Interactions of the land-surface with the atmospheric boundary layer: case studies from LASPEX

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The daytime interaction of the land-surface with the atmospheric boundary layer (ABL) is studied for two case study days representing pre-monsoon and monsoon conditions during the Land Surface Processes Experiment (LASPEX) field program which was carried out in the tropical semi-arid region in the northwest Indian state of Gujarat. In this study, a one-dimensional (column) ABL model which has a land-surface scheme that interacts with the ABL is used. Results indicate that in coupled land–atmosphere simulations, realistic daytime surface fluxes and atmospheric profiles are produced, though improvement is needed, particularly in the transpiration and soil heat flux formulation.

DEVELOPMENTS in numerical weather prediction and climate models have focused increased attention on simulation of land-surface processes[1,2]. There has been growing interest in understanding the interactions between the atmosphere and the underlying surface. One-dimensional models are being used by a number of academic institutions to study the role of land surface processes in the development of ABL with specific application to local (in addition to regional and global) weather forecasting[3,4].

In this study we use the Oregon State University one-dimensional (column) ABL model which was developed to simulate interactions of the land-surface with the ABL. Originally the model was intended for inclusion in large-scale numerical weather prediction and climate models[5]. In addition to a number of studies using the land-surface scheme from the OSU ABL model in stand-alone mode[6–8], several studies have examined land–atmosphere interactions using the OSU ABL model in a coupled land-surface-ABL mode[2,9,10]. Very few studies have used the LASPEX data to simulate ABL characteristics[11].

The purpose of this paper is to simulate the boundary layer parameters on the two days of case studies which represent the contrasting conditions as far as the Indian summer monsoon is concerned. It is intended to test the model's current capability to simulate the land-surface and atmospheric boundary layer for this tropical and semi-arid monsoon region.

A Land Surface Processes Experiment (LASPEX) was conducted during 1997–98 in the Sabarmati river basin of Gujarat, located in the semiarid part of western Indian region (Figure 1). The region provides contrasting meteorological conditions from one season to another. During summer monsoon season, the region can experience heavy rainstorms and during the winter and pre-monsoon seasons, induced western disturbances may produce widespread precipitation.

In LASPEX, meteorological observations were collected at five sites with Anand (22°35′N, 72°55′E) as the central site. These stations are at a distance of about 60–100 km from each other. Temperature, humidity, wind speed and direction were measured at 1, 2, 4 and 8 m levels above surface. The details of various sensors used in LASPEX and data acquisition system are given in ref. 12, while details of the observations can be found in ref. 13. Radiosonde and pilot balloon launches were conducted by the India Meteorological Department.

The experimental area of LASPEX lies between 600 and 1000 mm isohyets. Thus humidity content will be moderate. On an average the experimental area lies within a belt of 40–60% relative humidity at noon[14]. There is wide variation of soil properties in the land surface processes experimental areas. Anand has loamy sand type soil (Figure 1). The soil type varies between alluvial to sandy and has an important influence on the runoff and groundwater recharge and hence on the sub-basin to basin scale hydrological processes.

The primary seasonal difference in vegetation between May and July is the fractional coverage, approximately 60% in May and 70% in July, while measurements indicate that the value of the leaf area index (LAI) during May is 3.0, with a similar LAI during July. May observations of soil moisture are quite similar to those available from the NCEP reanalysis, while July observations are not available because the point of measurement is water logged (water entered into the measuring tube, inserted in the soil of neutron probe). As such, we make use of the NCEP reanalysis data set for initial soil moisture used in the model. NCEP's soil moisture (0.36 in 0–10 cm soil layer) represents super-saturated state as it is more than the climatic value (0.17) of field capacity of soil at Anand[14]. Soil moisture and soil temperature measurements are interpolated to the two layers in the land-surface scheme used in the model (Table 1).

Table 1. Land-surface conditions for 14 May and 16 July 1997 during LASPEX

Description	Parameter	14 May	16 July	Units
Soil layer (cm)	Soil moisture			
0–10	$_1$	0.10	0.36	$m^3 m^{-3}$
10–100	$_2$	0.08	0.26	$m^3 m^{-3}$
	Soil temperature			
0–10	T_1	28	27	C
10–100	T_2	22	31	C

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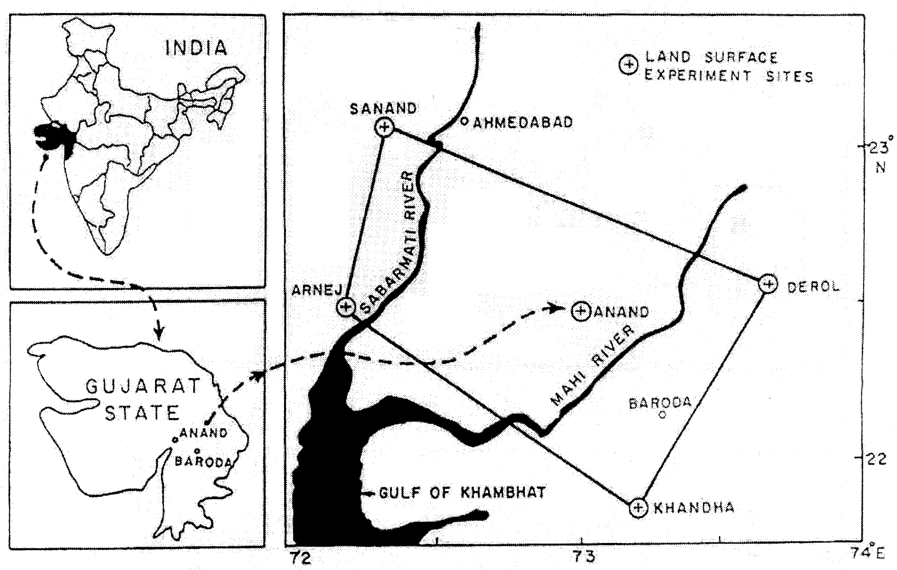

Figure 1. Location of LASPEX sites in northwest India.

Table 2. OSU ABL model land-surface parameters for LASPEX

Description	Parameter	Value	Units
Momentum roughness	Z_{om}	0.1	m
Thermal roughness	Z_{oh}	0.01	m
Minimum canopy resistance	r_{cmin}	13.3	s m^{-1}
Soil porosity	$_{sat}$	0.41	m^3 m^{-3}
Field capacity	$_{fc}$	0.25	m^3 m^{-3}
Wilting point	$_{wilt}$	0.07	m^3 m^{-3}

We examine the coupled land–atmosphere response for two case study days representing pre-monsoon and monsoon environments. Our interest is to contrast the local land–atmosphere response of these two environments. Since it is a column model, these days should have minimal advection. Additionally, while the model used in this study has a shallow boundary-layer cloud scheme, a mostly cloud-free environment is preferred in order to avoid complicating land–atmosphere interaction with the presence of clouds. As such, we choose 14 May and 16 July 1997 for our study since both days had minimal advection (of the set of days available for study), and there were no clouds on 14 May, and only minimal clouds on 16 July.

In this study we use the OSU ABL model which was developed to simulate interactions of the land–surface with the ABL. The model consists of a two layer soil model and ABL model. The physics used in this model is adequate to take into account the different thermodynamic processes in the ABL. The land–surface scheme consists of multiple soil layers and a simple plant canopy[15], modified to include the effect of vegetation using a 'big Stewart approach for canopy conductance which closely follows Noilhan and Planton[16]. The ABL scheme uses the original local (K-theory) and nonlocal (boundary-layer-scale mixing) development by Troen and Mahrt[17] with an update to nonlocal mixing of heat and moisture following ref. 5. The detailed description of the model may be found in ref. 2. Table 2 gives further descriptions of the important OSU ABL model land-surface parameters for LASPEX.

The footprint of wind measurement at 8 m represents about 400 m (50 times the measurement height) in the upwind fetch of the tower which is mostly covered by agriculture crops. The roughness length derived from log-linear profiles of wind under neutral stability may not represent the terrain in general which is consisting of tall trees, buildings, etc. located beyond 1 km from the tower. Hence the momentum roughness shown in Table 2 was obtained from the modified[18] classification table[19,20] as it was found to be in agreement with those derived from gustiness analysis of wind. It takes into account both nearby and far-off obstacles, vegetation, etc. in the upward direction within a distance of ~ 3 km over a sector of 20 to 30° width. The roughness length for heat is taken as one order of magnitude smaller than that for momentum (a more classical assumption).

Soil moisture and temperature observations taken at the LASPEX central site Anand and described earlier provide initial soil conditions for model simulations, while radiosondes launched from the same location at 0530 IST (0000 UTC) for both 14 May and 16 July 1997 provide initial atmospheric conditions. Surface measurements and atmospheric profiles taken throughout the study days provide model verification. Mean vertical motion (used in calculating vertical advection) was obtained from the National Centre for Medium Range Weather Forecasting

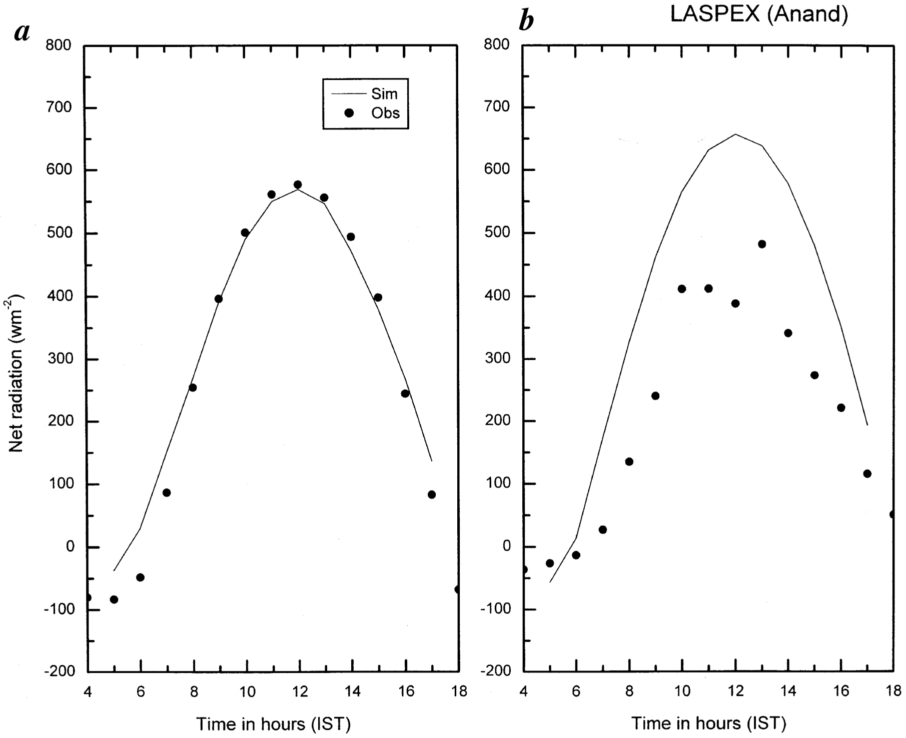

Figure 2. Time series of observed (symbols) and model (lines) net radiation at the Anand central site during LASPEX (***a***) 14 May 1997, and (***b***) 16 July 1997.

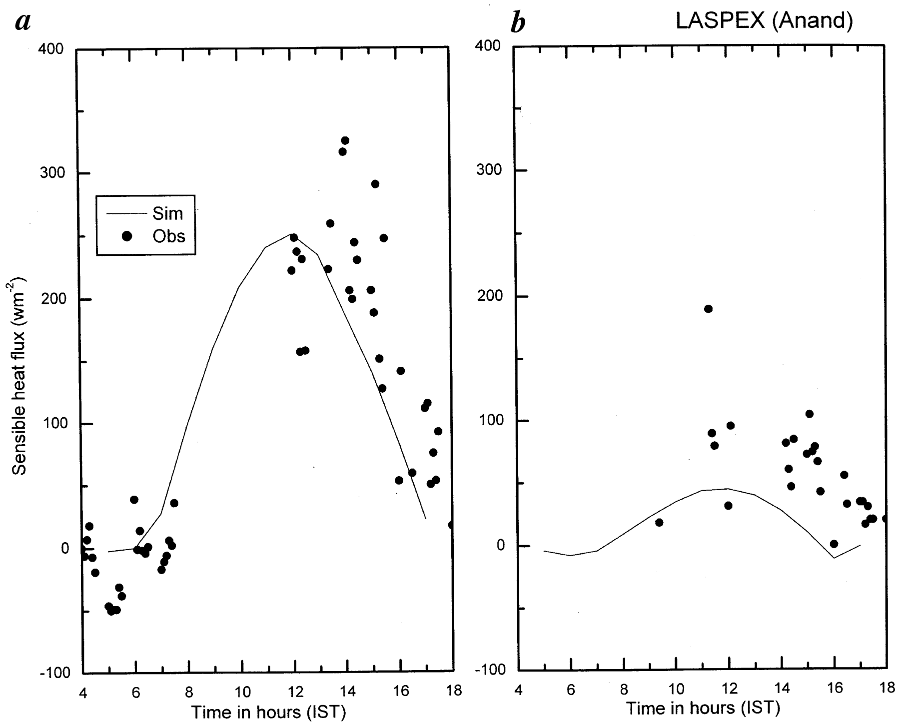

Figure 3. Same as Figure 2 except for sensible heat flux.

(NCMRWF, New Delhi, India) model analysis and is specified at each model level. The operational weather forecast system at NCMRWF is based on a Data Assimilation System and a Global Spectral Model at T80 horizontal resolution with 18 vertical layers. The horizontal spatial resolution is ~ 500 km which is quite large for the

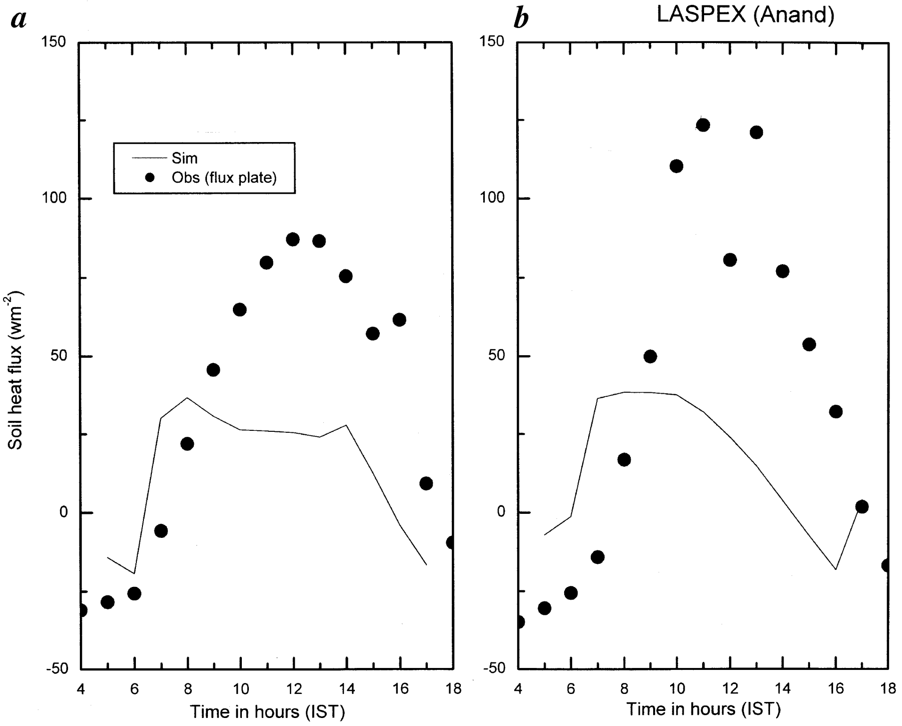

Figure 4. Same as Figure 2 except for soil heat flux.

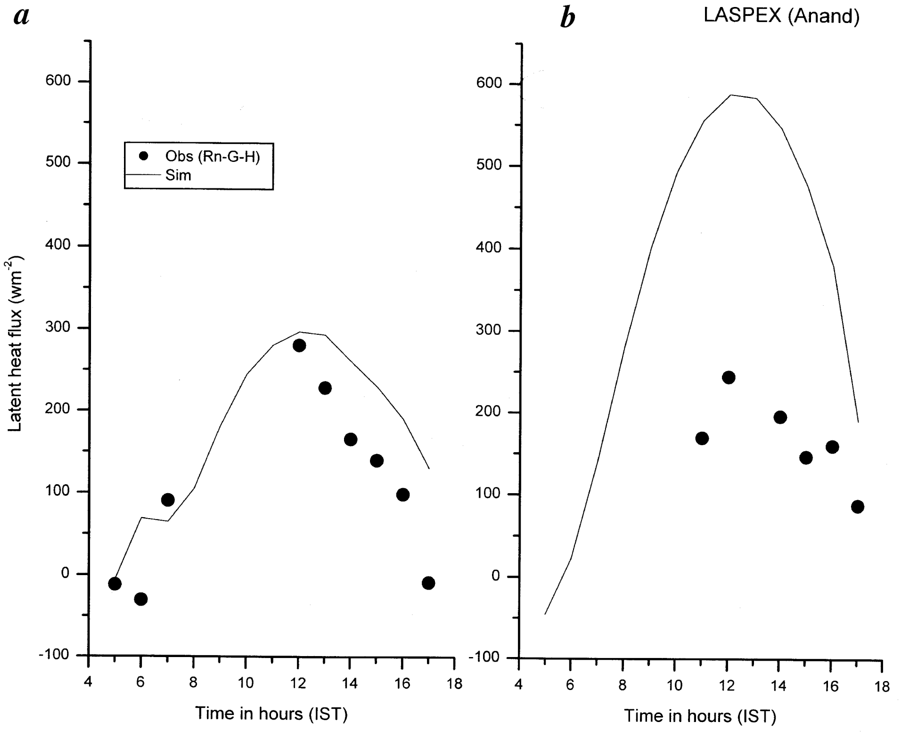

Figure 5. Same as Figure 2 except for latent heat flux.

present study. The study days chosen are thought to have minimal advective effects so that horizontal advection is assumed to be zero. Geostrophic winds are estimated from the actual winds at approximately 1500 m from the 0530 IST soundings on the study day and 24 h later, and are linearly interpolated in time and height-independent.

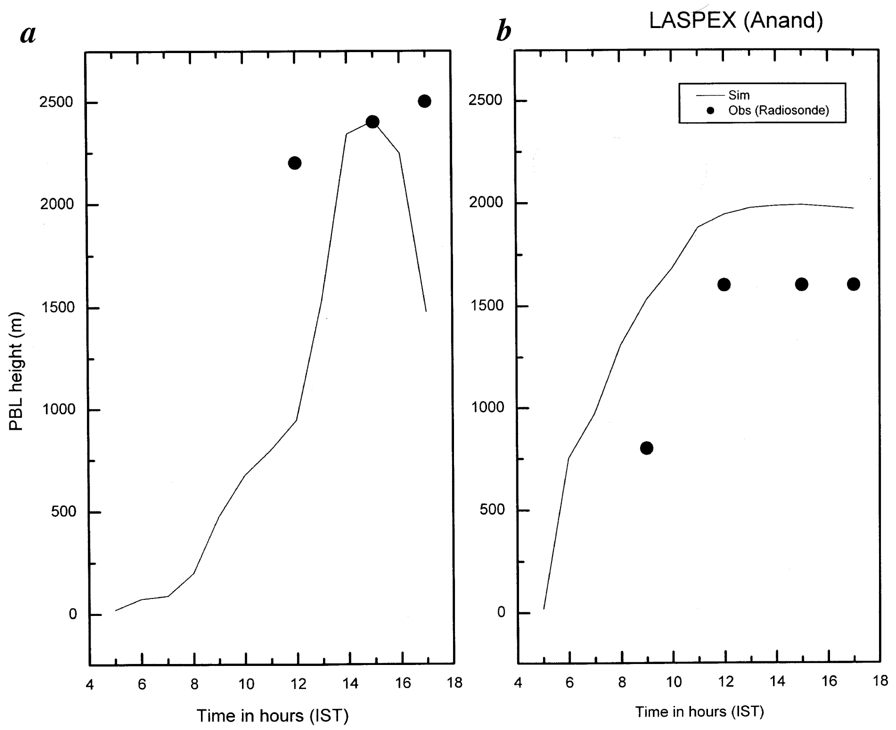

Figure 6. Same as Figure 2 except for boundary layer depth.

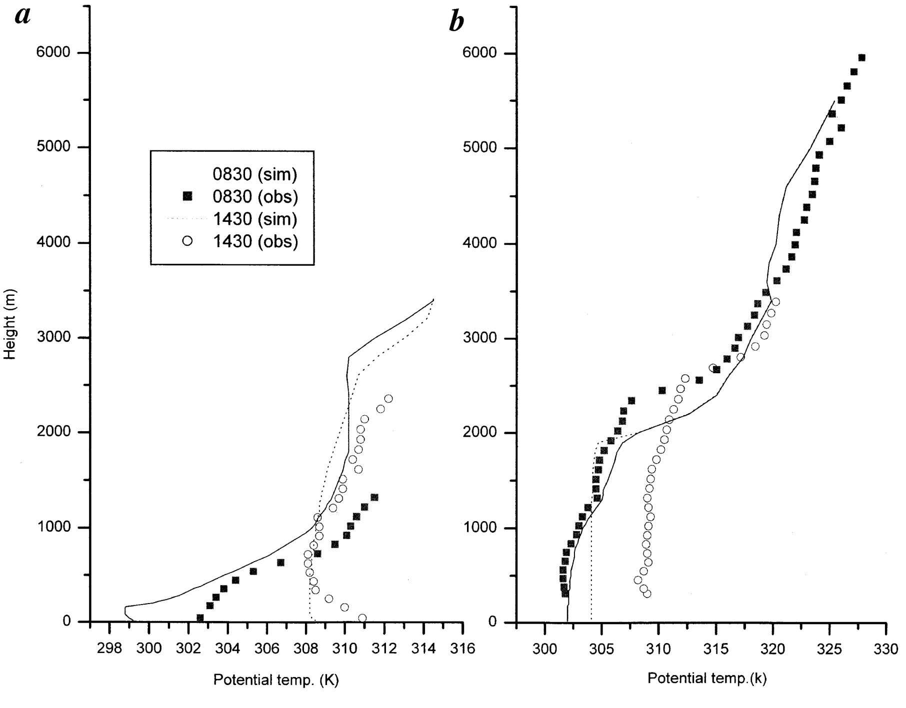

Figure 7. Profiles of observed (symbols) and model (lines) potential temperature at 08:30 and 14:30 IST (03 and 09 UTC) at the Anand central site during LASPEX for (***a***) 14 May 1997, and (***b***) 16 July 1997.

For this purpose, the radiosonde observations taken at Anand were used. The model vertical resolution is 20 m in the lowest 400 m, then 50 m up to 1.4 km, 100 m up to 2 km, and 200 m to the top of the model domain. The time step is 180 s; model simulations begin at 0530 IST and are integrated for 12 h.

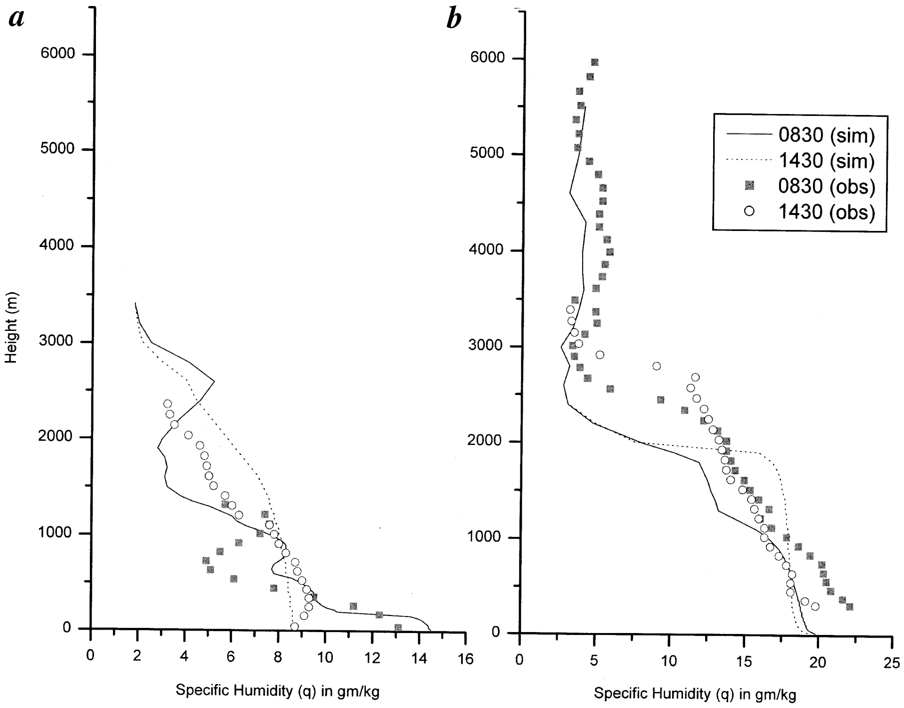

Figure 8. Same as Figure 7 except for specific humidity.

Model simulations were performed for two days that represent pre-monsoon (May) and monsoon (July) conditions, with contrasting regimes: May is near the end of the dry season with dry soil and low atmospheric humidity, while July falls in the monsoon season with moist soil and higher atmospheric humidity. Diurnal variation of simulated net radiation (Figure 2), sensible heat flux (Figure 3), soil heat flux (Figure 4), and latent heat flux (Figure 5) for May and July months are compared with observations. The observed sensible heat flux (10 min mean) is obtained from a sonic anemometer (Metek, Germany) which actually represents buoyancy flux, $C_p\ w'T_v'$ where w' and T_v' are fluctuations of vertical wind and virtual temperature respectively, measured by sonic anemometer. For pre-monsoon conditions net radiation and sensible heat flux are well simulated while they are over and underestimated respectively, for monsoon conditions (Figures 2 and 3). For monsoon conditions sensible heat flux is underestimated (though net radiation is high) at the expense of latent heat flux (Figure 5) which is overestimated. Soil heat flux is underestimated for both pre-monsoon and monsoon conditions, suggesting a need for a modification to the soil heat flux formulation, e.g. under conditions of large heat conduction into the ground, soil thermal conductivity exhibits an important control over the energy partition at the surface. Satellite-derived soil moisture representing a large area may be useful in improving the simulation. Of course they need to be compared with ground truth measurements for realistic simulation.

The observed PBL height (peak) at Anand compares well with that simulated (Figure 6) for pre-monsoon conditions. The peak PBL height for monsoon conditions is overestimated although sensible heat flux is underestimated suggesting that there may be other factors that affect PBL growth. The profiles of potential temperature (Figure 7) and specific humidity (Figure 8) for pre-monsoon and monsoon conditions are compared with those observed at 0830 IST (03 UTC) and 1430 IST (09 UTC). Although trends in potential temperature profiles are well simulated, some differences are observed near the surface (~ 200 m) in terms of shape and magnitude especially for monsoon conditions at 1430 IST (Figure 7). The simulated profile of specific humidity for monsoon conditions at 1430 IST (Figure 8) shows a sharp decrease at 2000 m as compared to that observed at 2500 m.

The performance of the land-surface scheme has been evaluated for two days from the LASPEX 1997 field program carried out in Gujarat state of northwest India, studied in coupled one-dimensional land surface-atmospheric boundary layer model simulations and compared with observations. These two days represent pre-monsoon (May) and monsoon (July) conditions. The study suggested that for drier pre-monsoon conditions, net radiation and sensible heat flux are well simulated by the model, but for wet soil conditions during monsoon, net radiation as well as sensible, soil and latent heat fluxes are not simulated well.

Findings here suggest that future work should focus on updates to the representation of land–surface processes in the model for the LASPEX region. The parameterization of canopy conductance for tropical crops may need improvement, as well as the soil heat flux formulation. It would be useful to make annual simulations for the central site of Anand with the land-surface scheme only run in an offline mode (e.g. in a PILPS-like study; ref. 21), using hourly atmospheric and radiation forcing to drive the offline land-surface scheme. The uncertainty associated with soil moisture (due to point measurement) and vertical velocity (from NCMRWF Analysis that represents a very large area) might be the reason for poor simulation and therefore these two parameters need to be improved for better representation of the local terrain. These will be attempted in the forthcoming papers on this topic.

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On the astronomical significance of the Delhi iron pillar

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The astronomical significance of the Delhi iron pillar has been highlighted by addressing its probable original erection site at Udayagiri and the probable image that was atop the pillar's capital. Based on the astronomical significance of Udayagiri's location on the Tropic of Cancer, and earlier solar observations at Udayagiri, it has been shown that the iron pillar may have been aligned with the cardinal directions such that, on summer solstice day, the early-morning shadow of the pillar fell along a specially cut passageway in the direction of one of the important bas reliefs (in cave temple 15) at Udayagiri site. Evidences have been provided to corroborate the identification of a circular disc-shaped object (20″ diameter and 2″ thick) that was probably atop the Delhi iron pillar capital.

THE Delhi iron pillar has been a major attraction for academics in history, archaeology, metallurgy and science, apart from the general public primarily due to its antiquity,

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