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Impact of the parameterization schemes in simulation of boundary layer structure at Anand using GCM and validation with LASPEX data

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ABSTRACT

A global spectral model (T80L18) that is operational at NCMRWF is utilized to study the structure of the boundary layer over the semi arid region of Anand. Various aspects of the boundary layer parameters are studied that include the evolution of vertical profiles of various meteorological parameters, diurnal variation of boundary layer height, fluxes etc. The impact of using a different boundary layer scheme (non-local closure) is examined for the evolution of the boundary layer processes for representative periods of pre-monsoon, monsoon, post-monsoon and winter seasons. It is seen that the non-local closure scheme for the boundary layer parameterization has a marginal impact at Anand compared to the simple first order closure scheme used in the global operational model at NCMRWF.

Key words : PBL parameterization, Boundary layer, Non-local closure, Global model

Analysis of the boundary layer structure is crucial and is very important in studying the various aspects of transport mechanisms of different meteorological parameters through the exchange processes occurring within the Planetary Boundary Layer (PBL). It is important that the boundary layer structure simulated by numerical models be reproduced in the most realistic manner. In global models, the large-scale atmospheric flow determines to a significant extent the properties of the PBL, and the PBL in turn reacts to these external forcings and modifies the large-scale flow.

In India, the National Center for Medium Range Weather Forecasting (NCMRWF) was established, to develop an appropriate medium range analysis forecast system (MAFS) for the monsoon region and provide agrometeorological advisory services for the farming community on an operational basis. The global model at NCMRWF is adopted from the National Centers for Environmental Prediction, previously known as the National Meteorological Center, USA. The global data assimilation scheme involves spectral statistical interpolation and six-hour forecasts of the global model that provide the first guess for the subsequent analysis. Five- day forecasts are obtained in real time based on the analysis at 0000GMT. Details of the global spectral model and analysis can be found in Kanamitsu (1989) and Parrish and Derber (1992) respectively. The

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parameterization of the PBL in MAFS of the NCMRWF uses a simple first-order closure approximation. In addition, a non-local closure approximation for the PBL was implemented as a second boundary-layer parameterization in the MAFS. Both model versions having different schemes for the PBL (the rest of the physics and dynamics remaining the same) were run and the results were compared. Previous studies comprising of conducting experiments by making ensemble of 5-days forecasts for August, 1999 (Basu, 2001) showed that inclusion of non-local closure scheme improved the systematic errors of wind, reduced the cold bias of the model and resulted in a more realistic precipitation distribution over the Indian subcontinent as compared to the first order local closure scheme. It was interesting to carry out experiments with both the boundary layer schemes for a few cases at Anand, i.e. at a specific location over semi-arid region of the country to see if there were any specific impact by using different schemes for the boundary layer parameterization.

DESCRIPTION OF THE SCHEMES

PBL parameterisation scheme of NCMRWF model

A short description of the model, which is run on an operational basis at NCMRWF, is given in Basu *et al.* (1998,1999). The PBL parameterization uses a first- order closure approximation whereby the turbulent fluxes are correlated to the mean vertical gradients through the eddy diffusivities. These eddy diffusivities are stability dependent (depending upon the bulk Richardson number) and are determined through mixing length considerations (Blackadar, 1962). It is assumed that the mixing length l varies as kz (k being the von Karman constant and z the height above the ground) close to the ground, but approaches constant value λ (= 250m) at greater heights. Thus, the eddy diffusivities are determined through

$$K = l^2 S \mid \delta v/\delta z \mid$$

where l is the mixing length given by

$$l = kz/(1+ kz/\lambda).$$

Here, S is a set of semi-empirical stability functions dependent upon the bulk Richardson number R and λ is the limiting mixing length.

Parameterisation using the non- local closure scheme

There are certain limitations of the mixing length theory (Stull, 1988), the most important being its inability to realistically represent mixing in the convective boundary layer involving the counter gradient fluxes (Deardorff, 1972; Troen and Mahrt, 1976; Hong and Pan, 1996). One alternative is to go for higher order closure approaches that are capable of representing a well mixed boundary layer structure. However, they are computationally more expensive. In addition, these schemes are in the strictest sense, local diffusion schemes and have a strong tendency to under entrain in the presence of a strong capping inversion. Recently an alternative approach has been suggested called the non-local K closure (NLC), which is computationally considered efficient and has the capability to represent large eddy turbulence within a well mixed boundary layer. This scheme (Troen and Mahrt, 1986, Hong and Pan, 1996) has been widely tested for general circulation models as well as numerical prediction models with further generalization and reformulation.

MATERIALS AND METHODS

In the present study, the scheme that is used is after Hong and Pan, 1996, where the turbulence diffusion equations for prognostic variables (C, u, v, θ, q) are expressed by

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial z}[K_c(\frac{\partial C}{\partial z}-\gamma_c)]$$

here, γ_c is a correction to the local gradient that incorporates the contribution of the large scale eddies to the total flux. The diffusivity coefficient in the mixed layer is given by

$$K_{zm}=kw_s z\,(1-\frac{z}{h})^p$$

where w_s is the mixed layer velocity scale, h is the PBL height and k is the von Karman constant. The PBL height is given by

$$h=Rib_{cr}\,\frac{\theta_{va}\,|U(h)^2|}{g\,(\theta_v(h)-\theta_s)}$$

where Rib_{cr} is the critical bulk Richardson number, U(h) is the horizontal wind speed at h, θ_{va} is the virtual potential temperature at the lowest model level and $\theta_v(h)$ is the virtual potential temperature at h and θ_s is the surface temperature. For the free atmosphere, however, the local K approach is utilized.

Numerical experiments

A few case studies have been run with both PBL schemes during 1997-99 along with one month continuous run representative of monsoon (August 1997) and winter (February 1997) seasons. For validation of LASPEX data sets, five day forecasts have been obtained for four initial conditions pertaining to the summer, monsoon, post-monsoon and winter seasons. Care was taken so that these five day forecasts coincide with the IOP (Intensive Observation Period) at Anand for the different months. Thus, both the models (operational model hereafter referred as FOC and the model having non-local closure hereafter referred as NLC) were run for five days with initial conditions of 0000GMT of 13 May, 13 July, 14 September and 14 December. The predicted profiles of different meteorological parameters nearest to the grid of Anand (located at 72°E 22°N) were extracted from the global prediction with FOC and NLC and compared with observations. In addition, the diurnal variation of surface fluxes was also compared with observations.

RESULTS AND DISCUSSION

During all the initial conditions, for which both FOC and NLC were run, it was observed that there was no major synoptic disturbance that could have influenced the weather over Anand. The flow pattern pertaining to all the days as obtained from NCMRWF analyses are discussed by Rajagopal (2001). Fig. 1(a)-(d) show the profiles of wind speed for various time periods for different months. It is seen that in general, the profiles compare reasonably well with observations, except for the month of May. By and large, the profiles by FOC and NLC evolve in a similar manner. Fig. 2(a)-(d) show the profiles of temperature for all the four months. It is seen that the temperatures are under predicted for July and September and over predicted for December by about 3-5 degrees. For the month of May, the temperatures are under predicted at the lower levels by about 2 degrees and over predicted by couple of degrees above 800 m. By and large, it is seen that the variation of the temperature in the vertical by both NLC and FOC are

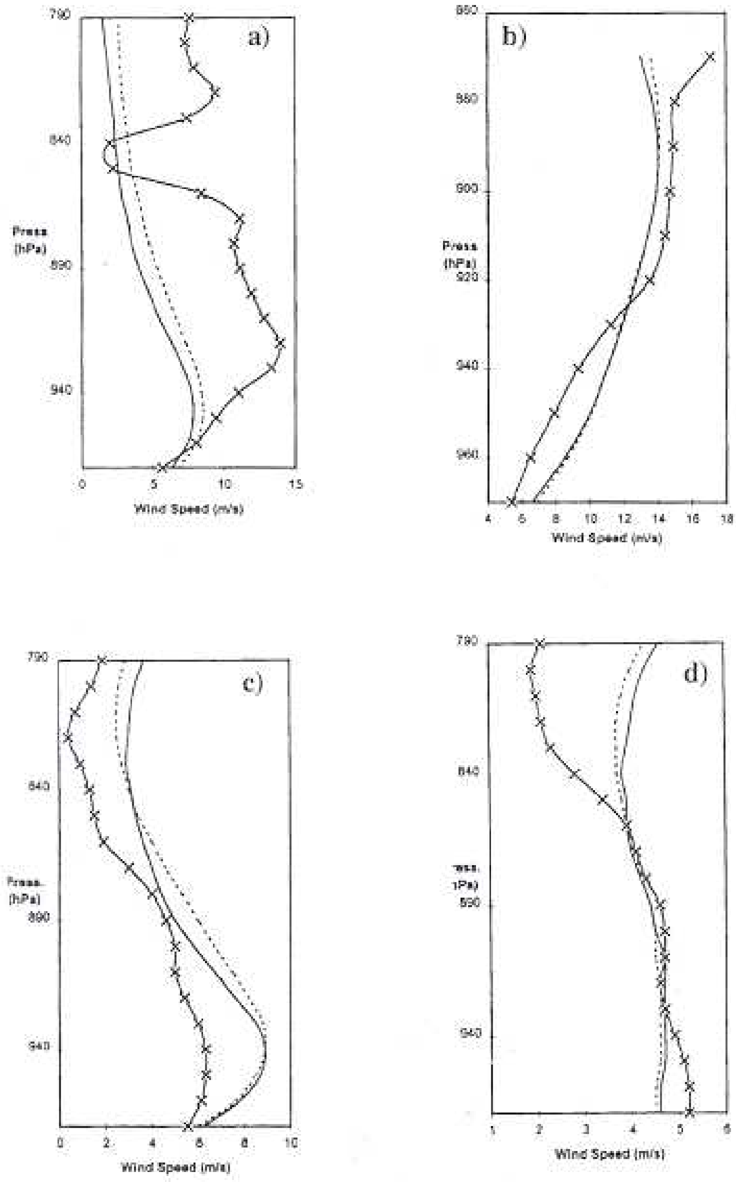

Fig.1 Vertical profiles of wind speed at a) 0530 hrs IST of 16th May'97 b) 0530 hrs IST of 16th July '97 c) 0530 hrs IST of 17th Sept.'97 d)1430 hrs IST of 14th Dec.'97

________ FOC --------NLC x____ __x Observations

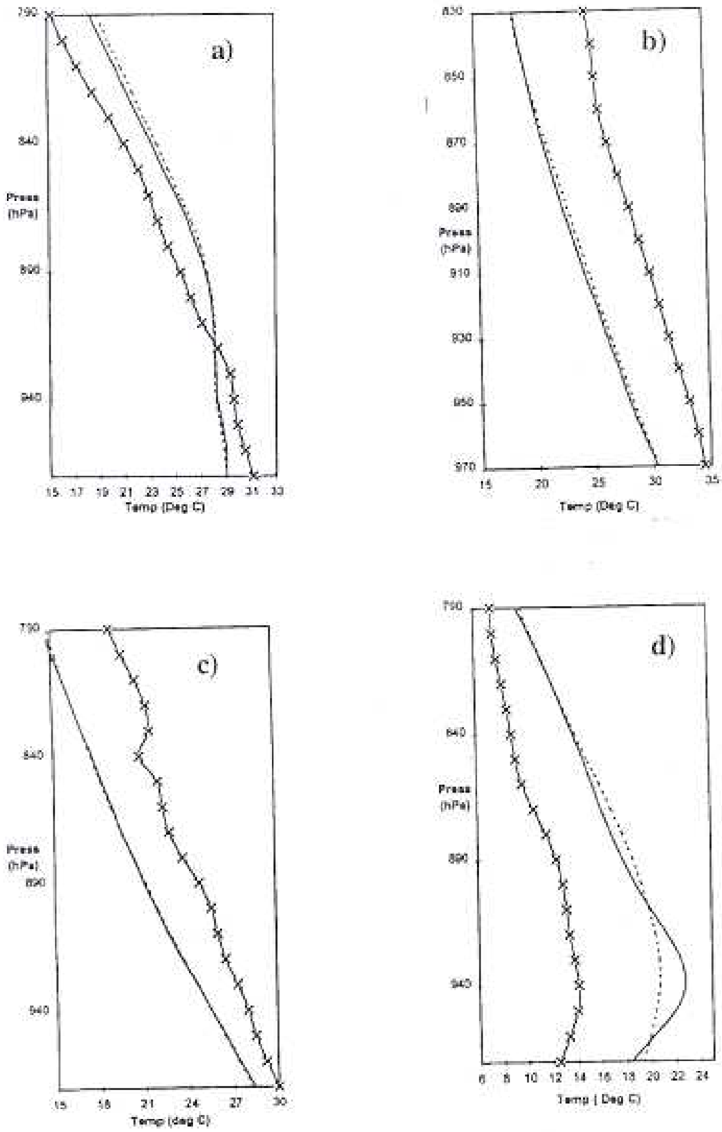

Fig.2 : Vertical profiles of temperature at a) 0530 hrs IST of 16th May'97, b) 1430 hrs IST of 13th July '97, c) 1430 hrs IST of 14th Sept.'97, d) 0530 hrs IST of 17th Dec.'97
________ FOC --------NLC x____ _x Observations

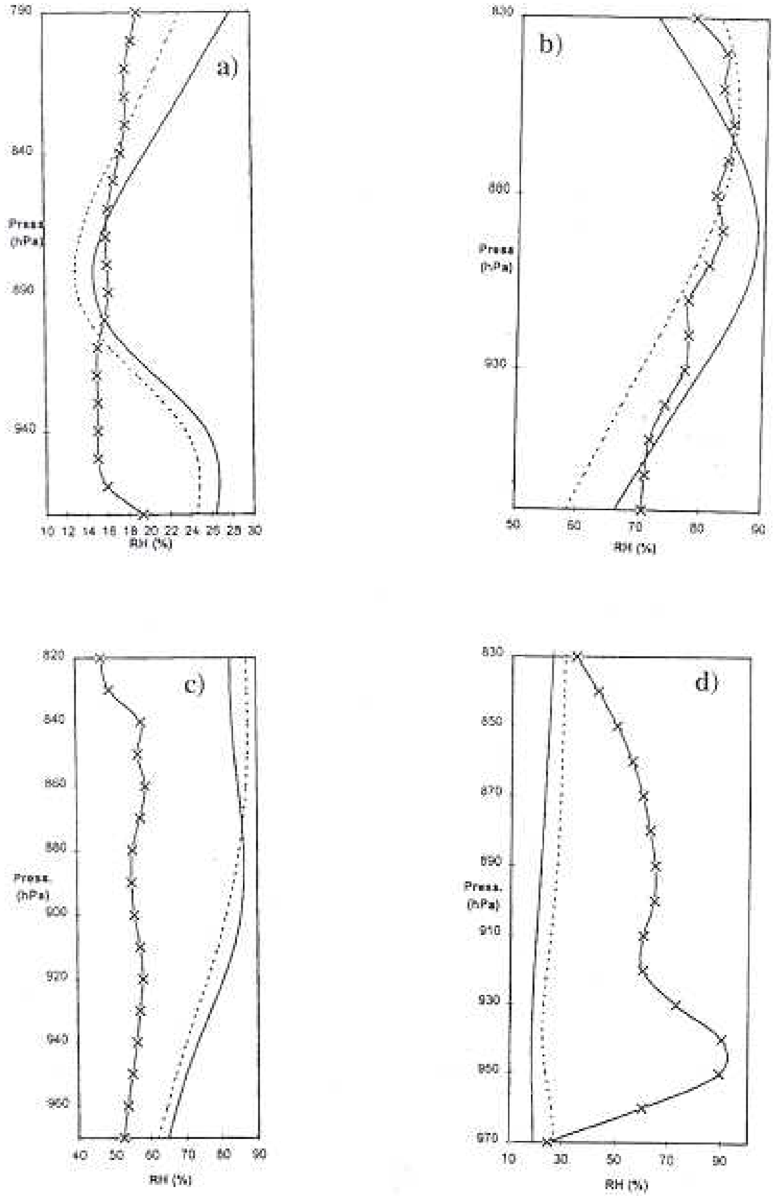

Fig.3 : Vertical profiles of relative humidity at a) 0530 hrs IST of 16th May'97, b) 1430 hrs IST of 13th July '97, c) 1430 hrs IST of 14th Sept.'97, d) 0530 hrs IST of 17th Dec.'97

________ FOC --------NLC x____ __x Observations

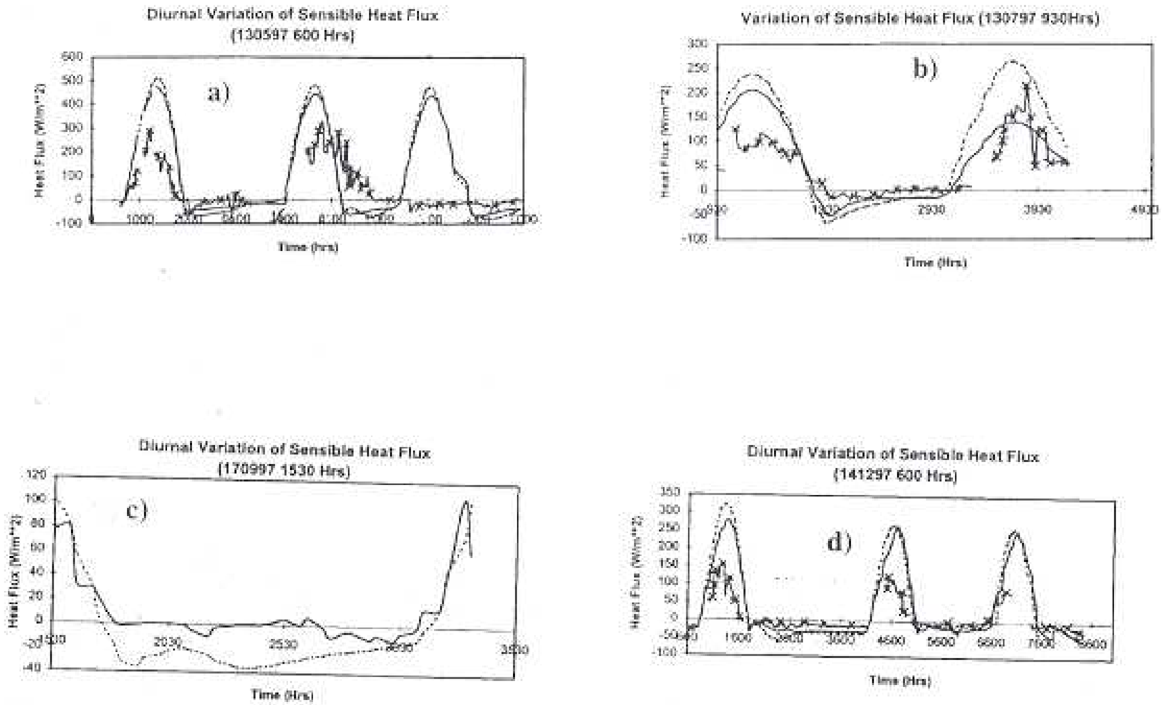

Fig.4 : Diurnal variation of sensible heat flux with initial conditions of a) 0600 hrs IST of 13th May'97, b) 0930 hrs IST of 13th July '97, c) 1530 hrs IST of 17th Sept'97, d) 0600 hrs IST of 14th Dec.'97

_____ FOC --------NLC x_____x Observations

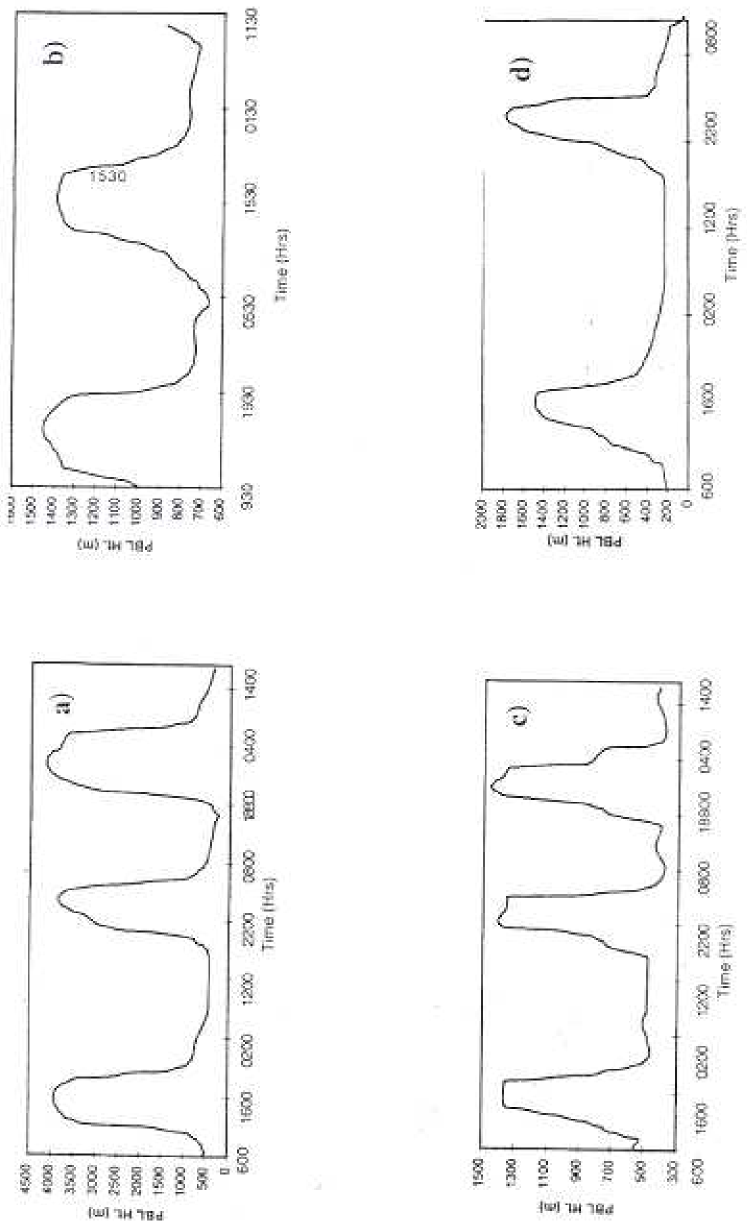

Fig.5 : Diurnal variation of boundary layer height using NLC with Initial conditions of a) 0600 hrs IST of 13th May'97, b) 0930 hrs IST of 13th July '97, c) 0600 hrs IST of 14th Sept'97, d) 0600 hrs IST of 14th Dec.'97

____FOC ---------NLC x____x Observations

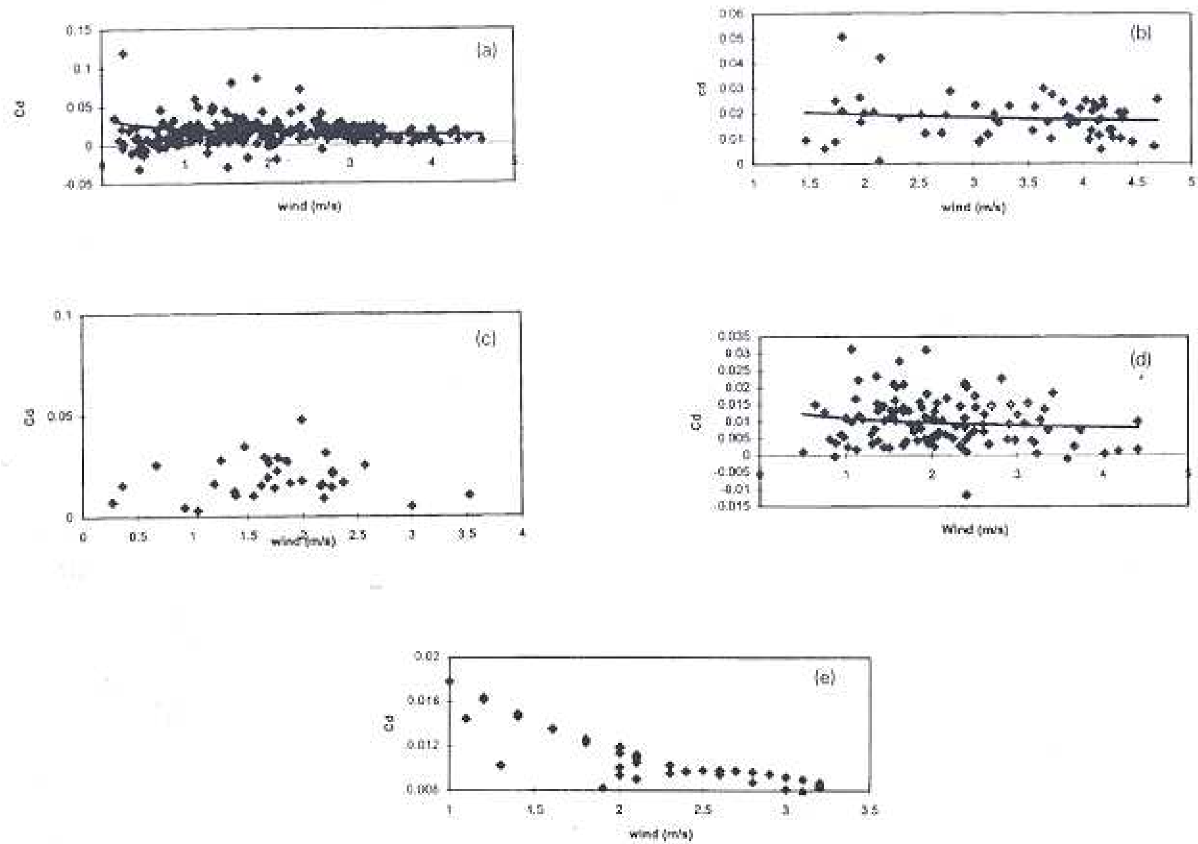

Fig.6 : Variation of drag coefficient with 10m wind a) 13th May'97 (Obs), b) 13th July 97 (Obs), c) 14th Sept'97 (Obs), d) 14th Dec.'97 (Obs) , e) NLC with initial condition 14th Dec, 1997

_______ FOC --------NLC x____ _x Observations similar to the observations although the magnitudes given by both the schemes differ from the observations by a fixed amount, which is more or less maintained throughout. This shows that there is a systematic bias in the simulation of the temperature profiles by the model at Anand. Figs. 3(a)-(d) show similar profiles for relative humidity, which shows under prediction during December and for other months, an over prediction. Although the profiles simulated by FOC and NLC are similar for May, September and December cases, there is a difference in the July case, which shows good comparison by NLC with observations above 910 hPa. In general, for other cases the humidity profiles from NLC are seen to be marginally closer to the observations compared to FOC especially at the lower levels. As seen, NLC shows 3% drier profile for September case and about 5% wetter profile for December case both of which are closer to the observations. Figs. 4(a)-(d) show the diurnal variation of the boundary layer heights for all the four months. As expected, the peaks of the boundary layer heights coincide with the afternoon hours and the values compare well with those obtained by Seetaramayya *et al.* (2001). The range of maximum value is about 3.5 km, which is very realistic. Since FOC does not explicitly resolve the boundary layer height, the results are presented only for NLC. Figs. 5(a)-(d) show diurnal variation of sensible heat fluxes for all the four months with FOC and NLC along with the observations. The peaks of the fluxes were brought out well by both the models although the magnitudes are higher by 1.5-2 times except for the July case. For September, the observations for the period for which the models were run, were not available. For sensible fluxes, NLC showed marginally higher values compared to FOC for the cases of May and December. On the contrary, there is a substantial difference in the magnitudes of sensible heat fluxes as simulated by FOC and NLC for the months of July and September. As seen, the maximum values of fluxes by NLC are relatively closer to observations for the July case. The variation of drag coefficients with 10m winds are presented in Figs. 6(a)-(d), these are estimated from observations for all the four months. These plots for December are shown with NLC. Similar plots for other months as well as from FOC are not shown for brevity. No specific relationships between the drag coefficient and 10 m winds could be obtained from these plots.

CONCLUSIONS

From the present study, it is seen that the boundary layer structure is simulated reasonably well by the global spectral model of NCMRWF using both FOC and NLC. However, NLC is able to predict the sensible heat fluxes marginally better compared to FOC. Keeping in mind the coarser resolution of the global spectral model both in the vertical as well as in the horizontal, the profiles of various meteorological parameters compare reasonably well with observations with NLC having a marginal edge over FOC especially for humidity. Although, over Anand, the performance of FOC and NLC are comparable, previous studies (Basu, 2001) have indicated that NLC in general produces better results compared to FOC in terms of precipitation distribution, flow pattern and systematic errors.

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REFERENCES

Basu, Swati. 2001. Impact of non-local closure scheme for PBL in a global spectral model of monsoon over India. Proceedings of TROPMET 2000, National Symposium on Tropical Meteorology. Published by IMS (Cochin Chapter), pp. 462-466.

Basu, Swati, Begum Z. N. and Rajagopal. E. N.1998. Impact of boundary layer parameterisation schemes on the prediction of the Asian summer monsoon. *Bound. Layer Meteorol.*, 86 : 469-485.

Basu, Swati, Sethu Raman, Mohanty U. C. and Rajagopal. E. N. 1999. Influence of the planetary boundary layer physics on medium-range prediction of Monsoon over India. *PAGEOPH*, 155 : 33-55.

Blackadar, A. K. 1962. The vertical distribution of wind and turbulent exchange in neutral atmosphere. *J. Geophys. Res.* 67 : 3095-3103.

Deardorff, J. W. 1972. Parameterization of the planetary boundary layer for use in general circulation models. *Mon. Wea. Rev.*, 100 : 93-106.

Hong, S. Y. and Pan. H. L. 1996. Nonlocal boundary layer vertical diffusion in a Medium Range Forecast Model. *Mon. Wea. Rev.*, 124 : 2322-2339.

Kanamitsu, M. 1989. Description of the NMC global data assimilation and forecast system. *Wea. Forecasting*, 4 : 335-342.

Mitra, A. K., Bohra A. K. and Rajan.D. 1997. Daily rainfall analysis for Indian summer monsoon region. *Int. J. Climatol.*, 17 : 1083-1092.

Parrish, D. F. and Derber. J. C. 1992. The NMC's spectral statistical interpolation analysis system, *Mon. Wea. Rev.*, 120 : 1747-1763.

Rajagopal, E. N. 2001. Validation of land surface parameters in NCMRWF model with LASPEX dataset. *J. Agrometeorol.*, 3: 217-226.

Stull, R. B. 1988. An Introduction to Boundary Layer Meteorology, Kluwer Academic Publishers, p. 666.

Seetaramayya, Tyagi, P. A. Nagar S. G. and Murty. B. S. 2001. Comparison of PBL heights between pre-monsoon and monsoon at Anand during 1997. *J. Agrometeorol.*, 3: 267-274.

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