

Sensitivity of land surface parameterization on Regional Spectral Model forecasts

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Experiments were carried out to study the impact of different land surface schemes on a Regional Spectral Model (RSM) forecasts. RSM is based on the perturbation method of NCEP, where the dependent variables are the differences between the regional and global model fields called 'perturbations'. The perturbation method ensures the use of global model values as the base fields all over the domain and predicts the mesoscale features embedded in the base field forecasts. The first version of RSM has a land surface scheme with a single layer of soil moisture, which is the same as the operational global model with which it is nested. The second version of RSM has a land surface scheme with two layers of soil moisture and a more complex treatment of evaporation. The model was integrated for five days nested with the operational global spectral model during August 2001. The RSM with 2-layer soil moisture scheme was found to have slightly less easterly bias over north India. However, the two-layer scheme showed higher evaporation and precipitation over Andhra Pradesh region. Additionally, major differences were also observed in all the components of the surface energy balance over the same region.

PARAMETERIZATION of land surface processes (LSP) is one of the most important components of the atmospheric modelling. The surface properties and the mechanism of momentum, heat and moisture exchanges at the land surface decide the redistribution of the intercepting radiation and precipitation. Surface fluxes of sensible heat, moisture and momentum are the key sources of kinetic energy for the large-scale atmospheric motions and influence the stability of the overlying planetary boundary layer (PBL). The computed frictional drag, evaporation, transpiration and heat transfer directly influence the PBL. The turbulence in the PBL is controlled mostly by surface heating. The microscale processes in the form of heat and moisture fluxes over land and sea are the driving forces for the large-scale circulation systems of the earth.

The sensible and latent heat energy fluxes at the surface are the lower boundary conditions for the thermodynamic and moisture equations in atmospheric models. The correct partitioning between sensible and latent heat fluxes determines the soil wetness. The time series of soil moisture anomalies are

primarily controlled by the potential evaporation (PE) and the relation of PE over precipitation. The balance of energy fluxes at the surface is crucial for the understanding of the interaction between land surface and the atmosphere. It is now known that LSP schemes incorporated in atmospheric models are largely responsible for the quality of model-predicted near-surface weather parameters, such as screen level temperature, dew point temperature and low level cloudiness.

One of the key issues in LSP parameterization is the role of vegetation in controlling evapotranspiration and rainfall interception. During summer, a wet surface will tend to evaporate more than a dry surface and for that reason will be cooler, resulting in a cold and wet bias at the boundary layer. The interactions between LSP and other model physics, such as PBL and convection are very complicated. Hence, the LSP scheme should be able to provide adequate feedback mechanism for PBL and other physical processes.

The performance of mesoscale models in simulating the mesoscale weather phenomena depends significantly on the surface boundary fields and the LSP schemes in it. The LSP schemes used in GCMs range from simple bucket models¹ to complex models with more realistic and detailed description of vegetation and soil processes^{2,3}. In the current study an attempt has been made to compare two different LSP schemes of intermediate complexity, which mainly differ in the treatment of evaporation, with respect to its impact on a regional model forecast. In this study, a Regional Spectral Model (RSM) nested with the operational T80 global model was employed with the two different LSP schemes.

Experimental procedure

The model

The RSM used in the study is the 1994 version of a limited area spectral model system adopted originally from NCEP and run experimentally at NCMRWF, New Delhi^{4,5}. It works on the philosophy of 'perturbation method'⁶. The model is one-way nested with the operational NCMRWF global spectral model with a horizontal resolution of T80 and a vertical resolution of 18 sigma levels. As the NCMRWF global model has been providing fairly accurate medium range forecasts over Indian region at a coarse resolution^{7,8}, the purpose of nesting RSM in it is to obtain higher resolution forecasts over the region. The RSM has a horizontal resolution of

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50 km with the same 18-sigma levels in vertical as the global model with which it is nested.

The nesting strategy used by RSM is domain and spectral nesting, which is characteristically different from the lateral boundary nesting strategy of conventional regional models. RSM allows global model forecast fields to be used over the entire domain and not just in the lateral boundary zone. The difference of the regional model fields from the base fields are called 'perturbations' which are converted to wave space for the purpose of using semi-implicit time integration. The base fields are the time-dependent global model forecasts. The nesting is done in such a way that the perturbation may be non-zero inside the regional domain but zero outside of it. Perturbation signifies all other features that could not be predicted by the global model but can be resolved over the regional domain by the regional model forecasts. The physics and the non-linear dynamics are computed in grid space only with full regional model fields. The basis functions for spectral conversion are double sine cosine series with 54 waves along zonal and 48 waves along the meridional direction. The domain is approximately 56°E–103°E and 3°N–39°N and covers the whole of India and nearby oceanic regions. The time step for RSM is 5 min and the nesting period is 6 h. The model incorporates all the physical parameterization schemes used in the global model.

RSM predicts the relatively smaller perturbations superimposed over the previously predicted large-scale components by the global model, which was run prior to it. Hence the errors introduced in the perturbation due to the lateral boundary will remain small which enables a longer period time integration compared to the conventional grid point regional models. The initial and boundary conditions are provided by the NCMRWF T80 global model analysis and forecasts. The lateral boundary is relaxed towards the global model values using Tatsumi's boundary relaxation scheme⁹. Also it is more logical for the perturbation values to approach zero along the boundary. The orography is derived from 10 min US Navy data. The model was integrated for five days daily nested with T80 global model for the month of August 2001 with the two LSP schemes described in the following subsections.

LSP schemes used in the study

The two LSP schemes used for the current study use one level and two levels of soil moisture and hereafter termed as LSP1 and LSP2 respectively with the associated digits representing the number of soil moisture levels. LSP1 is the scheme used in the operational NCMRWF global spectral model^{10,11}. The main features of LSP1 are the use of Monin–Obukhov similarity theory for the computation of the exchange coefficients of momentum, heat and moisture, the evaporation over land based on potential evapotranspiration (PE)¹² and the interactive bucket hydrology method¹ for updating the soil moisture. The predicted snow depth interacts with radiation through surface albedo. The soil model has three levels of

temperature, specified at depths of 10, 50 and 500 cm. The model soil has a field capacity of 15cm and assumes a uniform root zone of 1 m. The effect of vegetation is taken into account through stomatal resistance. The soil moisture M is updated using

$$\partial M / \partial t = R - E + S_n, \quad (1)$$

where R is the precipitation rate, E the surface evaporation rate and S_n the rate of snow melt.

The balance of all the fluxes at the surface determines the skin temperature T_s as given by the following equation.

$$C_s \partial T_s / \partial t = R_s + R_l + L + H + G, \quad (2)$$

where C_s is the heat capacity per unit area of the surface layer, R_s the net short wave flux, R_l the net long wave flux, L the latent heat flux, H the sensible heat flux and G the ground heat flux.

A major difference of the two-layer soil moisture scheme (LSP2) from the one-layer scheme (LSP1) is in the formulation of evaporation over land. The evaporation in LSP2 (ref. 13) has three components namely (i) evapotranspiration, (ii) evaporation from the bare soil and (iii) canopy re-evaporation. The thin upper layer, 10 cm thick responds mainly to diurnal variations and a thicker lower layer, 90 cm thick participates more in the seasonal changes of soil water storage. Here the direct soil evaporation is most appropriately related to the soil moisture of an upper thin layer while water for transpiration originates more from the deeper root zone. Each of these three components is proportional to the PE. Vegetation reduces the direct evaporation from the soil by shading the ground and reducing the wind speed near the ground. Transpiration is related to the density of vegetation and the soil moisture content. Canopy water content and canopy water capacity (assumed as 2 mm) are included to represent reduction of transpiration from surfaces covered by a water film.

The radiative fluxes, wind speed, moisture deficit, and atmospheric stability determine the potential evaporation, which in turn forces actual soil evaporation. When the soil is relatively wet, evaporation will be at its potential rate. When the soil is dry the rate of evaporation is controlled by the soil moisture gradient in the upper part of the soil. The interaction between PE and soil moisture under various atmospheric influences is very complex and nonlinear.

The experiments

August 2001 was selected for the experiments. RSM was run with the two LSP schemes for five days. The initial conditions were interpolated from the sigma level analyses and surface analysis of the operational Global Data Assimilation System (GDAS) at NCMRWF. The input surface fields were made the same for both the runs for making identical experimental

conditions and the 6-hourly global model forecasts were used as boundary conditions. The initial soil moisture is taken from the global model analysis in both the experiments. The single layer soil moisture from the global analysis is fed to both the layers of the two-level scheme and the canopy water content is initialized to zero. The forecast evolution of soil moisture and snow depth, etc. solely depends on respective LSP schemes and the complex feedback between the various physical processes. Both the experimental runs were carried out on CRAY SV1 computer. The detailed results and the subsequent discussion are presented in the next section.

Results and discussion

Gross forecast errors

In general the monthly averaged features of RSM forecasts reflected the systematic errors similar to the nesting operational global model like cooling of troposphere, cyclonic bias over Bay of Bengal and adjoining southern peninsula, easterly wind bias over north Indian plains and an anomalous increase in latent heat flux over the Bay of Bengal. Figure 1 shows the systematic error of wind for day-3 RSM forecast which

clearly depicts the cyclonic bias over Bay of Bengal, easterly wind bias over north India, weakening of Somalia current and strengthening of the Bay of Bengal branch of monsoon current by both the schemes (a) LSP1 and (b) LSP2. The contours are isotachs drawn at an interval of 2 ms^{-1} and the error of 4 ms^{-1} or more is shaded. The difference between the two is very small as the effective difference in the formulation of LSP schemes is also quite small. Nevertheless for this particular case study, it can be concluded that the easterly bias over north Indian plains is less for LSP2 compared to LSP1 as shown by the lesser area covered by the shaded region in Figure 1b, especially near the coastal Andhra Pradesh and adjoining region. The anomalous increase in latent heat flux over Bay of Bengal (not shown here) is slightly less for LSP2 compared to LSP1.

The monthly total precipitation for August 2001 as predicted by RSM for day-3 is shown in Figure 2 for (b) LSP1 and (c) LSP2 along with (a) the NCMRWF 1.5×1.5 degrees precipitation analysis¹⁴. The shaded region corresponds to the area more than 50 cm. Both the experiments produced reasonably good rainfall distribution including the north-south patch along the west coast of the peninsula and the scanty rainfall region over Tamil Nadu. Only along the north Indian plains and northwest India the area covered by the

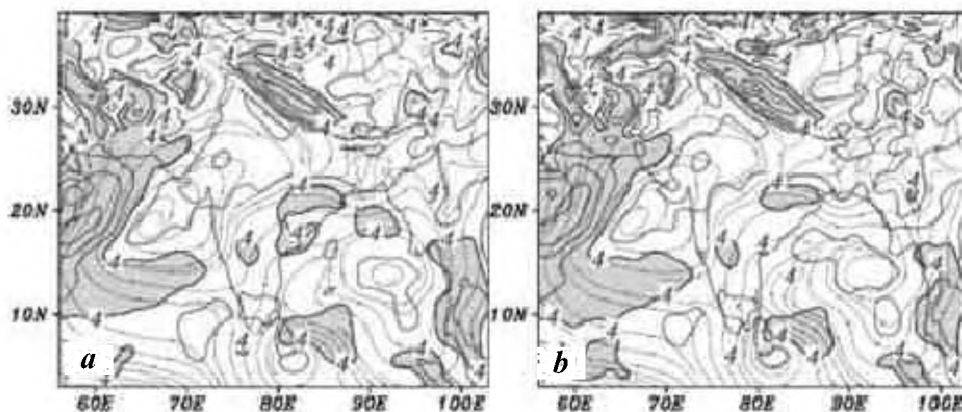


Figure 1. Systematic errors of wind (ms^{-1}) at 850 hPa for day-3 forecasts of August 2001 for RSM experiments (a) LSP1 and (b) LSP2. The isotach interval is 2 and 4 ms^{-1} or more are shaded.

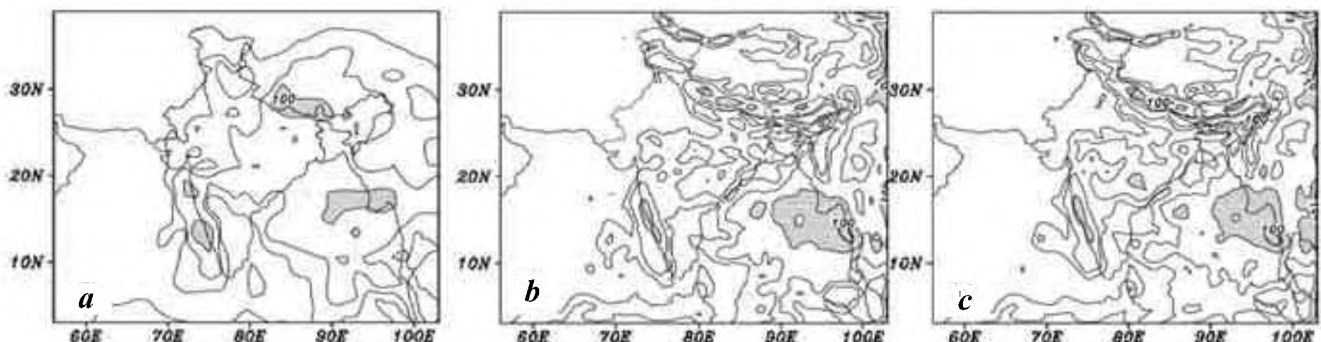


Figure 2. Monthly total precipitation (cm) (a) NCMRWF 1.5×1.5 analysis and day-3 forecasts for August 2001 for RSM experiments (b) LSP1 and (c) LSP2. The contours are 10, 20, 50, 100, 200 cm. Rainfall above 50 cm is shaded.

analysis by 10 and 20 cm contours is more than predicted distribution in both the forecasts. Here it needs to be noted that the analysis is done in a coarser grid ($1.5^\circ \times 1.5^\circ$) and the model resolution is approximately 0.5 degrees, and for that reason the comparison may not be very fair. Still one can see from the figures that there are quite substantial differences between the model-predicted rainfalls and the analysed one. In the analysed rainfall there seems to be no region over the plains of north India exceeding 50 cm which is matching with the LSP1 whereas LSP2 shows a shaded region around 81°E , 19°N . Though in general the forecast rainfall patterns show higher amount of rainfall to the south of the seasonal monsoon trough position, LSP2 shows more rainfall especially over AP and adjoining regions. LSP2 shows more area coverage for 20 cm contour over the east part of the sub-Himalayan Gangetic belts, but shows more patchy distribution compared to LSP1.

Figures 3 and 4 show the rmse's and anomaly correlations of (a) geopotential, (b) temperature and (c) wind, respectively at 850 hPa level for LSP1 and LSP2. rmse's of geopotential and wind are more or less comparable for LSP1 and LSP2 where LSP2 produced slightly higher error up to day-4. The

rmse's of LSP2 is higher by 1 K on all days for temperature at 850 hPa level. LSP1 shows higher anomaly correlation for wind and temperature whereas geopotential showed higher correlation for LSP2. In general LSP2 errors are found to be higher than LSP1 at lower levels whereas at higher levels the scores are found to show lesser sensitivity to the LSP schemes.

Impact on the generated surface fields

Figure 5 shows the mean daily distributions, for LSP1 and LSP2 respectively, of soil moisture (percentage volumetric content) (panels (a) and (b)) and skin temperature (Kelvin) (panels (c) and (d)) for day-3 forecasts averaged for the month of August 2001. The soil moisture values are plotted in the interval of 5 and the shaded part indicates values less than 40%. Though in general the distribution pattern appears to be identical in both cases, there can be observed quantitative differences. LSP2 shows a depletion of soil moisture especially to the south of the monsoon trough positions and over the coastal Andhra Pradesh and surrounding land areas as shown by the region surrounded on both sides by 45%

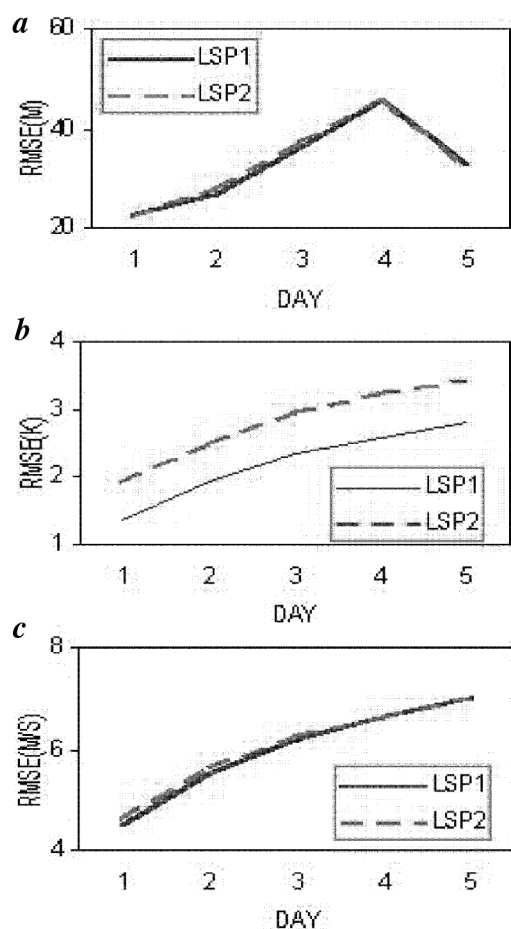


Figure 3. Root mean square errors (850 hPa, August 2001) of (a) geopotential (m), (b) temperature (K) and (c) wind (ms^{-1}) for RSM experiments LSP1 and LSP2.

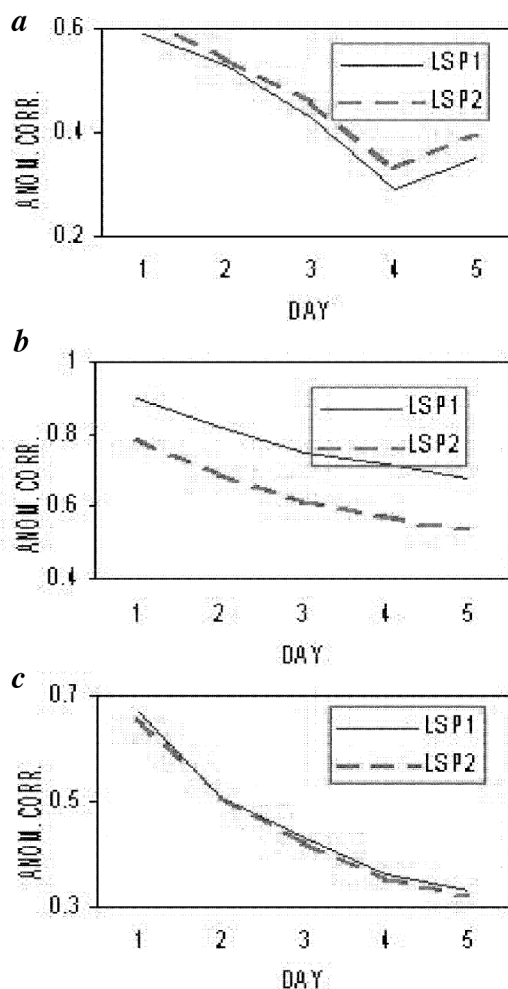


Figure 4. Similar to Figure 3 but for anomaly correlations.

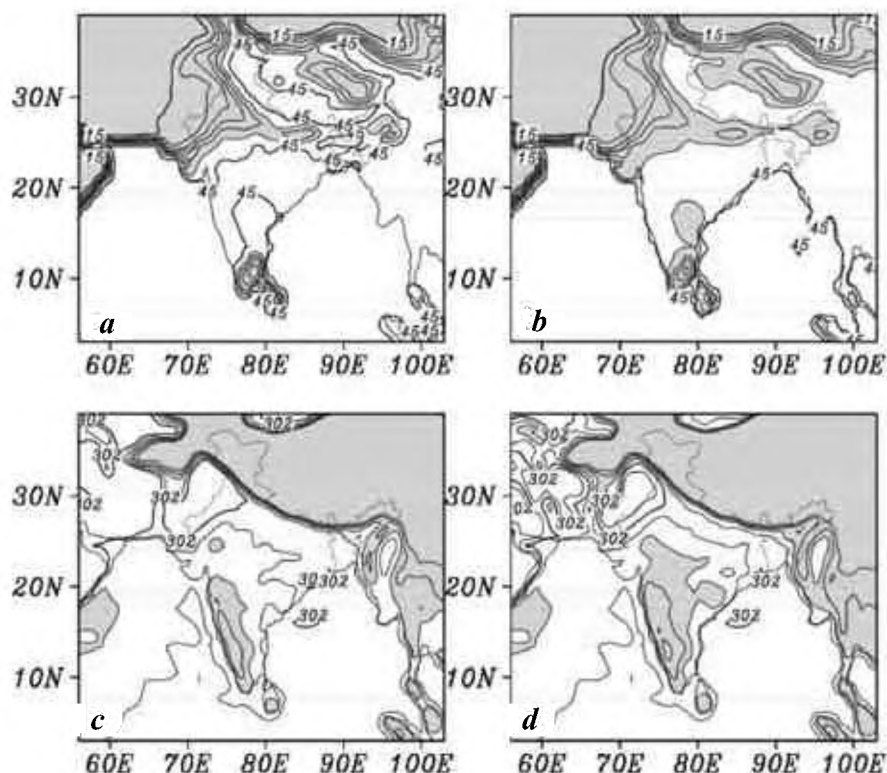


Figure 5. RSM mean daily day-3 forecasts for August 2001 for LSP1 and LSP2 experiments of soil moisture as percentage volumetric content (*a* and *b*; int = 5%) and skin temperature in Kelvin (*c* and *d*; int = 10 K). Soil moisture < 40% and skin temperature < 298 K are shaded.

contours in LSP1. The fast depletion of soil moisture in LSP2 scheme may be the result of the increase in evaporation contributed by the bare soil evaporation and the canopy re-evaporation. This may be contributing to the increase in precipitation forecasted in LSP2 over this region during the active monsoon conditions of August. Figure 5 *c* and *d* show the impact on the computed skin temperature over this particular area. LSP2 shows comparatively lower surface temperature as shown by the shaded region of surface temperature (less than or equal to 298 K) covering more over Andhra region in LSP2. Thus it can be seen that this particular region is most sensitive to the difference in the LSP schemes and hence the region 75°E–83°E, 15°N–23°N will be closely examined to further study the relative contributions of each of the components in the surface energy balance.

The daily mean net short wave and long wave fluxes at the surface (downward–upward) predicted on day-3 and averaged for August 2001 for LSP1 are plotted in Figure 6 *a* and *c* respectively. Figure 6 *b* and *d* display the difference (LSP2–LSP1) for the respective fields plotted on the left panels. The shading implies negative areas. The minimum contours around 81°E and 19°N are 110 Wm⁻² for LSP1 which is further reduced by –10 to –15 Wm⁻² for LSP2 implying a slightly lower rate of increase of radiational energy for LSP2 compared to LSP1 as far as the land surface is concerned. This is contributing to a lower build up of surface energy in the

overall surface energy balance and can be treated as sink (loss) for LSP2 in comparison with LSP1. In the case of net long wave radiation (panels (*c*) and (*d*)), the values around 81°E, 19°N are –28 Wm⁻² for LSP1 and LSP2 shows an increase in the radiational energy for the surface by 4–6 Wm⁻². Thus net long wave flux acts as source (gain) of the surface energy for LSP2 which, in turn indicate more cloudiness.

Figure 7 shows the monthly averaged values of daily mean (*a*) sensible heat flux, (*c*) latent heat flux and (*e*) ground heat flux respectively for LSP1 and the right side panels (*b*), (*d*) and (*f*), the respective differences (LSP2–LSP1). (Shaded regions indicate negative values). Since these are all sinks of energy as far as the land surface is concerned these have to be inversely related in the surface energy balance. From panels (*a*) and (*b*), around 81°E, 19°N, LSP1 has values ranging 30–50 Wm⁻² approximately and LSP2 shows comparatively lesser values of sensible heat flux (by about –40 Wm⁻²) compared to LSP1. This implies a relative gain of surface energy for LSP2 as the loss of energy (sink) is less for LSP2 compared to LSP1. Similarly, the latent heat values (Figure 7 *c* and *d*) range between 60 and 80 Wm⁻² for LSP1 and increased by 40–60 Wm⁻² for LSP2 over the same area, which means relatively a very significant loss in surface energy for LSP2 which is obviously due to the increase in evaporation. Also in the case for ground heat flux (Figure 7 *e* and *f*) where the values of 6–10 Wm⁻² for LSP1 are increased

by $6\text{--}10\text{ Wm}^{-2}$ for LSP2, a loss of surface energy is the result. The ground heat flux shows a large gradient over land areas in the region north-east of the mean monsoon trough for LSP2 which may be due to the two-level soil hydrology and its differential drying/moistening rate.

From the above analysis, the net effect of all the components in the surface energy balance resulted in to a loss or reduction in the skin temperature over the particular region under scrutiny. The biggest contribution is from latent heat flux term, which is due to the increased evaporation in LSP2. Thus the new scheme contributed to increased cloudiness, rainfall and diffuse long wave radiation. Even if diffuse radiation reduces the cooling, its effect is offset by reduction in incoming solar radiation due to the increased cloudiness. Over other regions there a lesser impact is found on the surface energy balance in the monthly scale.

From the analysis it is evident that LSP2 scheme with its modified and more detailed formulation of evaporation is contributing to the depletion of soil moisture and increase in precipitation under the particular monsoon conditions. The after-effects may vary for different seasons and different regions. But the verification of the surface changes may be very difficult due to the lack of observations and the only verification at the moment will be possible based on the precipitation output where LSP1 resembles the analysis pattern.

Concluding remarks

Role of interactive soil moisture in modifying the surface-atmosphere exchanges of momentum, energy and water

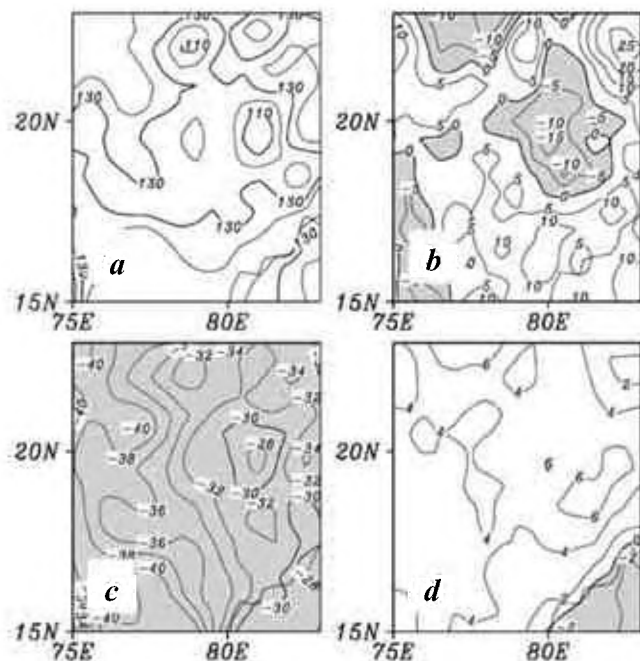


Figure 6. RSM mean daily day-3 forecasts for August 2001 in Wm^{-2} for LSP1 (a) net short wave flux (int = 10) and (c) net long wave flux (int = 5). Corresponding (LSP2-LSP1) is in (b) and (d). Negative is shaded.

vapour was studied in the current work using a RSM. It has been found that the 50 km RSM is able to produce reasonably good monsoon simulations up to day-3. Also the errors are supposed to be minimum up to day-3 for the current study which is more concentrated over the central part of the domain, namely coastal Andhra Pradesh region.

Two different LSP schemes were used for RSM forecasts with one-layer and two-layers of soil moisture and with different formulations of surface evaporation using August 2001 data. In contrast to the one-layer scheme LSP1, where the surface evaporation is based on Penman-Monteith theory, the two-layer scheme LSP2 accounts for the bare soil evaporation related to an upper thin layer soil moisture, transpiration originating from the deeper root zone and canopy re-evaporation. The influence of the two schemes on the systematic errors in wind field is not much different in the medium range forecasts with LSP2 showing slightly less easterly wind bias over A.P. and adjoining east coast of peninsula. The precipitation pattern shows an increase in

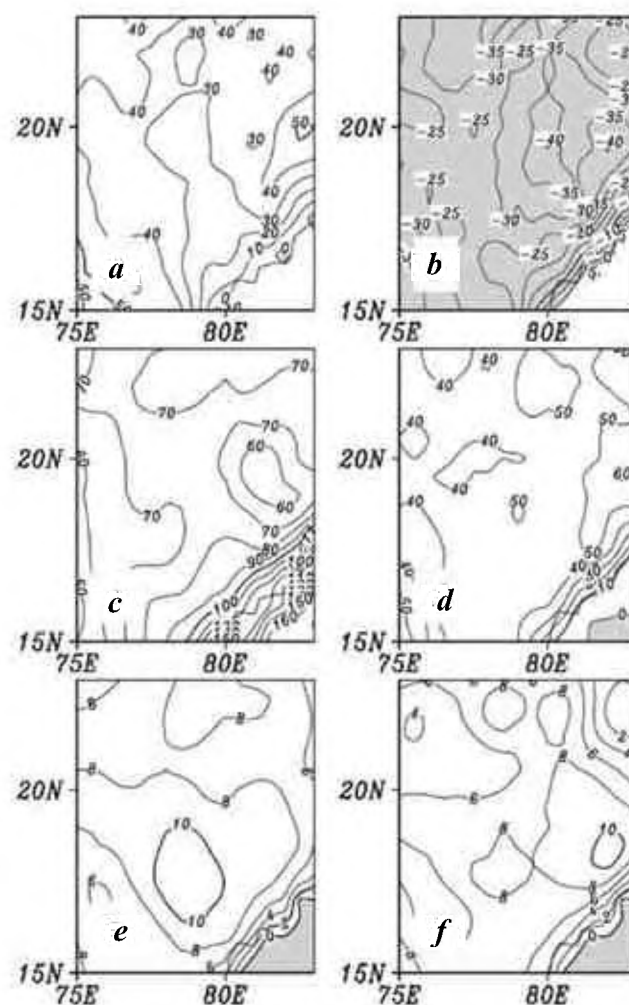


Figure 7. Similar to Figure 6 but for sensible heat flux (a and b) latent heat flux and (c and d) and ground heat flux (e and f). Unit is Wm^{-2} and negative is shaded.

LSP2 over the same region to the south of the eastern seasonal monsoon trough where again the difference is mostly felt in most of the surface fields.

The increase in surface evaporation over the A.P. region is found to be significantly depleting the soil moisture in the monthly average picture and a cooling of the ground. An analysis of the components of the surface energy balance revealed that contribution of the increased latent heat flux due to the increased evaporation in LSP2 plays a most significant role in reducing the surface energy. The increased latent heat release caused an increase in cloudiness and rainfall, but a decrease in the soil moisture in the monthly scale in the active monsoon phase.

The interaction among surface evaporation, soil moisture and the overlying boundary-layer development is quite complex and perhaps may vary according to the phase and strength of monsoon and the number of advective weather systems during the period of study. The differences in systematic errors are so minute in the short and medium range that the model biases and the boundary errors may be very important factors in drawing final conclusions. Hence in future, more extensive investigations and case studies may be needed by avoiding possible errors due to the orography near the boundaries of the domain of integration.

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