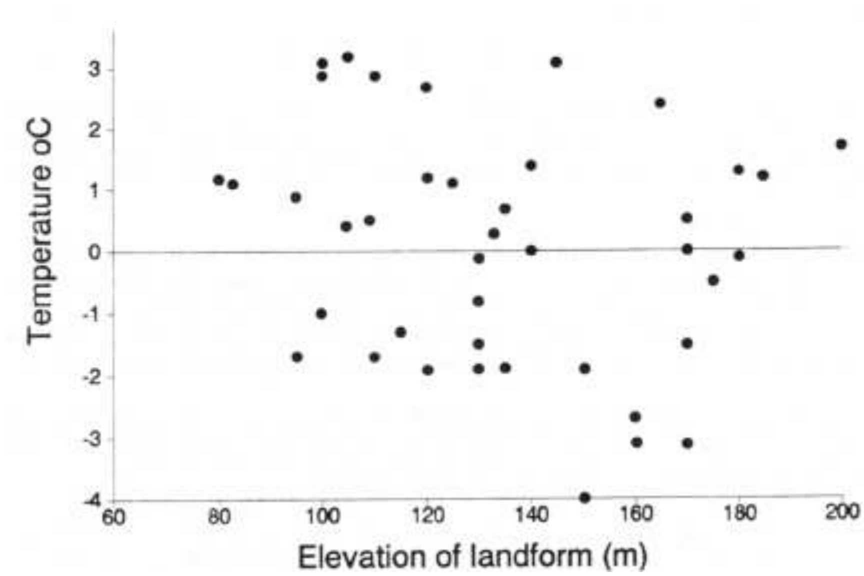

Figure 1. The influence of topographic relief on land surface temperature (r^2 =0.03 for n = 44).

The relationship between LST and TI was highly significant and indicated that thermal characteristics in the surface volume were the most important determinants of nocturnal LST. The regression equation defining the dependence of LST on TI was:

$$LST = -8.16 \pm SE\ 0.64 + 0.34 \pm SE\ 0.02 \times TI$$

(r^2 = 0.91 for n = 26 with an RSD of 0.60).

Table 2. Average temperatures (?C) between midnight and 8 am AEST at five field sites for the 35 coldest days in the study period 30.6.90 to 30.11.90 (n = 16). Measurements were made with contact electronic sensors.

Site		Soil	Surface	Air
1.	Plain. Grey self mulching clay	7.7	3.9	1.7
2.	Ridge. Brown friable clay	8.3	4.6	2.7
3.	Ridge. Duplex soil	8.4	6.6	4.0
4.	Ridge. Solonetz over stone	8.2	6.2	3.9
5.	Plain. Friable grey clay	8.3	4.5	1.6
Significance (P<)		0.0001	0.0001	0.0001
l.s.d. (P=0.05)		0.2	0.4	0.5

This study has important implications for both farm management and temperature research in agriculture. Results show that thermal mapping is not dependent on topographic relief alone, therefore, siting of ground stations for the collection of temperature data must be carefully considered so that surface dependent bias is avoided. Also, knowledge of nocturnal temperature patterns can be used to identify warm zones in the landscape and utilise them more effectively for increasing agricultural production. For example, using low frost risk areas for more sensitive crops, changing sowing times, scheduling insect or disease control operations and extending pasture growth on warm areas.

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Reference

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