Vertical velocities and available potential energy generated by landscape variability

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Introduction The surface conditions (dry vs. wet soil; presence of heterogeneities in surface or alternating of dry and wet patches) are important since they affect the partitioning between latent and sensible heat fluxes. In fact, a moist surface (e.g., vegetated) is more effective for the development of deep convection than a dry surface. Once initiated, the interaction of convection with shear can enhance the storm evolution and lead to severe weather. Specific humidity in the convective boundary layer is increased for wet surfaces, leading to larger CAPE.

In addition, vegetation gradients can trigger the formation of drylines, and strong gradients in surface fluxes resulting from these inhomogeneities can drive mesoscale circulations along the dryline itself.

Moreover, observations show that in dryline regions the probability of deep convection initiation is high in the late afternoon in the presence of weak ambient flow, with a strong influence of the land use and land cover on the diurnal temperature range.

R.A. Anthes, 1984: Enhancement of Convective Precipitation by Mesoscale Variations in Vegetative Covering in Semiarid Regions, JAMC, 23, 541-554: ..... Significant increases in convective rainfall under atmospheric conditions marginally favorable for moist convection in semiarid lands could be obtained by replacing a uniform bare or sparsely vegetated soil with alternating bands of dense vegetation. Because of the differential heating generated by these bands and the resulting organized mesoscale circulations, these increases would be larger than those associated with replacing the entire area with uniform vegetation...........

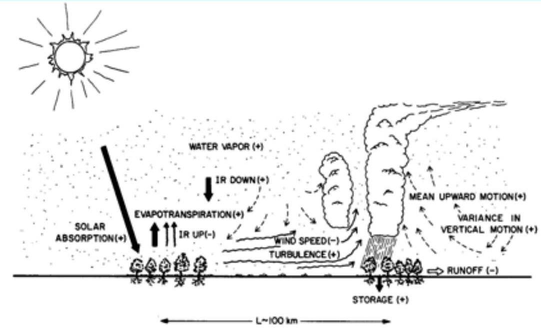


FIG. 4. Hypothesized effect of establishing bands of vegetation in a semiarid region of previously bare soil. Increases or decreases of an effect or process following the introduction of vegetation are indicated by pluses or minuses, respectively.

Methodology

The analysis is performed using a linear theory where the mesoscale dynamics is forced by the diurnal diabatic sensible heat flux and surface stress. Results are shown as a function of:

- ambient flow intensity
- different wavelengths of a sinusoidal landscape variability

The governing linearized equations are:

$$\mathcal{L}\,u - fv + \partial_x\phi = \partial_z\tau, \quad \mathcal{L}\,v + fu = 0 \quad \text{and} \quad \mathcal{L}\,w + \frac{\partial\phi}{\partial z} - b = 0 \quad \text{or} \quad \frac{\partial\phi}{\partial z} = b \qquad (1)$$

$$\mathcal{L}\,b + N^2 w = Q \quad \text{and} \quad \partial_x u + \partial_z w = 0 \qquad (2)$$

Where $\mathcal{L}$ is the linear Time operator: $\mathcal{L} \equiv \left(\frac{\partial}{\partial t} + \lambda + U\frac{\partial}{\partial x} - K\nabla^2\right)$;

We neglect the vertical diffusion term $K\,\partial_{zz}$

K	horizontal diffusion coefficient (+ 100 m²/s)
λ	Rayleigh friction coefficient, assumed the same in momentum and thermodyn eq.s
U	ambient flow intensity
u, v, and w	momentum components
Φ	geopotential
b	buoyancy perturbation
$N = 10^{-2}\ s^{-1}$	Brunt-Vaisala frequency
$f = 10^{-4}\ s^{-1}$	inertia frequency.

We prescribe that the vertical divergence of the stress is constant through the depth, h_T, of the surface layer (SL), and it vanishes above it.
We prescribe that the vertical divergence of the heat flux, h_Q, is constant through the depth of the convective boundary layer, and it vanishes above it.

$$-\partial_z\tau = \mu_T\,\tau_0\,\mathrm{He}(h_T - z)\,\exp i(k_0\,x);$$

$$Q = Q_0\,\mathrm{He}(h_Q - z)\,\exp i(\omega_0 t + k_0 x)$$

FORCING

Warm over vegetated patch and cold over non-vegetated

Rough over vegetated patch

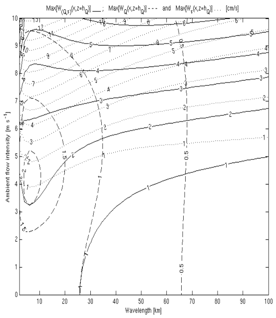
Since the deep convection occur mainly in the late afternoon, in order to evaluate the integrated daytime impact of the dynamics of the secondary flow on the atmospheric parameters, we time average the diabatic forcing.

Updraft

Combined updraft induced by the diabatic flux and by the surface roughness, $w_{(Q,\tau)}$, solid line;

updraft induced by the diabatic flux only, w_Q, dashed line;

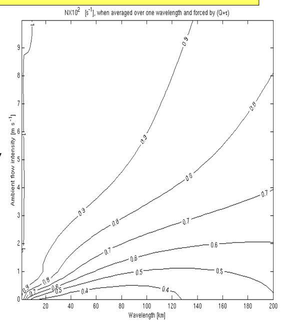
updraft induced by the surface roughness only, w_τ, dotted line.



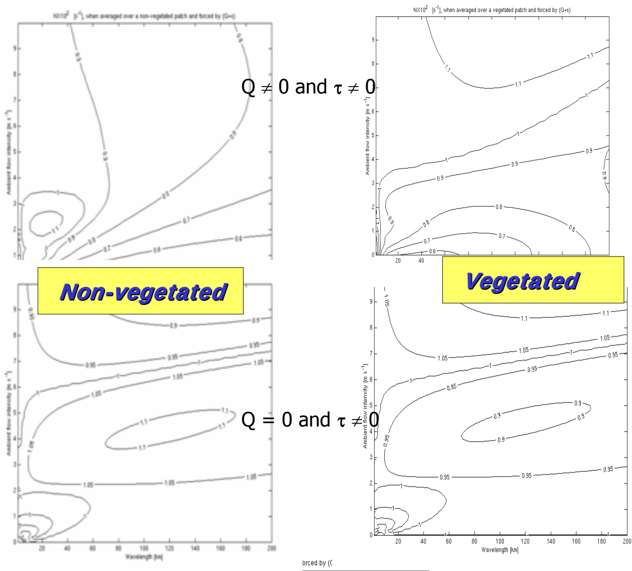
Maximum of the updraft at the top of the boundary layer.

Brunt Vaisala frequency N_{CBL}

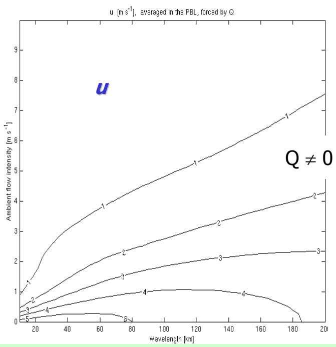
Brunt Vaisala frequency around the top of the C_{BL}, N_{CBL}, averaged in a wavelength where $Q \neq 0$ and $\tau \neq 0$,.

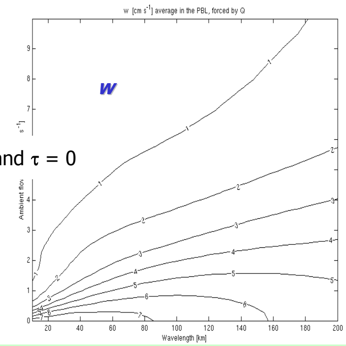


Brunt Vaisala frequency N_{CBL}

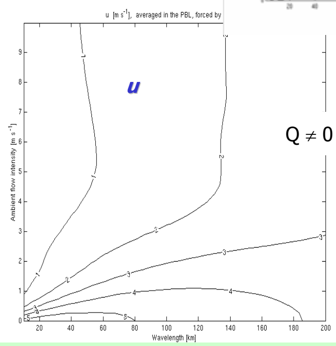


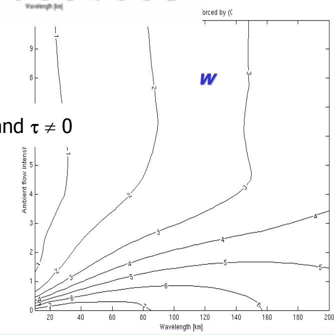
Average flow intensity, after sunset, in the *PBL*, resulting from the release of the *APE*





$Q \neq 0$ and $\tau = 0$





$Q \neq 0$ and $\tau \neq 0$

Conclusions

In our theory results are formulated in terms of mathematical solutions, in which the processes, through which a landscape variability modifies the environment, are easily identified, and in which the range of validity of the results found by different Authors are established as a function of the size of the patches and of the intensity of the wind. Our results show that, when the patches are a small fraction of the Rossby radius, the reduced thermal diurnal amplitude is due to the intrusion of cool air in the surface layer which lifts and replaces the warm air above the warm non-vegetated patches.

Concerning intentional changes of the surface characteristic in order to modify the environment of the lower troposphere for enhancing the chances of convective precipitation, the following considerations can be useful:

- The ambient wind greatly reduces the thermal contrast and the thermally driven updraft, however, at the top of the boundary layer this updraft is more intense in the presence of a light ambient wind.
- When the wind speed is moderate, the wave activity weakens the static stability at the top of boundary layer, and, since these waves are tilted, above the PBL a significant updraft is displaced over the vegetated patches.
- The contribution of the wind stress becomes relevant in the presence of a moderate wind speed, and, when the ambient flow is stronger than 5 m/s, the vertical velocity is mainly due to the mechanical effects induced by the changes of surface roughness.
- After sunset, the residual available potential energy in the PBL can drive significant secondary mesoscale flows.

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