NUMERICAL SIMULATION OF THE SURFACE BOUNDARY LAYER USING A SECOND ORDER CLOSURE MODEL COUPLED TO A SOIL-VEGETATION-ATMOSPHERE INTERACTION ALGORITHM

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ABSTRACT

The planetary boundary layer structure and surface flux evolution over a nuclear installation located in the subtropical region of Brazil ("*Iperó Experiment*") is investigated numerically using an one-dimensional second-order closure model coupled to a soil-vegetation-atmosphere interaction algorithm. Model results are evaluated against in-situ measurements performed during the Iperó Experiment. The main characteristics of the surface boundary layer generated by the numerical experiments were consistent with the observations.

RESUMO

A evolução temporal da estrutura camada limite planetaria e dos fluxos turbulentos de superficie em uma instalação nuclear localizada na região subtropical do Brazil (Experimento de Iperó) é investigada numericalmente através de um modelo unidimensional de fechamento de segunda ordem acoplado a um algoritmo de interação solo-vegetação-atmosfera. Os resultados do modelo são comparados com medidas realizadas durante o Experimento de Iperó. As características principais da camada limite superficial geradas nos experimentos numéricos são consistentes com as observações.

Key words: Surface boundary layer; Second-order closure model;Numerical simulation**.**

INTRODUCTION

Analysis of data available during the Iperó Experiment indicated that the existence of several phenomena of different scales occurring simultaneously over the region, with the topography and land cover playing a major role in the determination of the circulation patterns in this area. The data analysis indicated the presence of:

- Mesoscale circulations - like a sea breeze – reaching Iperó and causing a rapid cooling and moistening of the PBL lower levels and changing the speed and direction of the wind.

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- Diurnal oscillation in wind direction, possibly explained by the daytime anabatic NW-flow induced by topography and the associated secondary SW-flow. Large-scale upper level westerly circulation could also contribute to modulate the daytime observed NW wind at the surface.
- The persistent presence of the nocturnal low-level jet (perhaps associated to the secondary circulation) which has an important rule controlling the vertical evolution of the local stable boundary layer (SBL).

Here, it is hypothesized that the south circulation is part of a meso-scale "geostrophic" secondary flow associated to a daytime NW-anabatic flow induced by the sloped topography. At night, the air aloft decouples from surface, and the south-flow above without the presence of turbulence will accelerate, oscillating inertially around the geostrophic value.

The main objective of this work is to address, numerically, the above hypothesis to explain the local circulation and its scale interactions over the Iperó area, using a second-order closure model incorporating a land-surfece scheme. In this paper it will be described the capability of the SOCM to simulated the surface boundary layer.

IPERÓ EXPERIMENT.

Four two-weeks field campaigns were carried out, from 1991 to 1993, in a nuclear installation located in the subtropical region of Brazil, Iperó ("*Iperó Experiment*"), situated in the countryside of the State of São Paulo Brazil (23^{o}25' S, 47^{o}35' W), 120 km far from the Atlantic Ocean and about 550 m above the mean sea level (Oliveira *et al.*, 1998). The area is slightly slopped towards NW, with a ratio of 1.2:1000 km:km (Figure 1).

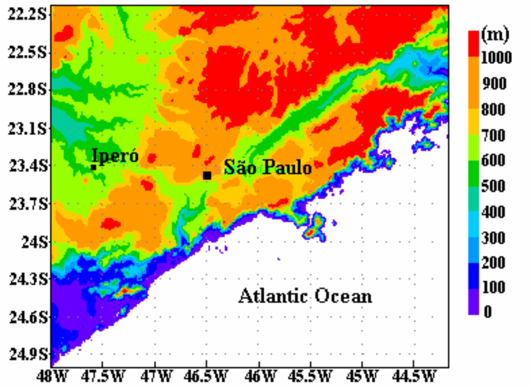

Figure 1: Map indicating the topography of the eastern part of the state of São Paulo, Brazil. Iperó is 120 km far from the shoreline (in straight line), located about 550 m above the mean sea level and 80 km from the city of São Paulo (also plotted). The topography data have a 1x1-km resolution. (Data source: Department of Geophysics, University of São Paulo, Brazil).

The first campaign took place in March 1991, in a 30 by 30 m flat area covered by short grass. The other three field campaigns took place in March 1992, July 1992 and March 1993, in a 500 by 500 m flat area used for agricultural proposes. Most of the land, around Iperó, is occupied by agriculture activities (70% of the region), which changes seasonally. The urban area represents 13% of the region.

Here, will be explored the data obtained in two field campaigns: (i) March 1993 – hereafter called summer period – and (ii) July/August 1992 - hereafter called winter period. During the summer and winter observational campaigns, measurements of net radiation, atmospheric, global and direct solar radiations were carried out 2 m above the surface; air temperature and air humidity at 2.0, 4.0 and 10.0 m above the surface (using a 12 meter tower); soil heat flux at 0.01 and 0.08 m below the surface and soil temperature at 0.01, 0.08 and 0.15 m below the surface. Vertical profiles of air temperature, air moisture and horizontal wind speed and wind direction were obtained using tethered balloons and radiosounding systems.

THE NUMERICAL MODEL

The second-order closure models (SOCM) used here contains variance and covariance equations and it correspond to a level four model in the classification of Mellor and Yamada (1982).The model considers a horizontally homogeneous atmosphere. Here, the characteristic time scales and diffusion coefficients were evaluated by Mellor and Yamada (1982), Nakanishi (2001) and Nakanishi and Nimo (2004).

NUMERICAL SCHEME, INITIAL AND BOUNDARY CONDITIONS

The boundary conditions, at the ground level, were evaluated using a soil-vegetation-atmosphere scheme described in Oliveira (2003). The set of parameters related to the soil-vegetation scenery employed here was obtained by Targino and Soares (2001) and is presented in Table 1.

Table1: Parameters used in the soil-vegetation-atmosphere algorithm.

Parameter	Value (Winter)	Value (Summer)
Roughness length (m)	0.05	0.09
Canopy roughness length (m)	0.06	0.1
Zero displacement height (m)	0.2	0.34
Soil thermal diffusivity (m^{2}s^{-1})	3.3 10^{-07}	2.4 10^{-07}
Foliage shielding factor	0.45	0.35
Foliage albedo	0.35	0.25
Foliage emissivity	0.95	0.98
Ground surface emissivity	0.95	0.95
Critical or saturated value of the ground soil moisture	0.21	0.30
Wilting value of the ground soil moisture	0.42	0.50

For the SOCM initial conditions it was assumed that the PBL has reached a final stage of the daytime evolution with a 1000 m mixed layer so that all variances and covariance vary linearly, in the vertical direction, from a specific value at the surface to nearly zero at 1000 m. For the mean state, this initial condition corresponds to constant potential temperature equal to 303 K and zonal and meridional wind components equal to -5.0 m s^{-1} and 0.0 m s^{-1}, respectively. The flow is considered to be in geostrophic equilibrium given by the large and meso scale horizontal pressure gradients. It was assumed that the resultant horizontal pressure gradient generates a geostrophic wind of 10 m s^{-1} from east, constant with height.

The numerical solutions of the SOCM equations were obtained using a finite difference scheme. The algorithm used are (i) forward in time and centred in space for the mean equations; (ii) forward in time for the heat balance equation on the surface and (iii) implicit for the variance and covariance equations. The equations were discretized in 81 levels in a staggered grid of 10 meters size. All mean quantities were located in the odd levels and the variance and covariance were located in the even levels. The heat balance equation was simplified, by linearization of the surface long wave radiational cooling, to an ordinary differential equation. Even though such numerical scheme is unconditionally stable for partial differential equation systems with constant coefficients, in this case the actual numerical stability was only achieved for time steps of 5 seconds.

RESULTS

Figures 2 and 3 display the time evolution of the observed and simulated friction velocity and characteristic scale of temperature for year day 213 of 1992 and yearday 71 of 1993, respectively winter and summer campaigns of Iperó Experiment. The simulations and observations agreed satisfactorily despite the degree of simplifications used in the soil-vegetation-atmosphere algorithm.

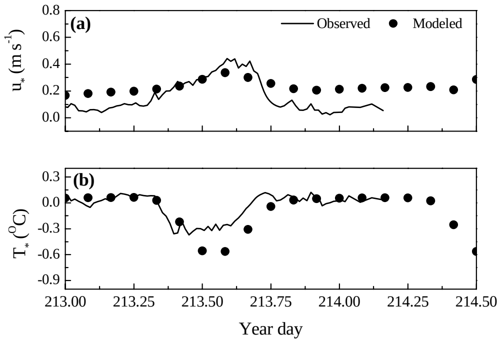

Figure 2: Time evolution of (a) characteristic velocity, u_*, and (b) characteristic temperature, T_* for the winter campaign. The continuous line represents the observed values and the solid circles the modelled values.

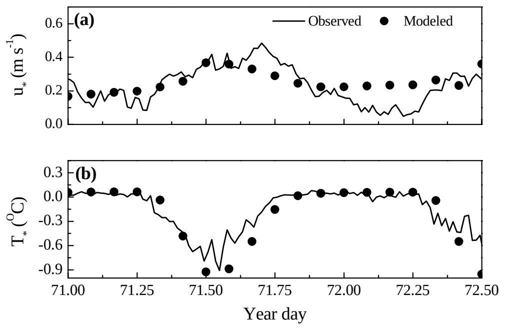

Figure 3: As figure2 but for the summer experiment

Figures 4 and 5 display the time evolution of the observed and simulated horizontal wind speed and wind direction for year day 213 of 1992 and yearday 71 of 1993, respectively winter and summer campaigns of Iperó Experiment. The simulated wind speed agrees with the observation better than the wind direction.

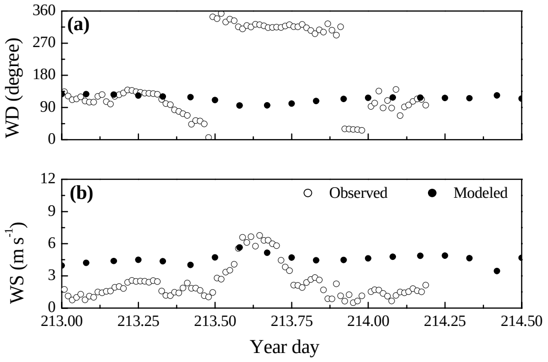

Figure 4: Time evolution of surface wind (a) direction, WD, and (b) velocity, WV, for the winter campaign. The open and solid circles represent, respectively, the observed and modelled values.

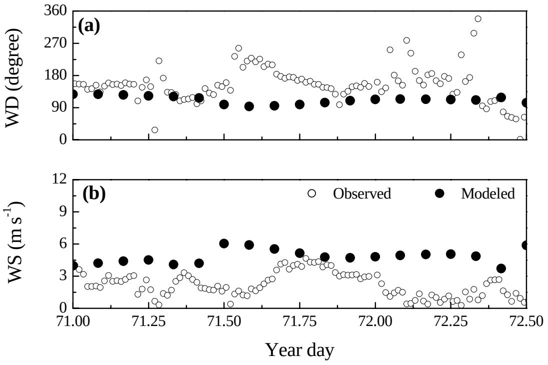

Figure 5: As figure 4 but for the summer experiment.

Figures 6 and 7 display the time evolution of the observed and simulated horizontal components of t he energy budget at the surface for year day 213 of 1992 and yearday 71 of 1993, respectively winter and summer campaigns of Iperó Experiment. They indicated that the soil-vegetation-atmosphere algorithm performed very well with the set of parameters used here.

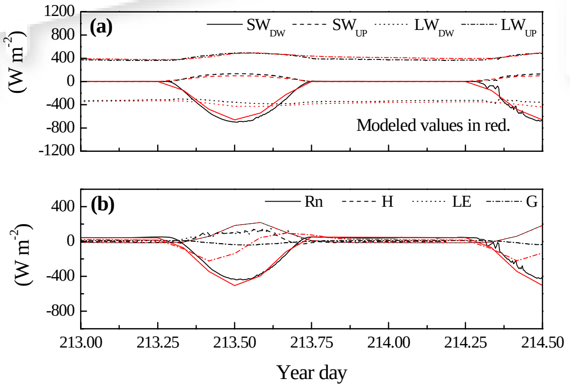

Figure 6:(Winter)

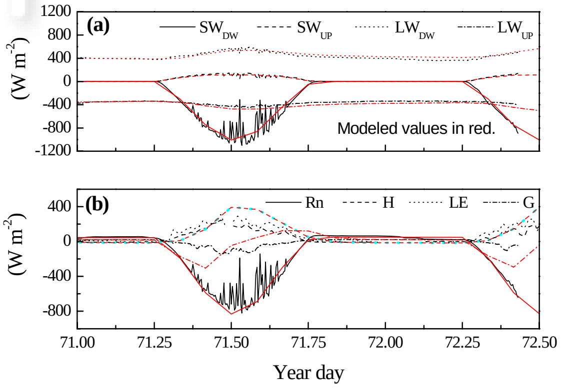

Figure 7. (Summer)

Time evolution of (a) surface radiation and (b) surface energy components during winter conditions. In (a) the symbols SW and LW indicate, respectively, short wave and long wave radiation. The subscript DW and UP denote, respectively, down and up. In (b) Rn is the net radiation, H is the sensible heat flux, LE is the latent flux and G is the soil heat flux. The black and red colours represent, respectively, the observed and modelled values.

CONCLUSION

This work described the simulation of PBL over the region of Iperó using a second order closure model coupled to a soil-vegetation-atmosphere interaction algorithm. The simulations were set up using information from the Iperó Experiment. The surface layer parameters, like friction velocity, characteristic scales of wind and temperature, wind speed and components of the surface heat budget, are satisfactorily simulated by the SOCM.

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