Recent changes on land use/land cover over Indian region and its impact on the weather prediction using Unified model

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Abstract

This study compares the changes of land use/land cover (Lu/Lc) or the surface type in last decades over India. Recent surface-type fractions show few major regional changes over India. There is a decrease in vegetation fraction, increase in urban and bare soil fractions over India. The Unified Model coupled with Joint UK Land Environment Simulator land surface model was used to investigate the recent Lu/Lc impact on weather prediction. Preliminary results show improvement in weather prediction by the incorporation of the recent Lu/Lc data. This highlights the need to incorporate more realistic Lu/Lc in the dynamical models for better weather prediction.

Keywords: land use land cover; land surface model; weather prediction; India; unified model

1. Introduction

Land surface acts as the lower boundary for the weather prediction models. The land surface forces and modifies the atmosphere above by transferring surface fluxes (latent heat flux, sensible heat flux, momentum and CO2). The energy, water and carbon balance at surface are characterized by the regional features like topography, land use/land cover (Lu/Lc), soil type, etc. The regional heterogeneity of land surface directly impacts the surface fluxes to atmosphere and its evolution. The surface heterogeneity of land surface is accounted by different types of Lu/Lc data in land surface models. The Lu/Lc plays a key important role in the modulation of regional and local weather. Recent climate studies also suggest that the Lu/Lc changes can have local and remote (teleconnection) impact in dynamical model prediction (Devaraju et al., 2015).

Importance of Lu/Lc change on precipitation was investigated and documented by Pielke et al. (2007). Pielke et al. (2011) had suggested that the intensive Lu/Lc change over regions like India has more direct impact on regional climate. Mahmood et al. (2010) had stressed the importance of global monitoring of Lu/Lc change for both observational and modelling studies. Studies suggest that there are impacts on diurnal changes and mean surface warming as a result of the Lu/Lc change (Kalnay and Cai, 2003). The study of Feddema et al. (2005) suggested that the changes in land cover may influence Hadley and monsoon circulations. Most of these studies had focused on impact on long-term climate.

Studies on impact of land surface processes are limited over Indian region. Unnikrishnan et al. (2013) showed that the weekly satellite-observed vegetation fraction improves land surface parameter prediction over Indian region through better surface flux estimation. Similarly, Kumar et al. (2013) observed that updating vegetation fraction improves regional climate model predictions. Recent study of Xu et al. (2015) noted that Lu/Lc change shows enhanced 2-m air temperature variability in India. It is worth to investigate the impact of recent changes in Lu/Lc over Indian region on weather prediction.

Indian Space Research Organisation (ISRO) has developed meso-scale models compatible Lu/Lc data over Indian region derived from Advanced Wide Field Sensor (AWiFS) (Biswadip, 2014). The National Centre for Medium Range Weather Forecasting (NCUM) Unified Model (NCUM) uses by default the International Geosphere and Biosphere Programme (IGBP) Lu/Lc dataset which is based on National Oceanic and Atmospheric Administration’s (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data during 1992–1993 period. This paper investigates the recent changes in the nine surface-type fractions and its impact using NCUM coupled with Joint UK Land Environment Simulator (JULES) land surface model by using both IGBP and ISRO Lu/Lc datasets. Two separate prediction experiments (one wet and one dry) are performed to investigate the impact of ISRO Lu/Lc data on weather prediction.

The details of data and model are provided in Section 2. Section 3 compares the surface-type fraction...
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2. Data and model

The NCUM adapted from Met office, UK is used at NCMRWF (Rajagopal et al., 2012) for daily weather prediction. This is a grid point model with approximately 25 km horizontal resolution at mid latitude regions and it has 70 vertical levels. It also uses 4D variational data assimilation for creating model initial conditions. The surface parameters like soil moisture, snow depth, sea ice and SST are assimilated using a surface analysis scheme (SURF). JULES land surface model (Best et al., 2011; Clark et al., 2011) is coupled to the Unified Model. JULES has four vertical levels for soil moisture and temperature prediction. It is a tiled land surface model with sub-grid heterogeneity and computes surface temperatures and fluxes separately for each surface type in a grid-box. It can represent a grid box with nine major Lu/Lc types (surface type fractions) namely broad leaf trees, needle leaf trees, temperate grass, tropical grass, shrubs, urban, inland water, bare soil and land ice. JULES exchanges surface fluxes (latent heat flux, sensible heat flux, and CO₂) and momentum to the atmospheric model at each time step. At the same time atmospheric component of Unified Model forces the evolution of JULES land surface model by precipitation, surface short-wave and long-wave radiation, surface wind speed, pressure and moisture.

The NCUM uses by default the AVHRR-based Lu/Lc data from IGBP with 18 class Lu/Lc data (Loveland and Belward, 1997) to derive nine surface types for JULES land surface scheme. The dataset was derived from AVHRR data covering the period between April 1992 and March 1993 and the data have a resolution of 30 arc-second (~1 km) globally.

Recently ISRO IRS P6 satellite-derived Lu/Lc data over Indian region have become available (Biswa, 2014). AWiFS sensor on board IRS P6 satellite during 2012–2013 period was used to derive these IGBP 18 surface types with a resolution of 30 s. Over Indian region, data in global IGBP data are replaced by ISRO Lu/Lc data. This global data was further processed using Central Ancillary Program (CAP) utility. CAP is a collection of UM utilities to make necessary ancillary input files for Unified Model-like topography, surface-type fraction, etc. Documentation of CAP is available at https://puma.nerc.ac.uk/trac/UM_TOOLS/wiki/ANCIL/CAPbuild#Introduction. CAP utility is used for converting 18 classes of Lu/Lc to 9 classes of JULES surface-type fractions. The aggregation method is used for the conversion to nine surface-type fraction of the target model grid boxes in CAP utility. The grid box surface types fraction \( F_m \) is calculated as below:

\[
F_m = \sum \left( f_m \cdot a_{mn} \right)
\]

where \( F_m \) is the fraction of nine surface types \((m=1–9)\), \( f_m \) is the fraction of each 18 IGBP class \( m \) and \( a_{mn} \) is the fraction of each nine surface-type \( m \) in each IGBP class \( n \). The look up table used for \( a_{mn} \) in CAP is shown in Table 1.

The comparison of surface-type fractions in both datasets are discussed in the next section.

3. Surface-type fraction comparison

The recent period surface-type fraction from ISRO Lu/Lc data shows changes in type fractions compared to the IGBP data. The spatial pattern and area average of all surface types (broad leaf trees, needle leaf
trees, temperate grass, tropical grass, shrubs, urban, inland water, bare soil and land ice) are compared in this section. Table 2 shows the changes Lu/Lc type in both datasets. Figure 1 shows the spatial variations of all nine surface-type fractions. The Figure 1(a) shows the surface-type fractions from IGBP and Figure 1(b) shows same from ISRO data. There is no land ice over the region. The average fractions of surface types are calculated over Central India region (17–28°N and 70–85°E) and all India is shown in Table 2. We can see from Figures 1 and Table 2 that there is a decrease in total vegetation type fractions (5.05%) over central India. Another major change is seen in area average bare soil fraction, which has increased in recent period (+3.72%), and area average urban fraction (+0.93%) over Central India. Similar change is also observed in all India. The increase in total average urban fraction, bare soil fraction and reduction in vegetation fraction are results of the anthropogenic activities during last two decades.

### 4. Impact on weather prediction

The two weather events are selected based on India Meteorological Department (IMD) weather daily weekly report. The heavy rainfall event over Jammu and Kashmir on 3 September 2014 led to floods over the region. This event was selected for the wet case study. IMD-NCMRWF satellite-merged rainfall (Mitra et al., 2009) was used for the comparison of model rainfall forecasts. This daily rainfall data are available at 0.5° resolution from IMD (www.imdpune.gov.in). The 26 March 2014 was selected as the dry case, on that day there were above normal temperatures (3–4K anomalies as per IMD weather report) over Western Ghats in Kerala. We have evaluated only the first 24-h model forecasts in this study.

The above normal maximum 2-m temperature was reported over Western Ghats, Kerala, India on 26 March 2014. The NCUM forecasts could reproduce the spatial pattern of above normal maximum 2-m temperatures over Western Ghats. Figure 2 shows the comparison of 2-m temperature model prediction using both Lu/Lc datasets. Even though the model is not able to predict the actual maximum 2-m temperature reported by IMD (40.3°C), it is seen that there is an increase of air temperature up to 1–2 K with the use of ISRO Lu/Lc data. The bias of model is also reduced by 1–2 K over the case study region. Lu/Lc types have different albedo, roughness length and surface conductance in the land surface model. The Lu/Lc type can directly impact surface fluxes in the model. The albedo and surface fluxes directly impact the surface energy budget and temperature forecast in the model. The change in Lu/Lc contributes to the change in temperature bias in the experiments.

A heavy rainfall was observed on 3 September 2014 over the Jammu and Kashmir region. Figure 3 shows comparison of model simulated rainfall with observations. It is seen from the figure that the use of the new Lu/Lc dataset has resulted in improved prediction of regional rainfall pattern. The rainfall biases (observation-model) from experiments are shown in Figure 4. The rainfall bias is reduced with ISRO Lu/Lc experiment. The observed average rainfall over the region (74.5–78°E and 33–36.5°N) was 19.2 mm, the model predictions with IGBP Lu/Lc gave an average of 8.9 mm while the ISRO Lu/Lc gave 11.1 mm. There is an improvement of rainfall by 2 mm day−1 (~20% of model rainfall) over the region. Lu/Lc types can impact the surface fluxes and lower boundary layer stability, any change in the surface evaporation and lower stability is reflected in the rainfall prediction in the model. This contributes to the change in the rainfall prediction in these experiments.

### 5. Summary and conclusion

The comparison of surface-type fraction from old IGBP data and recent ISRO data shows major regional changes. The major changes observed in the recent period are reduced total vegetation fractions and an increase in urban and bare soil fractions. These changes are the result of both anthropogenic activity and natural interannual variability of monsoon. The ISRO Lu/Lc data over Indian region were incorporated into NCUM and tested for two cases.

The preliminary results of both wet and dry weather case study of prediction show improvement in forecast by incorporating the ISRO Lu/Lc. Above normal temperature was improved by 1–2 K. This also raises the question whether the maximum 2-m air temperature over Indian region is increasing due to recent Lu/Lc changes? This question should be addressed with a set of ensemble multi-model predictions along with strong observational evidences. This result also matches with the observation of Sertel et al. (2010), who reported that the incorporating of recent land cover dataset produced more accurate temperature simulation in a regional model over Turkey.

The prediction of Jammu and Kashmir rainfall event by incorporation of ISRO Lu/Lc data showed increased rainfall of 2 mm day−1 (around 20% of model rainfall).
Figure 1. The surface fractions of (a) broad leaf trees, (b) needle leaf tree, (c) c3 grass, (d) c4 grass, (e) shrubs, (f) urban, (g) inland water and (h) bare soil fraction. Left panel shows the IGBP data and right panel shows NRSC ISRO data.
Figure 1. Continued.
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Figure 2. The comparison of 2 m temperature simulations using both Lu/Lc data sets. (a) The simulation with IGBP data and (b) simulation using ISRO data.

Figure 3. The comparison of model simulated rainfall (mm day\(^{-1}\)) with observation on 3 September 2014. (a) Observed rainfall, (b) model using IGBP data and (c) model using ISRO Lu/Lc data.

This result is also consistent with previous experiment of Xie et al. (2014), who found that Lu/Lc can impact on precipitation simulation in WRF regional model over Beijing. Our preliminary results suggest that the use
of more realistic Lu/Lc data can improve the weather predictions.

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