Journal of Agrometeorology 3(1 & 2) : 261-266 (June-December-2001)

Simulation of boundary layer parameters using one dimensional atmospheric boundary layer model

S. S. PARASNIS, M. K. KULKARNI AND J. S. PILLAI
Indian Institute of Tropical Meteorology, Pashan, Pune 411 008

ABSTRACT

Simulation of atmospheric boundary layer parameters has been carried out using the observations collected at Anand,Khandha, Sanand and Derol for two different periods during the Land-Surface Experiment in the year 1997 using the one-dimensional atmospheric boundary layer model. This is a combination of a boundary layer model and a two layer soil model. The pilot balloon wind observations collected at Arnej, Khandha and Derol have been used to obtain the vertical velocity component required as an input for the 1-d model. The boundary layer height showed progressive increase with time. The maximum height was attained at 1300 hours, which was attributed due mainly to the strong surface heating, and convective activity. The boundary layer height decreased rapidly to its initial value of 400 m at 1700 hrs. The results are discussed.

Key words : Boundary layer, Modelling, Land surface processes.

The numerical modelling of land surface processes is an effective way to understand the physical mechanism of exchange processes in the atmospheric boundary layer. The growing interest in the interactions between the atmosphere and the underlying earth's surface is driven by the realisation that the surface fluxes determine, the steady state of the atmosphere to a great extent and also they determine the mean profiles of the surface layer and the atmospheric boundary layers.

A relatively simple one dimensional model of Atmospheric Boundary Layer is described here, in which a soil atmosphere system that incorporates the interactions between soil and atmosphere in the parameterisation of surface fluxes is also included. The proposed model is a combination of a boundary layer model and two layer soil model. Simulation of boundary layer fluxes with the help of this model will have applications to local weather forecast; air-pollution, soil chemistry and soil hydrology.

MATERIALS AND METHODS

Atmospheric boundary layer model and prognostic equations

The model forecasts the tendencies due to turbulent mixing of the potential temperature (θ), specific humidity (q) and horizontal component of the wind (Vh or u and v). To simplify presentation, only the vertical diffusion terms due to boundary-layer turbulent mixing and the advection terms due to prescribed vertical motion field are considered in the prognostic equations (Troen and Mahrt, 1986).

The prognostic equations for atmospheric boundary layer are

$$\frac{\partial Vh}{\partial t} = \frac{\partial}{\partial z}\left(K_m \frac{\partial Vh}{\partial z}\right) - W\left(\frac{\partial Vh}{\partial z}\right) \quad (1)$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_h \left[\frac{\partial \theta}{\partial z} - \gamma_\theta\right]\right) - W\left(\frac{\partial \theta}{\partial z}\right) \quad (2)$$

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial z}\left(K_h \frac{\partial q}{\partial z}\right) - W\left(\frac{\partial q}{\partial z}\right) \quad (3)$$

where V, θ, q and h are the mean wind, potential temperature, specific humidity and boundary layer height respectively and K_m and K_h are the diffusivity coefficients for momentum and heat. γ_θ (km^{-1}) is the counter gradient correction for the potential temperature required for weakly stable conditions of surface layer.

Surface layer model

The counter gradient correction (γ_θ) is evaluated in terms of the surface flux of potential temperature. The surface fluxes are parameterised for stable case following Mahrt (1987) and for unstable case following Louis *et al.* (1982) modified by Holtslag and Beljaars (1989) as

$$u_*^2 = C_m |V_0| \quad (4)$$

$$(w'\theta')_s = C_h (\theta_s - \theta_0) \quad (5)$$

$$(\overline{w'q'})_s = C_h (q_s - q_0) \quad (6)$$

where C_m and C_h are the exchange coefficients for momentum and heat respectively (ms^{-1}). $|V_0|$ is the wind speed evaluated at the first model level above the surface. The potential temperature (θ_0) and specific humidity (q_0) are taken as their representations at the first model level while the potential temperature (θ_s) and specific humidity (q_s) at the surface are obtained from the surface energy balance.

Total evaporation

Total evaporation (E) is obtained by summing up the direct soil evaporation (E_{dir}), transpiration (E_t) and the canopy transpiration (E_c).

$$E = E_{dir} + E_t + E_c \quad (7)$$

The two layer soil model is used to obtain E_{dir}

Surface energy balance and potential evaporation

The soil or ground heat flux G is defined as

$$G = K_T(\Theta)\left(\frac{\partial T}{\partial z}\right)_{z=0} \quad (8)$$

where Θ is the volumetric water content as defined above, K_T is thermal conductivity ($Wm^{-1}K^{-1}$) and T is soil temperature.

The sensible heat flux is calculated as

$$H = \rho_0 C_p C_h (\theta_s - \theta_0) \quad (9)$$

which is a function of the air density (ρ_0), the specific heat for air, the heat exchange coefficient (C_h) the difference between the surface temperature (θ_s) and the air potential temperature at the first model level (θ_0).

The potential evaporation (E_p) which is used to calculate the total evaporation can be evaluated using surface energy balance equation. The surface potential temperature (θ_s) also is obtained by the surface energy balance equation in which the potential evaporation E_p is submitted for the actual evaporation E as a fraction of it.

The canopy evaporation E_C can be obtained as

$$E_C = E_P \sigma_f (c^*/s')^n \quad (10)$$

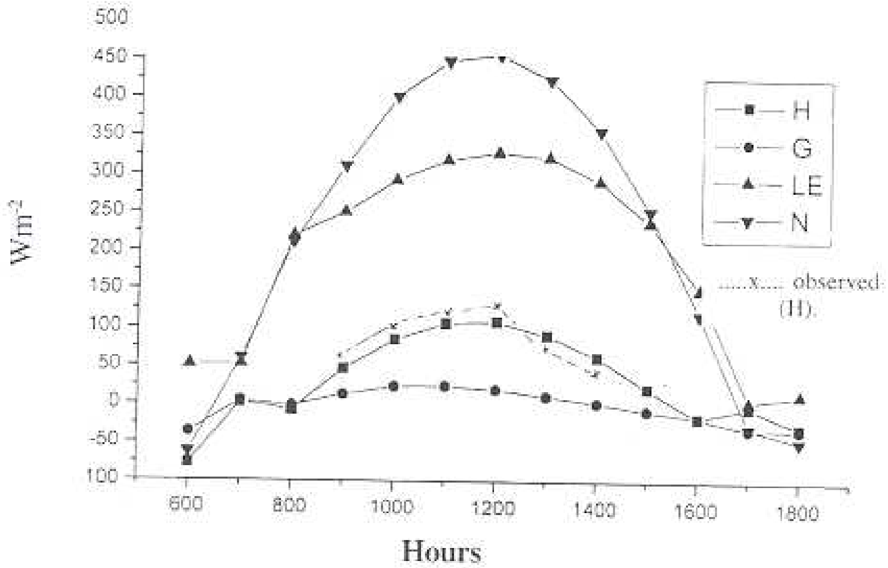

Fig. 1 : Simulated sensible (H), latent (LE), ground (G) heat fluxes, net (N) radiative flux, and observed (H). at Anand at 0600 UTC on 14 Feburay, 1997.

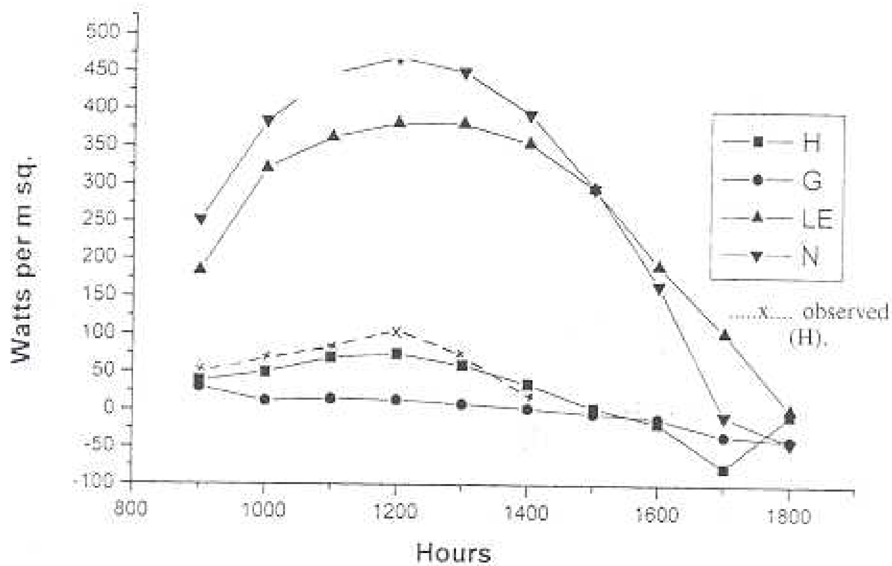

Fig. 2 : Simulated sensible (H), latent (LE), ground (G) heat fluxes, net (N) radiative flux, and observed (H). at Anand at 0900 UTC on 14 Feburay, 1997.

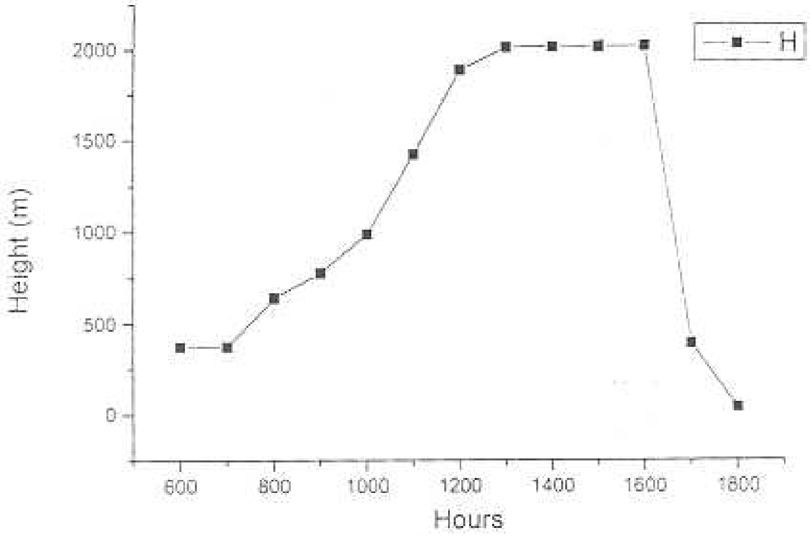

Fig. 3 : Simulated boundary layer height at Anand on 14 February, 1997

Where σ_f is plant shading factor, s' is saturation water content, c* is the canopy water content, n=0.5 (nondimensional)

Evaporation through transpiration (E_t)

Evaporation through transpiration (E_t) can be obtained in the following manner

$$E_t = E_p \sigma_f K_v \frac{\sum_{t=1}^{2} [\Delta z g(\Theta_i)] \left[1 - \left(\frac{C^*}{S'}\right)^n\right]}{\sum_{i=1}^{2} [\Delta z_i]} \qquad (11)$$

where K_v is a nondimensional plant resistance factor or plant coefficient with a value between 0 and 1. The canopy resistance may be used instead of the plant coefficient. g (Θ) is the wilting point.

Determination of surface specific humidity

The surface specific humidity (q_s) is calculated from

$$q_s = q_o + \frac{E}{\rho_0 C_h} \qquad (12)$$

where q_0 is the specific humidity at first model level, ρ_0 is the air density at surface (kg m^{-3}), C_h is the exchange coefficient for moisture and E is the total evaporation.

Data

In the present model, the soil moisture observations collected at Anand in the Sabarmati region of Gujarat state during the LASPEX-97 programme were utilised. The soil moisture data is available for some of the days of intensive observation period (IOP). The input parameters required for the 1-d atmospheric boundary layer model are u (zonal), v (meridional) along with vertical velocity component, temperature and mixing ratio profiles. The pilot balloon wind data at three stations viz. Arnej, Khandha and Derol for the computation of vertical velocity and the temperature, mixing ratio, u and v component profiles for station Anand were used. The simulations of boundary layer parameters as well as the computations of sensible heat flux, latent heat flux, ground heat flux and net radiative flux using the 1-d model are presented below.

RESULTS AND DISCUSSIONS

Surface energy balance

Surface energy balance on Feb. 14, 1997 is shown in Fig. 1. Fig. 2 shows the computations of fluxes for the same day but for different time, i.e. 0900 UTC. It is interesting to note that the values of all fluxes in both the Fig. 1 and 2 show consistency. Also, shown in this figure the observed values of sensible heat flux (dotted line in figure 1 and 2). The observed and simulated values of sensible heat flux are comparable. The sensible heat flux (H), latent heat flux (LE), ground heat flux (G) and the net radiative flux (N) depicted in the Fig. 1 and 2, showed variations relating to the progress of the day. Particularly the sensible heat flux, latent heat flux and net radiative flux showed diurnal character.

Boundary layer height

The one dimensional atmospheric boundary layer model also simulates the boundary layer height. Fig. 3 shows the evolution of boundary layer height from 0600 to 1800 hrs for Feb.14, 1997. It is seen that the boundary layer height which is initially 400 m, gradually increased as the day progressed. The value of boundary layer height remained almost stationary between 1300 to 1700 hrs and afterwards dropped suddenly to the initial value. The maximum height was attained at 1300 hours mainly due to the strong surface heating and convective activity and then it remained stationary to 1600 hrs. The boundary layer height decreased rapidly to its initial value of 400 m at 1700 hrs.

CONCLUSIONS

The one-dimensional atmospheric boundary layer model, briefly described above is a combination of a boundary layer model and a two layer soil model. The model's capability to simulate the fluxes has been tested. It is noticed that the model simulates the surface fluxes to a reasonable extent.

ACKNOWLEDGEMENTS

The authors are thankful to the Director, Indian Institute of Tropical Meteorology, Pune for the facilities provided for this study. Authors also acknowledge with thanks the Ministry of Science and Technology, Government of India, New Delhi for providing the financial assistance. They are also indebted to Mr. Arulraj S. for his assistance in development of the model in the early stages.

REFERENCES

Holtslag, A. A. M. and Beljaars, A. C. M. 1989. Surface flux parameterisation schemes developments and experiences at KNMI. ECMWF Workshop on Parameterisation of Fluxes and Land Surfaces. 24-26 Oct., 1988. pp. 1221-1247, Reading, England (Also as KNMI Sci. Rep. 88-06, 1988).

Louis, J. Tiedtke, F. M. and Geleyn, J. F. 1982. A short history of the operational PBL - Parameterisation of ECMWF. Workshop on planetary boundary layer parameterisation. European Centre for Medium Range Weather Forecasts, Shinfield Park, Reading, Berks, U. K.

Mahrt, L. 1987. Grid - averaged surface fluxes. *Mon., Wea. Rev.,* 115 : 1550 - 1560.

Mahrt, L. and Pan, H. L. 1984. A two layer model of soil hydrology. *Bound. Layer Meteorol.,* 29 : 1 - 20.

Pan, H. L. and Mahrt. L. 1987. Interaction between soil hydrology and boundary layer development. *Bound. Layer Meteorol.,* 38 : 185-202.

Troen, I. and Mahrt. L. 1986. A simple model of the atmospheric boundary layer: sensitivity to surface evaporation. *Bound. Layer Meteorol.,* 37 : 129-148.