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Comparison of model forecasts with LASPEX-97 data

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ABSTRACT

Surface meteorological parameters and the surface energy budget from the nearest grid point from two global models are compared with the Land Surface Processes Experiment (LASPEX) averaged data collected over Anand, Gujarat state. We explore how well short-term 24-h forecasts from the models reproduce the observed diurnal cycle for selected days in May, July and September 1997. This intercomparison helped in identifying and suggesting possible improvements in the model parameterizations of land surface and boundary layer.

Key words: Global model forecasts, Field experiment data, Parameterization of physical processes, LASPEX-97

Data from observational research programs provide a valuable framework for testing model parameterizations. The First International Satellite Land Surface Climatology project (ISLSCP) Field experiment (FIFE) over Kansas, USA is one such example. Betts *et al.* (1996) compared the 1987 FIFE data set with the land-surface and boundary layer (BL) components of the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) reanalysis modelling system. They showed that an erroneous interaction in the model among the surface fluxes, precipitation and the surface diurnal cycle led to excessive precipitation during some months than that observed over FIFE site. This led to the development of improved BL model parameterization for the NCEP model (Hong and Pan, 1996), which improved the precipitation forecasts.

Over India the Land Surface Processes Experiment (LASPEX) conducted during 1997 over the Sabarmati river basin in Gujarat gave an extensive series of surface and upper air data. In this study we compare the surface meteorological parameters and surface energy budget from the LASPEX data with large scale model short range forecast results at the nearest grid points. We explore how well the model forecasts reproduce the observed diurnal cycle for selected days during different Intensive data Observing Periods (IOP). Our objective is to see how far the model forecasts represent the data and whether this comparison can identify and suggest some way to improve the model parameterizations of the land surface and BL, which could lead to improved forecasts with these models.

MATERIALS AND METHODS

Description of the models used

Two versions of the NCEP medium range forecast model are used in this study. First is a version run operationally over Indian region at NCMRWF (documented in NMC, 1988) and the other is a 1995 operational version at NCEP (described in Hong and Pan, 1996). The model domain covers the entire globe with a spectral triangular truncation for the horizontal representation and with a finite difference approximation in the vertical using a sigma co-ordinate system. The NCMRWF version uses a T-80 spectral resolution with 18 unequally spaced sigma layers in the vertical (T80L18). The NCEP version has a T-126 spectral resolution with 28 sigma layers, but for the present study we scaled it down to T-80 due to computer limitations. The model physics has undergone significant changes from the T80L18 to the T80L28 versions (Betts *et. al.*, 1996, Hong and Pan, 1996). Since the surface, boundary layer, and precipitation physics are very important aspects to this study, we briefly describe the model parameterizations of these processes in both the model versions.

The T80L28 model utilizes a two-layer soil model, which includes soil thermodynamics and soil hydrology, both modeled as diffusion processes with diffusion coefficients strongly dependent on soil water content. Surface evaporation is modeled as three components: direct evaporation from the bare soil surface, transpiration through the leaf stomata, and re-evaporation of precipitation intercepted by the leaf canopy. Potential evapotranspiration formulation is based on a Penman type equation. Bulk aerodynamic formulas are used to obtain the surface momentum stress and sensible heat flux with the turbulent exchange coefficients computed based on Monin-Obukhov similarity theory. A modified Arakawa-Schubert parameterization for cumulus convection is used. These parameterization schemes are described in detail by Betts *et al.*(1996). The vertical diffusion in the BL is parameterized by a nonlocal scheme (Hong and Pan, 1996). The T80L18 model has a simple two layer soil thermodynamics modelled as diffusion process with constant diffusion coefficients. Soil hydrology is modeled with a simple water balance method. Potential evapotranspiration formulation is same as that for the T80L28 model, but surface evaporation is just taken to be a fraction of this potential value according to soil moisture availability. Also this model uses an Anthes-Kuo cumulus convective parameterization. The NCEP nonlocal BL vertical diffusion scheme (Hong and Pan, 1996) has been incorporated in the T80L18 model in place of a local stability dependent vertical diffusion scheme (Sanjay and Singh, 1998).

Data products used for comparison

From the several sets of LASPEX surface and upper air data available, we used selected near surface parameters from the Anand site ($22^0 35'$ N, $73^0 55'$ E) during the five-day IOP's from 13th to 17th of May, July and September 1997. This consisted of one minute averaged temperature at 2 m and relative humidity at 4 m from the 8 m instrumented tower, soil temperature measured at surface, 10 and 100 cm depth, soil heat flux using a flux plate installed at 5 cm depth, incoming and reflected short-wave and net radiation from well calibrated radiometers put on a 2 m stand and rainfall with a resolution of 0.2 mm using a tipping bucket. Also 10 minute averaged surface sensible heat flux data computed by the eddy correlation method using a sonic anemometer manufactured by M/S METEK, Germany exposed at 9 m on the tower is utilized. All the observed parameters are 15 minute time averaged to make a single LASPEX site time series.

Initial conditions to both models are

obtained by interpolating the NCEP/NCAR global re-analysis standard pressure level data at 2.5° equal lat./long. grids to the model horizontal and vertical resolutions. 24 hour integrations are carried out with both models starting at 0000 UTC on each day of IOP during the three months. Various model parameters at the nearest grid point (centered at 23.11°N, 73.11°E) to the LASPEX site are stored at each forecast time step (15 minutes).

The diurnal cycle on individual days can be influenced by advective processes. To give some indication of systematic differences in the diurnal cycle between the model forecasts and the data, we then averaged the individual 15 min. values over the five days of each IOP to represent a monthly mean diurnal cycle comparison.

RESULTS AND DISCUSSION

Surface energy budget

We first compare the different components of the surface energy budget given by

$$R_n + G + S_h + L_h = 0$$

where R_n is the net radiation, S_h and L_h are the surface sensible and latent heat fluxes and G is the ground heat flux. Our sign convention is that fluxes toward the surface are positive, so that on a typical sunny day, R_n is positive while S_h, L_h, and G are negative. Fig. 1 compares the monthly mean diurnal cycle for R_n, G, S_h and L_h from top to bottom panels respectively. The x-axis is 24 hours starting from 0000 UTC with the three panels from left to right showing May, July and September comparisons. During the first IOP in May there is very little clouding in both models and observation, but the models show higher R_n than the data. The models use fixed seasonal climatological surface albedo at this grid point of 0.19, while the data indicate (near solar noon) slightly higher values (0.21 to 0.22). The difference in mean daytime R_n between models and data could be partly attributed to these albedo differences. In July, the models have higher fixed albedo of 0.22 which is found to be comparable to that observed. Also models had more clouding and precipitation, hence the mean R_n bias is not as large in May. Still both models indicate higher R_n than data. But it should be noted that the fluctuations in R_n seen for observed data is reproduced better by the T80L28 model only as it had more frequent updates of radiative forcing. In September R_n in T80L28 model is found to be significantly lower than that of T80L18 and also than the observed data. This could be attributed to more clouding and precipitation in the T80L28.

The ground heat flux comparisons show that in May the T80L18 model has consistently larger downward values than data while for T80L28 model G is found to be lesser than the data. Both models show lesser downward G than data during July and September. This suggests that there is scope for improvement in ground heat flux parameterization scheme in these models. The S_h and L_h comparisons show that both model fluxes are biased. As there are no Ln observations available from LASPEX, it is estimated from the surface energy budget as a residual flux. During May the mean S_h is found to be too high and L_h too low. In fact the T80L18 model (which has a simple formulation for surface evaporation) shows nearly zero evaporation in this dry period, whereas the estimated L_h in the data show

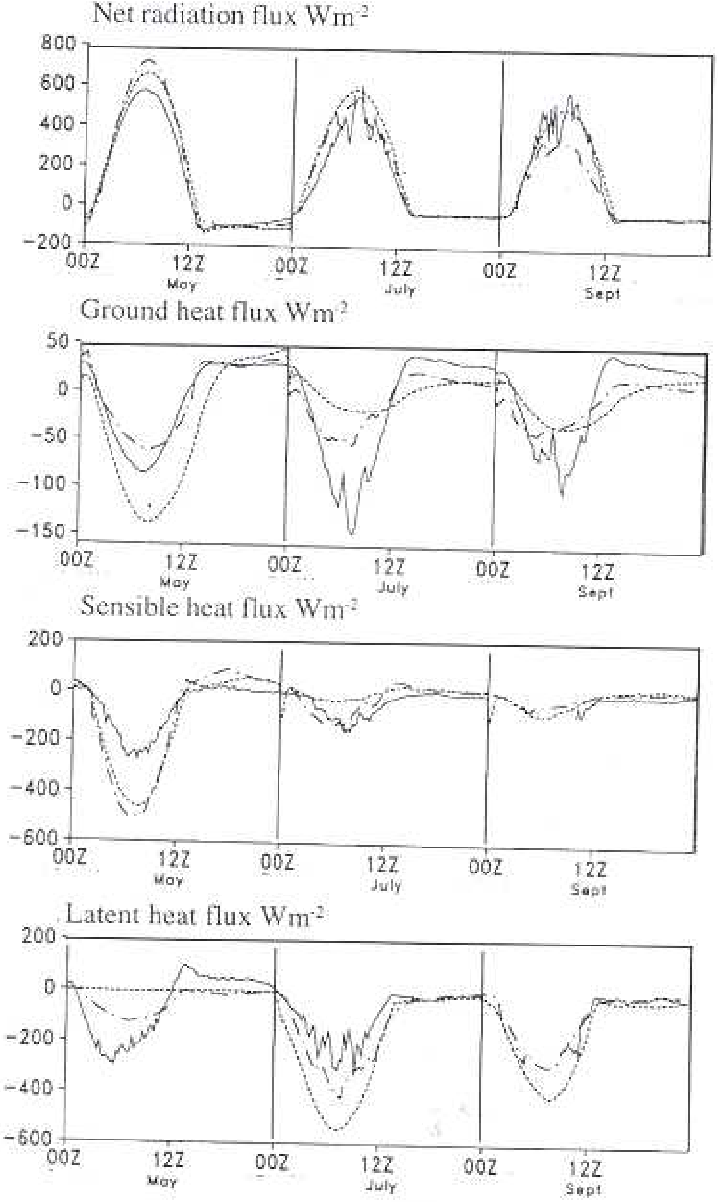

Fig.1 : Comparison of IOP mean monthly diurnal cycle during May, July and September 1997 of the different components of the surface energy budget. LASPEX data (solid curves) and model forecasts using T80L18 (dashed) and T80L28 (dash-dot). Fluxes toward ground are taken positive.

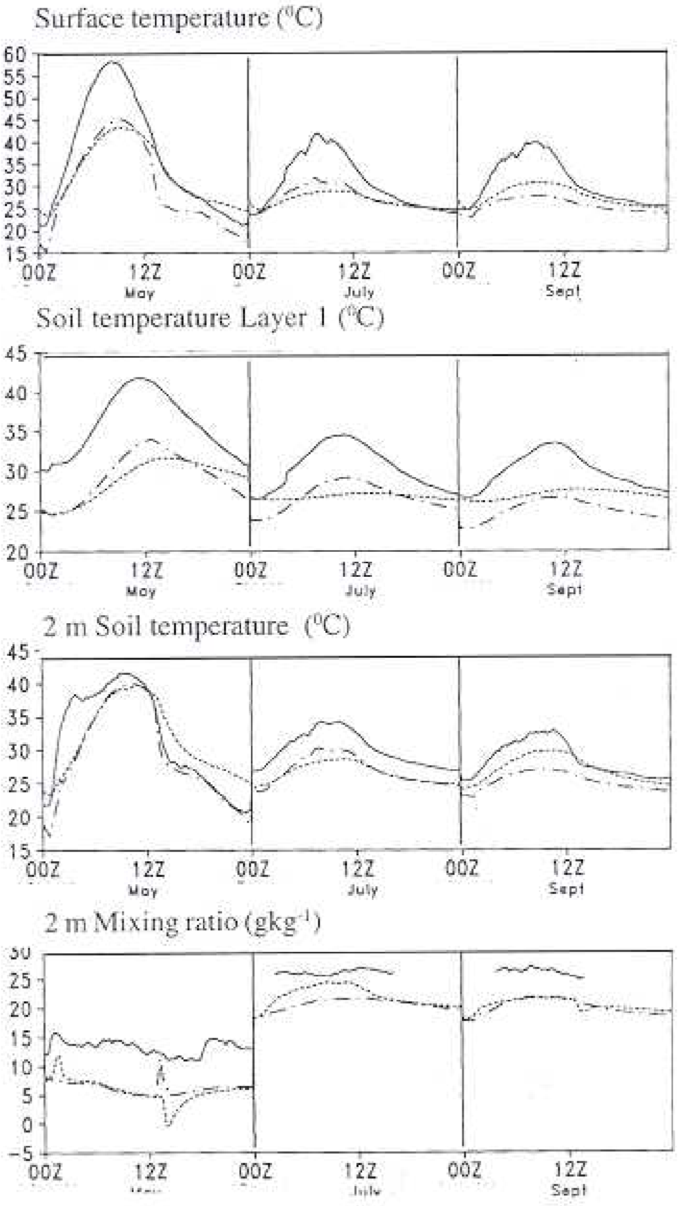

Fig.2 : Same as in Fig. 1, except for near surface thermodynamic parameters.

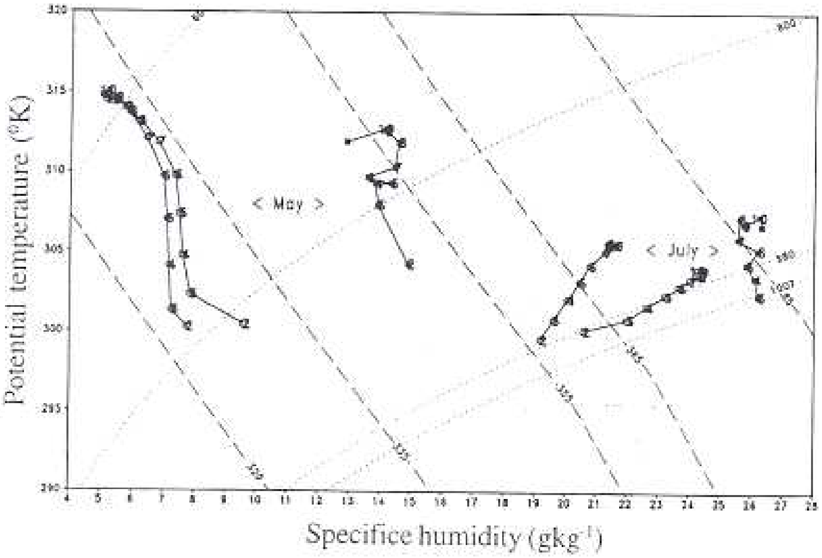

Fig.3 : Comparison of IOP mean monthly daytime diurnal cycle during May and July 1997 of near surface potential temperature and mixing ratio. LASPEX data (filled square), and model forecasts using T80L18 (open squares) and T80L28 (open circles). Values at each hour from 0200 to 1000 UTC are connected by lines (see text).

approximately -300 Wm^{-2} at local noon. The T80L28 model is able to show maximum L_h of about -150 Wm^{-2} even though the soil surface is very dry. An analysis of the three components of L_h (figure not presented) indicates that largest contributor is transpiration from the deep root zone, indicating that the inclusion of the two-soil layer model has improved the surface evaporation in this model. During the wet soil conditions in July both models show lower S_h and higher L_h than data. Again L_h in the T80L28 model is found closer to the data. In September the comparisons are incomplete as most of the daytime observed surface fluxes were not available.

Thermodynamic parameters

Fig. 2 compares the monthly mean diurnal response of the near surface thermodynamic parameters. The surface temperature in the data is the surface soil temperature while for the models it is the roughness height value. The 2 m air temperature and mixing ratios in the models are computed using a profile consistent with the parameterization of the surface layer. We see that both models are systematically cooler at the surface and have a smaller temperature range between sunrise and afternoon maximum. This difference is seen not only during the dry period in May but also in July and September under wet conditions although differing in magnitude. The comparisons of observed soil temperature at 10 cm within the ground with that of the first soil layer in both models (0-10 cm) also indicate a cool bias. The deep soil temperature in the data at 100 cm is around 33°C in May and 30°C in July and September, while the deep layer (500 cm) climatological fixed annual mean values for this grid point used in both models is much lower at 24.8°C. The 2 m air temperature comparisons are found to be better than that for the surface temperature even though both model values are consistently lower than the data in all three months. The data show unusually steep increase from morning to afternoon during May, which was identified to be due to the inadvertent exposure of the temperature sensor to direct sunlight.The temperature differences during the day time heating cycle between the surface and the 2 m becomes larger in the data than in both models (figure not shown). The small ground-air temperature difference could be related to the fact that the models have the same roughness lengths for heat and momentum (Betts *et al.* 1996). This could also be partly responsible for the large differences in the diurnal cycle of surface temperature. The trend in the near surface mixing ratio, for the data at 4 m, and both models at 2 m indicate that the data are always more moist than the models during all three months. Both models as well as data show weak drying from morning to evening during May. In July and September the nighttime observations are not available. But it is clear that during these wet periods also the data is more moist and shows very little trend in near surface mixing ratio. Whereas, both models are found to be drier and indicate a weak moistening from morning to evening but differing in magnitudes.

Fig. 3 summarizes the mean diurnal cycle during clear sky conditions in May 1997 and cloudy period in July 1997 of near surface potential temperature (θ) and mixing ratio (q) in the data (filled square) compared with the same average from the T80L18 (open square) and T80L28 (open circle) models. We show the hourly values starting from morning at 0200 UTC to afternoon at 1000 UTC joined by lines. The numerals denote time in UTC. The local solar noon is at about 0630 UTC. The agreement in May is fairly good. The data trace a path of almost constant q from the morning, θ minimum to the afternoon maxima near 0900 UTC, when the surface starts cooling. There is a large change in θ in the morning, when the BL is shallower followed by smaller changes in the afternoon when the BL reaches a much deeper quasi-equilibrium state. Both models, however, start from much lower θ minima in the morning and reach much higher θ maxima in the afternoon maintaining a drier q profile throughout the daytime as compared to the data. Lines corresponding to saturation at the surface pressure (980 hPa for the models and 1007 hPa for the data) and 800 hPa are shown dotted in Fig. 3 so that the daytime rise of saturation level or lifting condensation level (LCL) could be seen. During dry surface conditions in May the near surface air is found to be more than 150 to 200 hPa from saturation in morning time for data as well as for both models. By afternoon while the saturation pressure departures for the data rise to about 250 hPa, both models indicate still higher values of more than 400 hPa suggesting that model BL drift towards potentially warmer and drier state diurnally than the observed data. Also drawn in Fig. 3 are the isopleths of equivalent potential temperature (θ_e) as dashed lines. Betts and Ball (1995) demonstrated with the help of a simple mixed layer budget equation for θ_e (which determines the moist adiabat for convective precipitation) that the balance between the surface source of θ_e ($S_h + L_h$) and the downward entrainment of low θ_e air at BL top determines the diurnal rise of θ_e to its afternoon maximum over land. They showed that the reduced evaporation, and therefore increased heating at the surface, increases the entrainment at the top of BL. This leads to a lower afternoon θ_e in the BL, a more stable troposphere, and might therefore lead to less convective precipitation. This feature is found to be well reproduced by the data as well as both the models during the dry convective period in May 1997. But we find contrasting results for July because of significant differences in cloud and rainfall between the observation and both model forecasts. Two biases are found in model forecasts: more frequent rain and clouds. Similar to that for May the data traces a path of almost constant q (about 26 gkg^{-1}) with a lesser diurnal range in θ. In sharp contrast both models show near saturation at the surface throughout the daytime with the θ-q profile almost parallel to the surface pressure isopleth (980 hPa) indicating rapid moistening during the daytime. θ_e rises from about 355 °K in the morning to more than 375 °K in the afternoon even though there was significant rainfall in both the models. Whereas for the data although the morning θ_e values are higher (about 380 °K), the diurnal range is about 5 °K only with no significant rainfall on any day of the IOP during July 1997. Thus it is clear that the coupling between the surface fluxes, precipitation and the surface diurnal cycle is quite different in the model forecasts than is observed. One reason could be that the cumulus parameterization schemes used in both models are not able to adequately represent unsaturated convective downdrafts which sharply end the rise of θ_e once it rains as noted by Betts *et al.* (1996). However, the more important question is why it rains in the models when actually there was no rain over LASPEX site. In a related study (Sanjay *et al.*, 2001) we have compared the upper air sonde data from LASPEX with the model profiles and could identify that a bias in the model BL parameterization scheme in the presence of BL top clouds led to excessive precipitation.

In conclusion, this study shows that relatively simple comparison of the diurnal cycle over land with observed data sets can be very useful in identifying bias in the model parameterizations and for suggesting directions for possible improvements.

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