

Assessing the response of forests to environmental variables using a dynamic global vegetation model: an Indian perspective

Forest ecosystems form an intricate non-linear relationship with their surroundings. Therefore, the underlying processes are difficult to quantify. As a result, it makes the task quite challenging to evaluate the response of vegetation to their surrounding environment¹. Predicting responses of vegetation dynamics requires a clear understanding of how different physiological and ecological processes are influenced by environmental drivers. A clear causality between the types and levels of stresses and corresponding responses of forests is necessary for making any rational inferences². Significant progress in scientific understanding of plant–environment relationship, supplemented with the historical sequence of discoveries, is gradually improving the knowledge about the underlying functional relationship of plants with the environment. On the other hand, improved computational capabilities to handle multiple complex equations representing various functional relationships have made it possible to upscale the eco-physiological processes from an individual leaf to a global forest cover through computer-based programs, usually termed as a ‘Model’.

These models are developed to capture the transient response by adopting various approaches and assumptions³. Models provide a framework to test our quantitative knowledge and hypotheses to answer queries related to plant process or combination of processes⁴. There have been continuous attempts to model the vegetation response through important ecological entity and processes; such as, the modelling of phenology, physiological functions, growth and succession, diversity and dominance, habitat suitability, competition and mortality, susceptibility to insect and pest attack, cycling of nutrients, fluxes of energy, water and CO₂, etc. Ecological process-based models are the most recent generation of models for such studies. These models are capable of simulating transient patterns of vegetation, carbon stocks, nutrient cycling and fluxes, productivity of the ecosystem, and possible effects of temperature, precipitation and CO₂ fertilization. Once the effect of specific climate variables that govern the growth of forests is un-

derstood, the process-based models can simulate the potential implications of climate change and climatic variability. A wide variety of process-based models available nowadays simulate eco-physiological process from leaf to stand, from stand to landscape, and from landscape to global scale⁵. The forest science has evolved in recent decades, and thus, the forest models. The improved understanding of the complex processes has given impetus to a new generation of process-based models⁶. The new generation of models can simulate a large range of eco-physiological processes explicitly at varying temporal resolution for local as well as global coverage.

The most recent generation of models which integrates dynamic physiological processes to simulate the response of environmental variables to predict its impact upon plants at regional to global scales are categorized as Dynamic Global Vegetation Models (DGVMs)⁵. These are process-based mechanistic models used for assessing the impact of climate change on forests^{3,7}. These models have been developed using field-based observations and experimental data⁵. As DGVMs are the most recent generation of models, they may often inherit the frameworks and philosophy of pre-existing models for representing various processes within a model⁵.

Forest managers in India are looking for well-validated models for integrating the output at the policy level. This has been restricted by testing of only a few DGVMs that focus on the national level impact studies, such as the Integrated Biosphere Simulator (IBIS)⁸ and the Lund Potsdam Jena model (LPJ)⁹. Unlike other developed countries, India still lags in developing DGVMs while there have been very limited attempts in the testing of existing DGVMs. In the absence of testing of multiple DGVMs, mostly the simulation outputs of IBIS¹⁰ have widely been referred to in the climate change policy documents in India. However, a large number of DGVMs have evolved in the recent decades⁵ that need to be tested in application to Indian forests. Inter-comparison of the simulation results and ensemble approach of testing of different DGVMs would help in establishing the

stimulus–response relationship with more confidence, such as to measure the impacts of changing ambient environment on the functioning of the forest ecosystem. The focus of research is desirable to test the strength of models when simulating plant–environment related attributes such as the phenology, leaf area index, stem biomass, root–shoot ratio, soil–plant biogeochemistry, plant growth, structure and composition of plant community, and competition among them, etc. Sensitivity analysis of parameters, to which models may behave in an awkward way, need to be evaluated. How well a DGVM captures the structure, basic assumptions and the dynamics of a forest ecosystem at the regional level for different dominant forest types requires validation with reference to India.

In India, there has been limited attempt to develop DGVMs while the use of DGVM of external origin has been limited to IBIS and LPJ⁵. DGVMs represent various interlinked plant–environment relationship through multiple files, routines and sub-routines linked to each other which is usually not easy to comprehend if the user is not a part of the development team. This makes the task cumbersome for the users to understand the inbuilt equations that represent different modules in a DGVM. At the same time, the programming language that describes the complex processes through various equations is not so easy to understand and therefore scope to fine-tune the model becomes a tiresome process. This provides an opportunity to develop a model where developers have clear understanding of processes presented within a model and the inherent limitations of the model. This will hold the scope of modifying or changing sub-modules of the model to describe the environment–plant relationship more explicitly at regional level. Long-term observation of plot data together with the assemblage of fragmented knowledge could be used for the fine tuning of existing models and for developing independent sub-modules of a DGVM.

Development of models for agriculture crops (InfoCrop)^{11,12} by Indian Agricultural Research Institute, Delhi is

commendable while such models for forests by Indian groups are lacking. Recently, a collaborative attempt was made by the authors with the G.B. Pant National Institute of Himalayan Environment and Sustainable Development, Almora, India, and the York University, and the Ontario Tech University, Canada to develop a dynamic model for the Indian Chir pine (*Pinus roxburghii*) – the PhenoPine¹³, that can be used to trace the phenological changes in Chir pine in response to ambient temperature rise. The PhenoPine is an initial module of the DGVM that we plan to develop as a full-fledged model for the pine-dominant landscape. In due course, we wish to develop models for other dominant and mixed forests that could be coupled with the climate models to assess the response of forests under projected climate change scenarios at regional to global scales.

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Earthquake swarms in Palghar district, Maharashtra, Deccan Volcanic Province

The Palghar district of Maharashtra falls in zone III of the seismic zoning map of India, where earthquakes up to magnitude 6.0 can occur¹. A swarm activity was started in the Palghar district of Maharashtra in November 2018 and is still continuing (till the end of November 2019). According to reports from the National Centre for Seismology (NCS), more than 1,000 earthquakes of micro-to-minor magnitude have occurred in the Dahanu and Talasari talukas of Palghar district, from 3 November 2018 to 15 February 2019. The biggest tremor of magnitude M_L 3.7 was recorded on 1 February 2019, at 3.54 PM (IST). The people of Dahanu and Talasari talukas were panicked by the abnormal ground vibration and burst sound that they felt. In fact, Jawahar city in Palghar district has experienced swarms several times earlier. Another vulnerable region in Maharashtra is Amravati, which witnessed swarm activity in August 2018 (ref. 2). In 1856, the region experienced an earthquake of magnitude 5.7 (Figure

1 a)^{3,4}. The objective of the present study is to provide preliminary information about the ongoing swarm activity immediately after its occurrence. Since the local networks have been deployed a few days after the swarm activity, we attempted to understand the nature of swarm activity, utilizing data from the existing Gujarat seismic network.

The entire study region is almost covered with Deccan traps (Figure 1 b). The major fault in the region is the West Coast Fault (WCF), whose origin is linked to the splitting away of the Indian plate from the Gondwanaland^{5,6}. The Ghod and Upper Godavari are the other faults in the vicinity of Palghar⁷. Further, the lineament/dykes in the region dominantly trend in the N–S and NW–SE directions⁶. The field observations reveal that the lineaments represent fracture zones, shear zones, faults and dykes⁶. The coast parallel Panvel flexure is another major tectonic feature present in the area^{4,6}, along which the Deccan basalts dip to the west, with an increasing

amount of dip. The axial trace of this flexure trends in the NNW direction, parallel to the WCF.

To monitor the seismic activity in and around Gujarat, a dense network (GSNet) of 54 broadband seismographs (BBS) was deployed by the Institute of Seismological Research (ISR)⁸ (Figure 1 a). The seismic data from 45 permanent (online) stations are received via very small aperture terminal (VSAT) at the central station of ISR, in a continuous mode. Among these, one station, Madhuban in Dadra & Nagar Haveli (DNH), is located just north of the region affected by the swarm and four other stations are installed in a stand-alone (offline) mode within 70 km epicentral distance, in Mota Randha (DNH), Kavdej, Limzar and Godvani villages of Navasari district, south Gujarat. The data from offline stations are manually collected periodically, once a month. The Guralp CMG-3T broadband sensors and 24-bit Guralp CMG-DM24/REFTEK (RT 130-01) data loggers are installed at all the seismic