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IMPLEMENTATION AND VERIFICATION OF THE UNIFIED NOAH LAND SURFACE MODEL IN THE WRF MODEL

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1. INTRODUCTION

In recent years, modeling of land surface processes in numerical weather prediction models has received considerable attention. One of the reason is that the land surface interacts strongly with the atmosphere at all scales which affects short and long term numerical weather prediction. As a result proper parameterization of land surface processes in the land surface models (LSMs) and its coupling with the atmospheric model has become increasingly important. The unified Noah LSM is the result of a major collaborative effort among NCEP, NCAR, AFWA and OSU. In the present work we would present some verification results of the coupled Noah LSM and Weather Research and Forecast (WRF) modeling system for some selected summer cases. Surface observations from the International H2O Project 2002 (IHOP) field experiment were used for these verifications. A few clear sky days from this period were identified as good candidates for verifying the coupled WRF/Noah LSM system. The purpose of the present work is to 1) evaluate the general performance of the WRF/Noah LSM coupled model, and 2) study the impact of land surface heterogeneity (by using different land data sources as model initial conditions) on coupled WRF model simulations.

2. NUMERICAL EXPERIMENTS

Various numerical experiments were conducted to test the performance of the coupled WRF/Noah system using IHOP 2002 surface data. Nine NCAR surface flux stations plus one additional flux station, operated by the University of Colorado group, were set up to support the IHOP 2002 atmospheric boundary layer mission in the Southern Great Plains for the period of May 13- June 26 2002.

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Among the few selected clear sky days during this period, we are presenting some of the results for 31 May 2002 for brevity.

The location and description of ten flux-tower stations are shown in table 1. These locations vary in landuse type, soil texture etc.

Table 1: Summary of IHOP surface, soil, and vegetation network

IHOP No	Land Cover	Lat.	Long.	Z (m)	Soil type
1	Winter wheat	36°28	100°37	871	Sandy clay loam
2	CRP grass	36°37	100°38	859	Sandy clay loam
3	Sagebrush, mesquite, cactus	36°52	100°36	780	Sandy loam
4	Grass	37°22	98°15	**509**	Loam
5	Winter wheat	37°23	98°10	**506**	Loam
6	Winter wheat	37°21	97°39	417	Clay loam
7	Grass, grazed	37°19	96°56	382	Clay loam
8	Grass, May be burned	37°24	96°46	430	Silty clay loam
9	Grass, grazed	37°25	96°34	447	Silty clay loam

For our purpose, we have initialized the model with different land data sources namely, the AFWA AGRMET (Agricultural Meteorology modeling system), NCEP North-America land data assimilation systems (NLDAS), and NCEP operational EDAS (Eta model Data Assimilation system). AGRMET is available globally at a resolution of 47 km, whereas NLDAS (1/8 degree resolution) and EDAS (40-km resolution) are available for CONUS and part of Canada and Mexico.

Some of the improvements in the unified Noah LSM include: frozen-ground physics, patchy snow cover, time-varying snow density and snow roughness length, modified soil thermal conductivity and some additional background fields like max snow albedo etc. A 10-km grid spacing was used for the WRF numerical experiments. Using initial data from different land-data assimilation systems, the model was integrated for 24 hours in each of these selected cases starting at 31 May 2002, 12Z. For the simulations described in this paper, the following sets of experiments were performed:

(i) Initializing with AGRMET data
(ii) Initializing with EDAS data
(iii) Same as (i) but for IHOP soil moisture and soil temperature for the sites
(iv) Same as (ii) but for IHOP soil moisture and soil temperature for the sites.

In the following section, we would show some of the results of the above experiments.

3. RESULTS AND CONCLUSIONS

Fig 1 shows the initial soil moisture fields (for soil layer 1, soil layer 2 and the average of three soil layers) from AGRMET and EDAS on WRF simulation domain. We noticed difference in soil moisture fields as seen by these two sources and it is expected that this variability would be reflected in the model simulations. Fig 2 shows the downward solar radiation simulated by the model for the case (i) at IHOP eastern and western sites. These results show that model could simulate the diurnal cycle well and compares very well with observations. Similar results were found for case (ii) also. Fig 3 shows the comparison of latent heat flux at sites 1, 2 and 3 for case (i) and case (ii). One major feature in this simulation is that the model is able to capture the observed variability among the IHOP sites even though they are located fairly close to each other and with 10-km grid spacing in WRF. Results from both cases show that for case (i), LH flux at site 1 compares well with observations whereas for EDAS, LH flux at site 2 are better compared with observations. On comparing the sensible heat flux (fig 4), we find that for AGRMET case, site 1 and site 2 are better compared with observations whereas for EDAS only site 2 has a better comparison with observation. Further comparison of latent and sensible heat fluxes for the case (iii) where WRF was initialized with IHOP data show some improvements for the sites 2 and 3 (fig 5). But the WRF performance heavily depends on the variation of the soil moisture during the entire period of integration for the particular sites. We find improvements only for those cases where on initializing with IHOP soil moisture and temperature, the simulated soil moisture stays close to observation during the period of integration (e.g. fig 6, which shows the soil moisture for the sites 1, 2, 3 for case (iii). Each figures in fig. 6 show soil moisture fields for the 3 soil layers).

Table 2: RMSE and BIAS of WRF forecasted surface variables using AGRMET and EDAS as initial soil conditions for the May 31 2002 case

MAY 31 2002 : AGRMET : RMSE							
Site	H	LE	LW	SW	MR	TSK	T2M
1	29.73	16.31	6.48	11.16	1.46	3.16	2.02
2	10.96	26.11	5.53	12.16	1.49	5.20	2.01
3	48.12	47.49	10.28	11.49	1.77	8.98	3.31
4	22.09	38.01	10.52	10.63	1.26	7.04	1.70
6	62.35	42.39	11.48	10.62	1.05	5.95	2.67
7	No data	No data	7.69	16.98	1.08	4.53	1.48
8	29.47	163.72	11.39	16.07	0.78	1.09	1.11
9	13.99	161.31	10.42	21.53	2.03	6.91	1.44
AVG	30.95	70.76	9.22	13.83	1.36	5.35	1.97

MAY 31 2002 : AGRMET : BIAS							
Site	H (W/m^2)	LE (W/m^2)	LW (W/m^2)	SW (W/m^2)	MR (g/Kg^{-1})	TSK (K)	T2M (K)
1	6.15	-3.17	6.08	2.48	0.99	-0.08	-1.41
2	2.32	-21.27	4.62	-2.14	1.19	-4.20	-1.41
3	-30.05	26.00	-5.63	-4.15	1.47	-6.88	-2.78
4	-2.40	14.85	9.08	4.97	0.83	-5.63	-0.66
6	-37.21	17.56	1.92	-1.32	0.83	-4.46	-0.62
7	No data	No data	-0.93	1.82	0.87	-4.14	-1.02
8	20.97	98.51	10.23	3.43	0.41	-0.85	-0.48
9	1.20	91.60	10.05	-3.85	1.50	-5.98	-0.88
AVG	-5.56	32.01	4.42	0.15	1.01	-4.02	-1.16

MAY 31 2002 : EDAS : RMSE							
Site	H	LE	LW	SW	MR	TSK	T2M
1	26.98	44.06	7.96	7.96	2.22	4.27	2.56
2	10.55	16.94	6.96	6.69	2.22	5.57	2.33
3	44.90	53.41	10.16	10.16	2.50	8.96	3.40
4	31.33	78.76	11.35	11.35	1.42	8.20	1.97
6	59.62	42.29	11.39	11.39	1.54	5.88	2.75
7	No data	No data	7.57	7.57	1.29	4.15	1.32
8	25.92	169.59	12.08	12.08	0.88	1.08	1.11
9	15.32	164.38	10.65	10.65	1.48	6.74	1.26
AVG	30.66	81.34	9.73	13.44	1.69	5.61	2.09

MAY 31 2002 : EDAS : BIAS							
Site	H (W/m^2)	LE (W/m^2)	LW (W/m^2)	SW (W/m^2)	MR (g/Kg)	TSK (K)	T2M (K)
1	-7.52	24.59	7.54	2.19	1.67	-0.73	-1.67
2	2.46	-10.79	5.90	-2.27	1.83	-4.25	-1.50
3	-25.98	30.97	-4.22	-4.32	2.19	-6.68	-2.77
4	-21.81	43.47	8.42	5.11	0.73	-6.36	-0.71
6	-33.85	16.81	3.38	-1.64	1.28	-4.30	-0.59
7	No data	No data	3.02	0.98	1.00	-3.83	-0.90
8	18.70	102.75	10.91	3.98	0.57	-0.85	-0.43
9	0.32	94.32	10.20	-2.24	1.20	-5.77	-0.64
AVG	-9.66	43.16	5.27	0.22	1.31	-4.09	-1.15

Tables 2 shows the root mean square error and the bias for some of the surface parameters for case (i) and case (ii). The average of the RMSE for sensible heat flux (SHF) and latent heat flux (LHF) is around 30 (30) and 70 (80) W/m^2 for case (i) (case (ii)) respectively which is quite reasonable. On comparing these values, it is noticed that AGRMET (case(i)) seems to have better results than EDAS (case (ii)). It shows lower RMSE and bias (for AGRMET as compared to EDAS) for almost all the surface parameters. The model, however, show cold bias for all the sites for both the cases.

In general, the model performs reasonable well in capturing the heterogeneity in surface heat fluxes among different IHOP stations. These results show the importance of soil moisture and its proper initialization and evolution in the model. Further experiments with refinements in the model are underway to further investigate the land atmosphere interactions as represented in WRF.

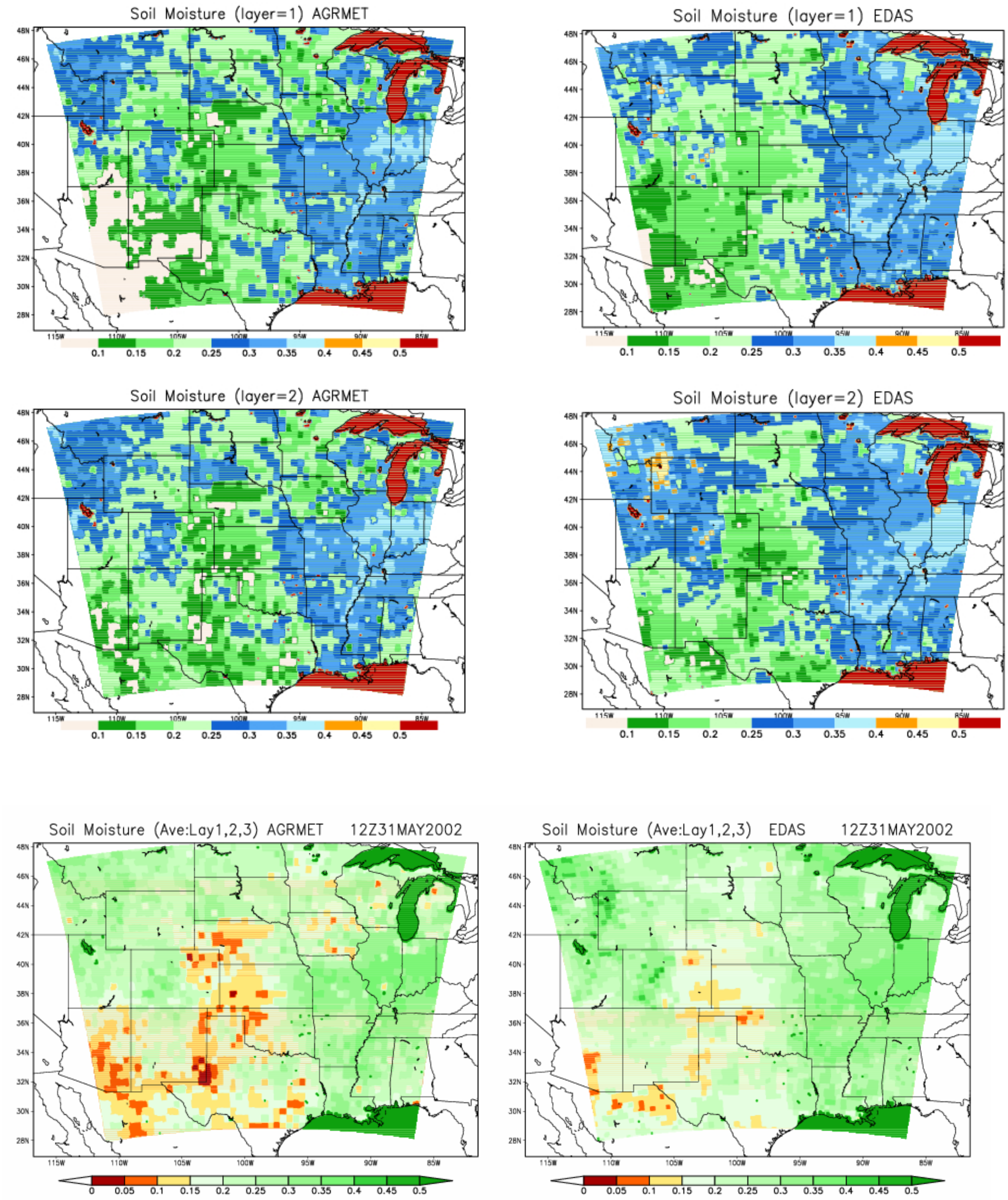

Fig 1: Soil moisture for layer 1, layer 2 and the average of layers 1, 2 and 3 from AGRMET and EDAS

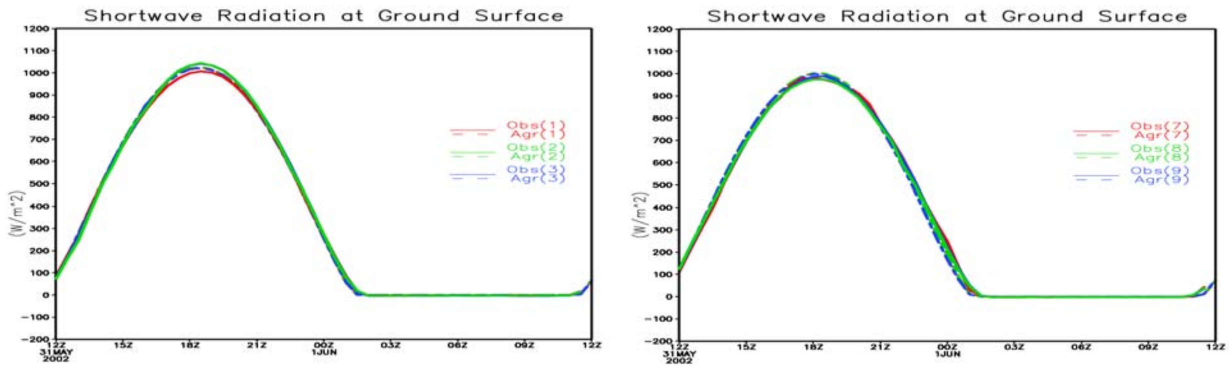

Fig 2: Short-wave downward radiation at western(1,2,3) and eastern (7,8,9) sites simulated by WRF initialized by AGRMET, as compared to IHOP data.

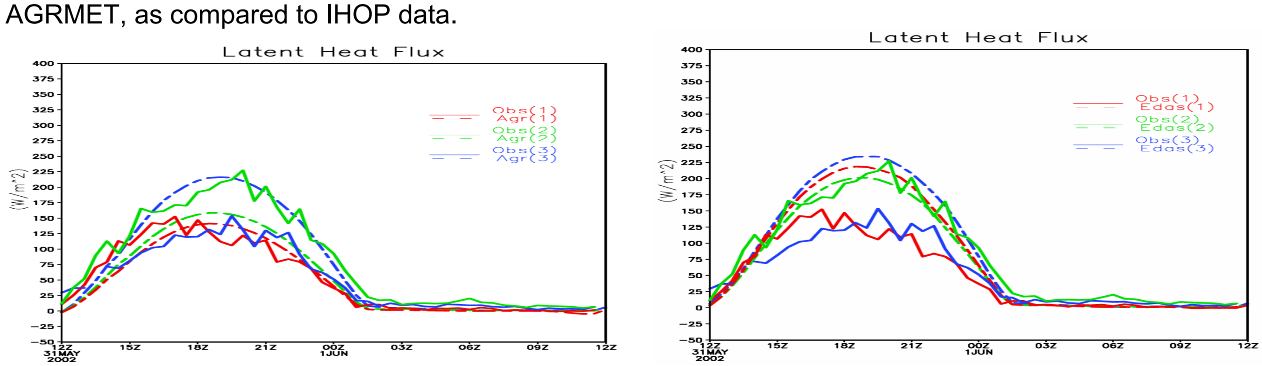

Fig 3: LHF at sites 1,2,3 for AGRMET and EDAS

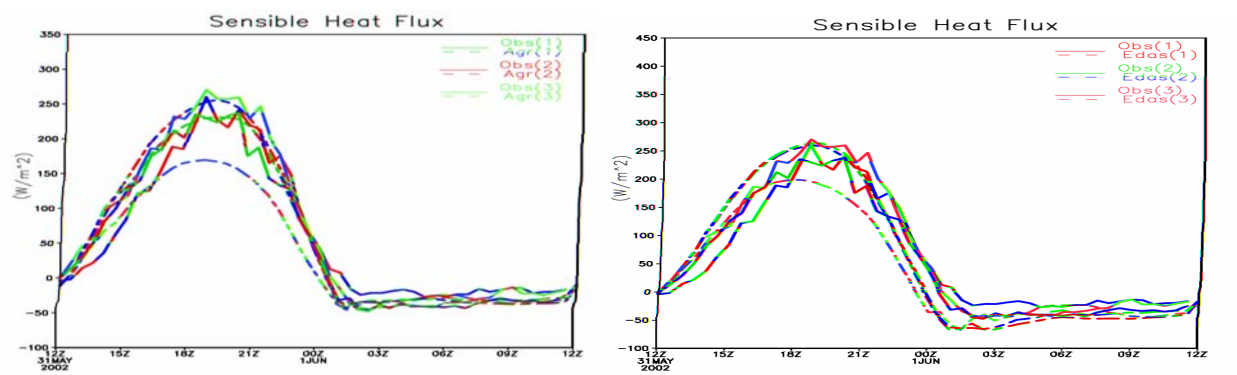

Fig 4: Comparison of sensible heat fluxes (at sites 1,2, and 3) between WRF and IHOP data for simulations initialized AGRMET (left) and EDAS (right).

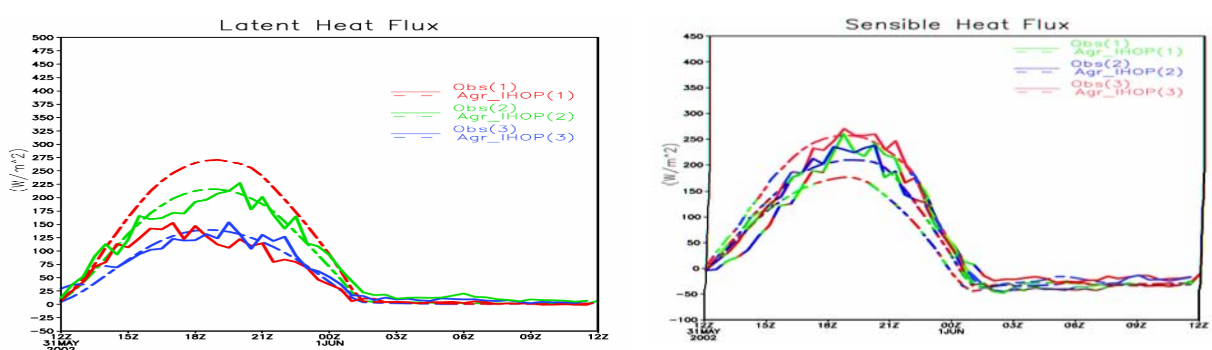

Fig 5: Same as in Fig.4, but for latent heat fluxes.

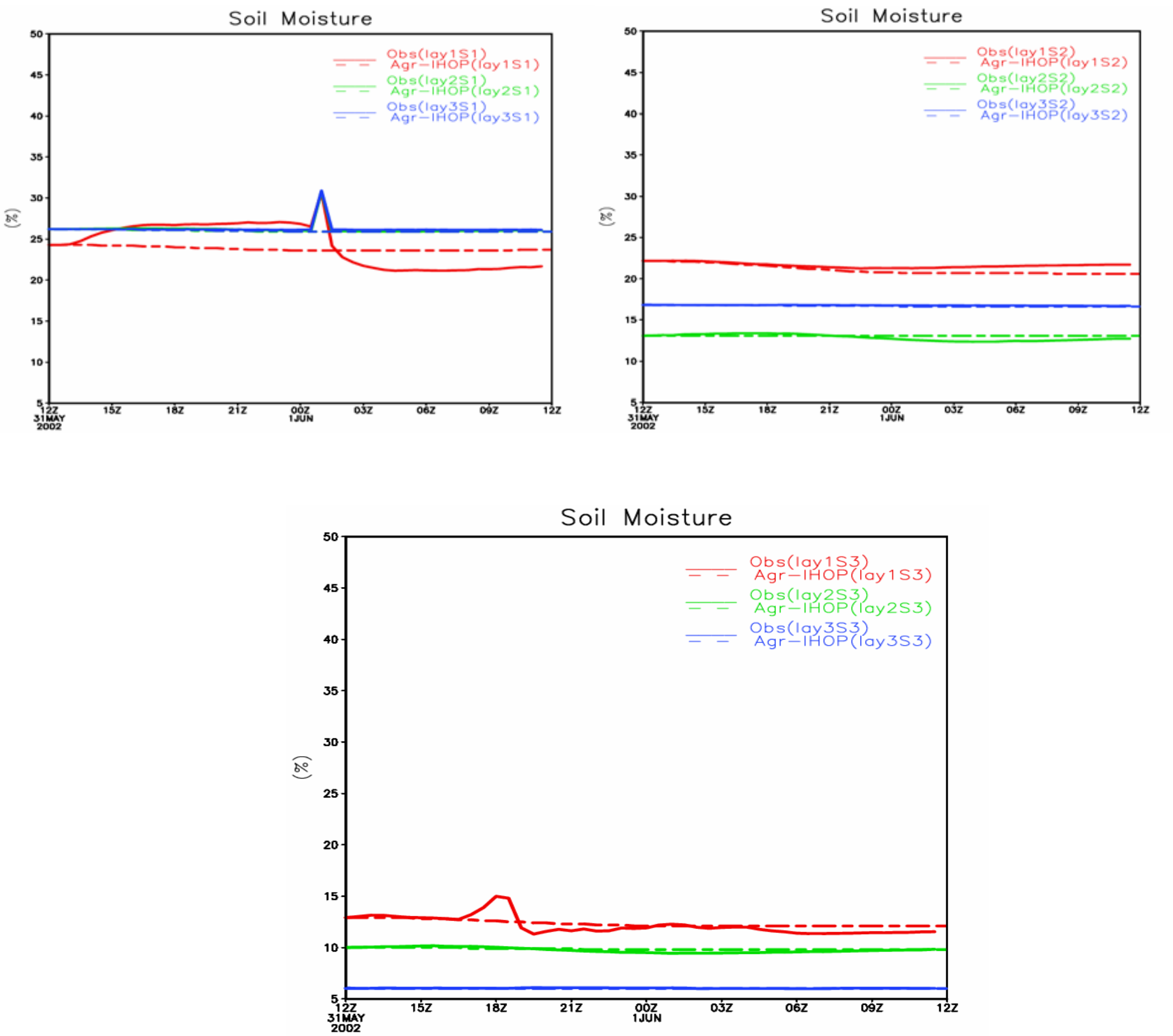

Fig 6: Soil moisture at sites 1, 2, 3 simulated by WRF initialized by using IHOP soil moisture for sites 1, 2, 3 and AGRMET for the rest of WRF domain.