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Clouds form preferentially over native vegetation

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Abstract: The replacement of native vegetation for agriculture leads to significant changes in land surface characteristics, such as albedo, surface roughness and canopy resistance. These land surface changes induce changes in the atmospheric boundary layer. It is shown that in Western Australia, this change in surface characteristics and in particular, the albedo, has reduced the occurrence of convective cloud formation through limiting the vertical development of the boundary layer.

Keywords: land-atmosphere interaction; albedo; boundary layer.

1 INTRODUCTION

In clearing native vegetation for agriculture, land surface characteristics, such as albedo, surface roughness and canopy resistance are changed. Consequently, surface energy components are redistributed and changes in the partitioning between sensible and latent heat flux will affect boundary layer development and the vertical transport of heat and water vapour in the atmosphere. These effects could ultimately influence cloud formation and precipitation (*ie.*, Pielke, 2001).

The vermin proof fence of Western Australia provides a unique insight into the effects of land surface changes on the climate by having two contrasting surfaces in close proximity. Neither side of the fence has significantly different topographical features and it is sufficiently removed from the ocean to eliminate coastal effects. In essence, the fence provides an indication of what the land surface once was (the native vegetation side) to what it has now become with western agriculture and so enables a simple comparison of the meteorological effects of changes in surface conditions (Lyons *et al.*, 1993; 1996).

The replacement of the native perennial vegetation with agriculture based on winter growing annual species has meant that the vegetation has gone from one which transpires year round to an annual vegetation that only transpires during the winter (Huang *et al.*, 1995b; Lyons *et al.*, 1996). Modern cultivars are also more opportunistic in relation to available water, *ie.* they have higher transpiration when soil moisture is favourable and consequently use as much of the available energy as possible to evaporate water during their growing season. As well, the native vegetation has a darker colour, tends to be more random in its height and rougher to the air flow. Consequently, surface energy components are redistributed and changes in the partitioning between the sensible and latent heat flux led Lyons *et al.* (1993), Huang *et al.* (1995b) and Lyons *et al.* (1996) to suggest that clouds (Figure 1) would form earliest over the native vegetation as it is characterised by high sensible heat flux. The clouds shown in figure 1 are a common feature of the fence and consistently form over the native vegetation (Lyons *et al.*, 1993) in marked contrast to the clear skies observed over the agricultural area.

The purpose of this analysis is to extend the earlier analysis of Huang *et al.* (1995b) and Lyons *et al.* (1996) and in particular, investigate the mechanisms that lead to preferential cloud formation over the native vegetation in marked contrast to the agricultural area. This is done through the analysis of case studies where satellite photographs illustrate strong convective mixing along the native vegetation side of the fence as well by comparison with an analysis of the effect of surface changes on average annual conditions (Lyons, 2002). As our focus is on changes that have occurred since agricultural practices were introduced to Western Australia, the modelling concentrates on a one dimensional approach without consideration of potential edge effects along the boundary between the native and agricultural vegetation. Such effects are the subject of a subsequent analysis (Ezau and Lyons, 2002).

2 MODEL AND ANALYSIS

The one-dimensional, soil-canopy-boundary layer model originally developed at Oregon State University (Ek and Mahrt, 1989) and extended by Huang and Lyons (1995), *NOSU*, has been used to simulate the interaction between the land surface and overlying atmosphere. It calculates the flux of water vapour to the atmosphere separately from both

Figure 1: Aerial view of the fence with convective cloud confined to the native vegetation.

soil and vegetation, but still uses a one-source model to estimate the sensible heat flux. Soil evaporation is estimated by a threshold formulation, whereas canopy transpiration is computed as a function of the soil water content. The simulated fluxes of sensible and latent heat from this model, have been found to be in close agreement with observed regional surface heat fluxes (Huang and Lyons, 1995).

The application of this model, like other boundary layer models, is dependent on the estimation of a soil moisture profile. A realistic estimate of initial soil moisture is critical, especially for the latent heat flux (Ek and Cuenca, 1994). It has been estimated via a robust water balance technique which provides an estimate of the soil moisture profile directly from long term surface meteorological records (Li and Lyons, 2002).

An initial morning radio-sounding (0700 local standard time) was used to initialize the numerical model and all model simulations were conducted for twenty four hours. In each run, two separate simulations were conducted representing the different surface conditions found on either side of the fence, following Huang *et al.* (1995b). This analysis will concentrate on the daytime evolution of the mixed layer over the two surfaces and in particular, the evolution of relative humidity at the top of the boundary layer.

Following Ek and Mahrt (1994) and Chang and Ek (1996), the rate of change of relative humidity at the top of the boundary layer, assuming well mixed conditions for both temperature and humidity, results from (i) increasing relative humidity as a consequence of surface evapotranspiration, (ii) decreasing/increasing relative humidity from the entrainment of dryer/moister air from above the boundary layer, (iii) a decrease in relative humidity as a result of the surface sensible heat flux and the entrainment of warmer air at the boundary layer top and (iv) an increase in relative humidity as a result of increasing boundary layer depth where for a given potential temperature, the temperature at the boundary layer top decreases with boundary layer growth. Thus relative humidity at the top of the boundary layer is changing in response to adiabatic cooling from boundary layer growth. The importance of boundary layer heating with respect to boundary layer growth can be expressed as the ratio of terms (iii) and (iv). Each of these terms were evaluated from the model output by taking the model level closest to and below the computed boundary layer depth as representative of the top of the mixed layer.

3 CASE STUDIES

Satellite pictures for November 05, 1999 and February 03, 2000 illustrate the strong development of convection in the vicinity of the rabbit fence with relatively clear skies over the agricultural area. In both cases, the satellite pictures suggest that the convection was limited to the region over the native vegetation, although there was clearly some influx of tropical moisture from the north west at upper levels. Representative surface conditions for November and February were taken from Huang *et al.* (1995b).

Figure 2 illustrates the temporal variation of the humidity profile over both the native and agricultural vegetation for these two days. Under well mixed conditions, the relative humidity reaches a maximum near the boundary layer top and the clear difference between the surface forcings from the native and agricultural areas is evident. As *NOSU* is strictly a boundary layer model and does not incorporate cloud processes, areas where the humid-

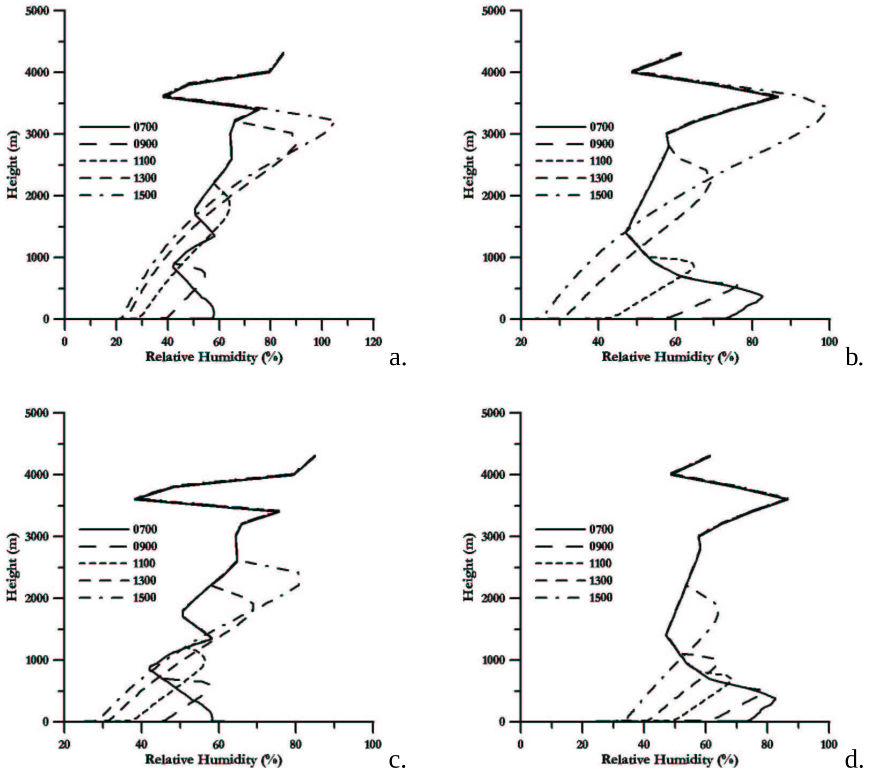

Figure 2: Temporal variation of the relative humidity profile over native vegetation for (a) November 05, (b) February 03 and over agricultural vegetation for (c) November 05 and (d) February 03.

ity profile exceeds 100% are not accurate. Nevertheless, the model indicates a marked increase in relative humidity at the top of the boundary layer and highlights the increased height of the boundary layer over the native vegetation in comparison to the agricultural land. This is in agreement with the earlier work of Huang *et al.* (1995b) who suggested that the main role of the native vegetation was to provide a deeper boundary layer and hence increase the chances of convection reaching the lifting condensation level.

Given that the model does not incorporate cloud processes, it is not able to simulate deep convection but is clearly suggestive of clouds forming earlier over the native vegetation. The inversion above the boundary layer acts as a limit to further development in these simulations and hence the model only simulates shallow convection. Should deep convection break out, the exchanges between the convective boundary layer and the free atmosphere above are beyond the assumptions inherent in the model. As a one-dimensional model, this is also not simulating any edge effect but rather the effect of two markedly different surfaces.

A comparison of the various terms responsible for the humidity increase shows that the agricultural area, particular in November before the wheat has been harvested, has a higher surface evapotranspiration which leads to increased relative humidity at the top of the boundary layer. However, this term is overshadowed by the increase in relative humidity due to the increasing boundary layer depth. That is, as the boundary layer grows faster over the native vegetation, the temperature at the boundary layer top decreases with this growth thus assisting the increase in relative humidity. Ek and Mahrt (1994) showed that where boundary layer warming can be neglected compared to boundary layer growth, the relative humidity at the boundary layer top increases with time unless the boundary layer dries out at a rate that exceeds the boundary layer growth term. Such drying would require rapid entrainment of dry air from aloft. In these case studies, the air above the developing boundary layer has high levels of moisture and the only evidence of dry entrainment is observed over the agricultural area perhaps as a result of limited access to the moisture aloft because of the lower boundary layer development.

4 DISCUSSION AND CONCLUSIONS

The significant differences between the native vegetation and the agricultural area are in the albedo, surface roughness and canopy resistance. Changing each one of these in turn leads to a decrease in the height of the humidity maximum and the over-all depth of the boundary layer. Albedo by its self leads to the greatest decrease. Conversely, changing the albedo of the agricultural area to that of the native vegetation but leaving all other values constant, results in higher relative humidity at the top of the boundary layer and a deeper boundary layer. Both conditions are more preferential to cloud development. The significant difference in surface albedo between the native and agricultural areas has resulted in decreased convective enhancement over the agricultural area through slower boundary layer growth.

This is in contrast to the findings of Segal *et al.* (1995) who argued that the latent flux is the dominant forcing in the destabilization that can lead to deep convection. They suggested that the sensible heat flux has a secondary role, as drier surfaces are less conducive to deep convection even though the associated boundary layer is deeper. Equally, Lynn *et al.* (1995) suggested that the largest potential for deep convection occurred over wet ground but they had used the soil moisture distribution to ”control” the distribution of land surface fluxes and not considered variations in albedo.

When the mixed layer top becomes sufficiently close to the condensation level cumulus clouds will be initiated (Mahrt, 1979). The critical distance between the mixed layer top and the condensation level is the penetration depth of the most vigorous thermals or eddies. Once initiated cumulus clouds act to retard both mixed layer growth and further increases in cloud cover, particularly if warming above the inversion, due to cloud induced subsidence exceeds cooling due to cloud detrainment near the cloud base. Severe convective storms are most likely to survive when the development of cumulus is suppressed by the stratification at the top of the mixed layer so that the convective storm does not have to compete with extensive cloud activity for the limited supply of moisture. In the presence of such stratification local forcing or low level convergence is required to trigger storm development (Mahrt, 1979). These simulations suggest that the darker albedo of the native vegetation provided that local forcing to assist in convective development over the native vegetation in contrast to the lack of development over the agricultural land. Thus changes in the surface albedo through clearing for agriculture have decreased the local forcing necessary to trigger storm development.

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