2

CLIMATE AND ENVIRONMENTAL MODELLING PROGRAMME (CEMP)

The basic approach of CEMP is a fusion of innovation and sound mathematical modeling that can fill critical knowledge gaps and also enable real-life applications. The emphasis continues to be on understanding of the climate system and applications through multi-disciplinary modelling combining climate science with water, agriculture, health energy and sustainability in general.

CEMP uses a hierarchical modelling platform along with a spectrum of analysis and visualization tools. Most of the process models, with associated computer codes, are developed in-house. The CSIR climate observation and modelling network (COMoN) is a comprehensive data infrastructure. COMoN has been designed and developed by CEMP as a multi-application sustained network in a resource and effort sharing participation by multiple agencies.

CEMP has often adopted approaches that are unconventional but scientifically sound. After its cognitive network for monsoon forecasting, CEMP pioneered long-range, high-resolution forecasting of monsoon with novel methodology, such as a conceptual framework and methodology for advance dynamical forecasting of the date of onset of monsoon. CEMP has been communicating its experimental forecasts of monsoon to various agencies since 2003 for post-forecast evaluation.

Advance weather informatics, like forecasts of fog, can aid many sections of the society as well as strategic and industrial sectors. The dynamical fog forecasting model developed by CEMP was transferred to IMD for integration to the national weather services.

To complete the cycle from development to application, CEMP integrates effective outreach to its activities. An important outreach programme in weather informatics is in collaboration with Karnataka State Natural Disaster Monitoring Centre (KSNDMC). Forecasts generated using the novel methodology developed at CSIR-4PI (erstwhile C-MMACS) are disseminated by KSNDMC for the benefit of the farmers. CEMP had been the first to develop an industrial interface in weather informatics.

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A. Climate Analysis, Modelling and Projections

2.1 Assessment of Reliability of Regional Climate Projections

Projections of climate change are emerging to play major roles in many applications. However, assessing reliability of climate change projections, especially at regional scales, remains a major challenge. An important question is the degree of progress made since the earlier IPCC simulations (CMIP3) to the latest, recently completed CMIP5. We consider the continental Indian monsoon as an example and apply a hierarchical approach for assessing reliability, using the accuracy in simulating the historical trend as the primary criterion. While the scope has increased in CMIP5, there is essentially no improvement in skill in projections since CMIP3 in terms of reliability (confidence). Thus, it may be necessary to consider acceptable models for specific assessment rather than simple ensemble. Analysis of climate indices shows that in both CMIP5 and CMIP3 certain common processes at large and regional scales as well as slow timescales are associated with successful simulation of trend and mean.

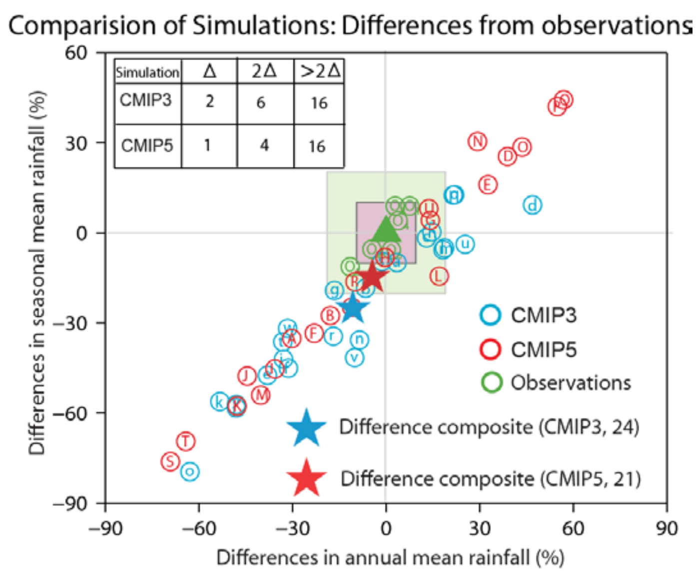

Figure 2.1 Distribution of historical (1951-2005) simulations in seasonal and annual rainfall over continental India for CMIP5 (red, uppercase) and CMIP3 (blue, lower case) in terms of the difference (simulation – observed composite) as percentage of the corresponding observed composite. The dispersion in the observations (green) is shown in terms of the difference (observation – observed composite) as percentage of the observed composite. The adopted acceptable uncertainty is defined by the difference (Δ) between the maximum and the minimum in the observed values, centered at the observed composite; the inner shaded box (pink) is defined by 1Δ, while the outer square (green) is defined by 2Δ. The inset table shows the number of simulations that fall in each category.

However, these regional (continental) trends may not represent global trends, and the oceanic trends, due to increased evaporation, are likely to be markedly different.

Ramesh K V, Goswami P
Nature Scientific Reports, 2014.

2.2 Monsoon in a Changing Climate

A revised scenario of global and regional monsoonal rainfall, and their changes in the 21st century under RCP4.5 and RCP8.5 scenarios was examined based on projections by 29 climate models that participated in the Coupled Model Intercomparison Project phase 5. The projections show that the global monsoon area defined by the annual range in precipitation is likely to expand mainly over the central to eastern tropical Pacific, the southern Indian Ocean, and eastern Asia. Over the Asian monsoon domain, projected changes in extreme precipitation indices are larger than those over the other monsoon domains, indicating the strong sensitivity of the Asian monsoon to global warming. The projections also indicate a delay in the retreat of the monsoon, while the onset will either advance or show no change, resulting in lengthening of the monsoon season. However, the models' limited ability to reproduce the present monsoon climate and the large scatter among the model projections limit confidence in the results. The projected increase of the global monsoon precipitation can be attributed to an increase of moisture convergence due to increased surface evaporation and water vapor in the air column although offset to a certain extent by the weakening of the monsoon circulation.

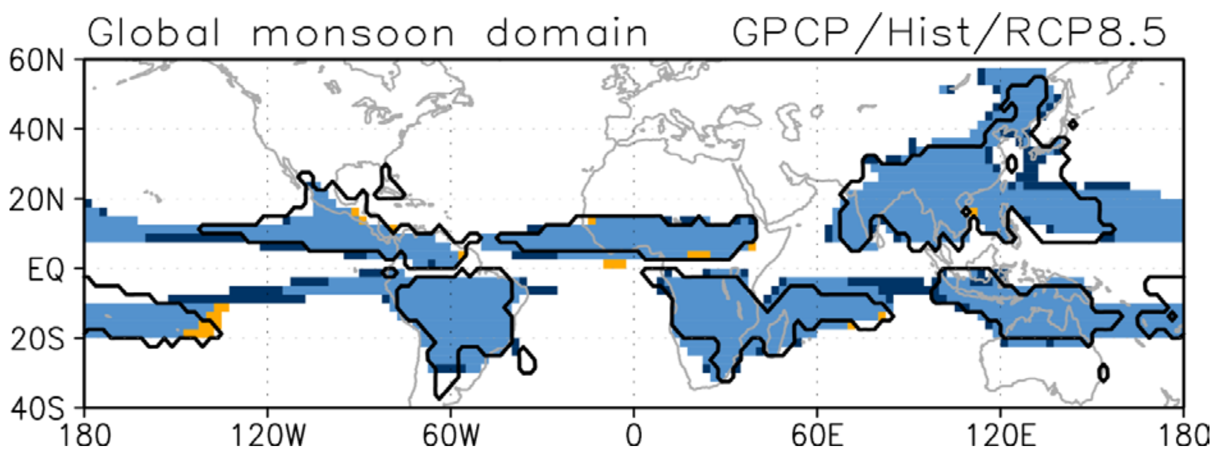

Figure 2.2 Observed GPCP; (thick contour) and simulated (shading) global monsoon domain, based on the definition by Wang et al. (2011). The simulations are based on 29 CMIP5 multi-model mean precipitation with a common 2.5 by 2.5 degree grid in the present-day (1986-2005) and the future (2080-2099; RCP8.5 scenario). Warm yellow (dark blue) shading: monsoon domain only in the present-day (future). Blue shading: monsoon domain in the both periods.

This study in the global context complements our earlier study on continental India monsoon. Thus while there may be an increase in in oceanic and hence global monsoon, the continental Indian monsoon may continue to decrease.

Akio Kitoh[1], Endo H[1], Krishna Kumar K[2], Iracema F A Cavalcanti[3], Goswami P and Tianjun ZhoJ[4], Geophys. Res. Atmos., 2013

[1]Meteorological Research Institute, Japan. [2]Indian Institute of Tropical Meteorology, India.
[3]Center for Weather Forecasting and Climate Studies (CPTEC), Brazil.
[4]LASG, Institute of Atmospheric Physics, China.

B. Long-range Forecasting of Monsoon Rainfall and Date of Onset

2.3 Long-range, High-Resolution Forecasting of Monsoon Rainfall

Given the tremendous socio-economic impacts of monsoon rainfall essentially on all socio-economic sectors of India, accurate forecasts of monsoon rainfall can be a critical input. However, for effectiveness such forecasts should have the scope, lead and reliability required by the users. As long-range forecasting of monsoon is still a evolving science with many challenges, CSIR-4PI (erstwhile C-MMACS) had initiated a sustained effort to develop and improve methodologies for long-range forecasting of monsoon.

The forecasts of monthly anomalies are made by computing the anomalies with respect to 25 year model mean for each ensemble. The ensemble average is then determined as an average over the ensembles with equal weight for different scenarios. The monthly and seasonal anomalies are expressed as percentage of the model mean.

Spatial distribution seasonal rainfall anomaly (% of mean) for June-August, 2013 from IMD observation (left panel) and CSIR-4PI (erstwhile C-MMACS) long range forecasting (right panel) are represented in Figure 2.3.

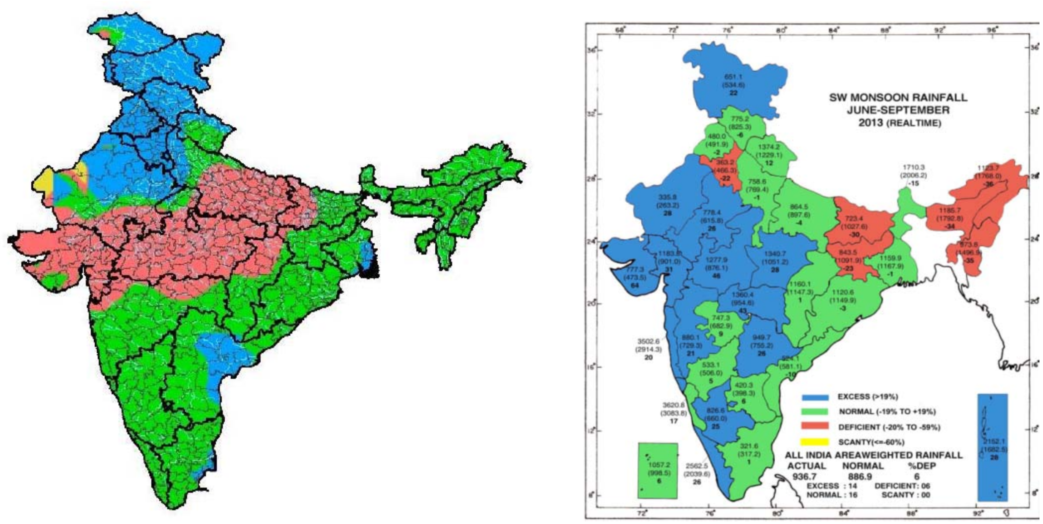

Figure 2.3 Comparison of CSIR-4PI (erstwhile C-MMACS) 2nd outlook forecast for the period June-August 2013 rainfall anomaly with IMD observation. The simulation is an ensemble average of five initial conditions between April 01 and May 15, 2013 from NCEP Reanalysis.

Since 2003, CSIR-4PI (erstwhile C-MMACS) has been generating and communicating its long-range experimental forecasts (issued in march-April) for objective post-forecast validation. These experimental forecasts, pioneered by CSIR-4PI (erstwhile C-MMACS) have created new approaches and benchmarks for long-range forecasting of monsoon.

Gouda K C and Goswami P

2.4 Advance Forecasting of Date of Onset of Monsoon

The onset of summer monsoon over Kerala heralds the rainy (and hence agricultural) season for India; thus advance and accurate forecast of the date of onset can have many applications, especially in agricultural planning. However, advance dynamical forecasting of the date of monsoon has been rarely attempted anywhere in the world due to poor skill in forecasting daily rainfall. Although forecasting of day to day variability of rainfall beyond a few days remains a major challenge, we have argued that large transitions like the onset of monsoon should have a high signal-to-noise ratio, and should be predictable. Along with this hypothesis, a dynamical framework with a general circulation model (GCM) optimized over India (variable-resolution GCM adopted from LMD, France) was advanced (Goswami and Gouda, 2010); further, objective criteria and algorithm for identifying the date of onset from the GCM simulations were developed (Goswami and Gouda, 2010).

Although the date of onset shows a standard deviation of only seven days, many years are known to show large deviations; besides, many years are also characterized by false onsets. Thus accurate forecasting of date of onset is non-trivial. The methodology was first tested in hindcast mode (forecasts of past events) and the skill was found to be useful, with an average error of 2 days.

These methodologies have been followed to generate advance (> 15 days) forecast of the date of onset of monsoon. The CSIR-4PI (erstwhile C-MMACS) Forecasts of date of onset, announced in April, 2013, matched with the date of onset announced by IMD (May 31, 2013).

Table 2.1 Performance of CSIR-4PI (erstwhile C-MMACS) Experimental Forecasts of Monsoon Onset

Year	Actual Onset Date	CSIR-4PI (erstwhile C-MMACS) Forecast Onset Date	Error (Days)
2007	May 28	May 26	2
2008	May 31	May 28	3
2009	May 23	May 23	0
2010	May 31	May 29	2
2011	May 29	June 03	5
2012	June 04	June 04	0
2013	**May 31**	**May 31**	**0**
Average error in prediction of date of onset			2 Days

CSIR-4PI (erstwhile C-MMACS) began its experimental forecast of the Date of Monsoon in 2007. The 7 year performance of dynamical prediction of DOM using CSIR-4PI (erstwhile C-MMACS) methodology shows (table 2.1) the average error to be essentially same as that for the hindcast skill, with only one forecast with large (but smaller than standard deviation) error of five days. As the post-forecast evaluation of CSIR-4PI (erstwhile C-MMACS) forecasts begin to present robust skill, other agencies are beginning to come forward with advance forecasts of date of onset.

Gouda K C and Goswami P

C Forecast Methodology, Applications and Outreach

2.5 High-resolution (Village Cluster) Rainfall Forecast for Real Time Applications

Evaluation of real-time rainfall forecast at the *hobli* (village cluster ~ 10 km2) level from an atmospheric mesoscale model over Karnataka (located at southwest India, with nearly 56% of the workforce engaged in agricultural activities) for the southwest (June–September) and northeast (October–December) monsoon seasons of 2011 is presented in this study. The forecast system has been operationally implemented through data assimilation from a number of local observatories for effective applications as well as for proof of concept. A highlight of the study is the validation of the rainfall forecasts against observations at comparable resolution established by Karnataka State Natural Disaster Monitoring Centre, Government of Karnataka (KSNDMC). An evaluation of the forecast skill against daily observed rainfall is presented. A number of statistical evaluations show that the forecasts have enough skill to be useful for end users (Figure 1). A few areas of systematic bias (Figure 2) and relatively higher forecast error were identified for further improvement in forecast skill.

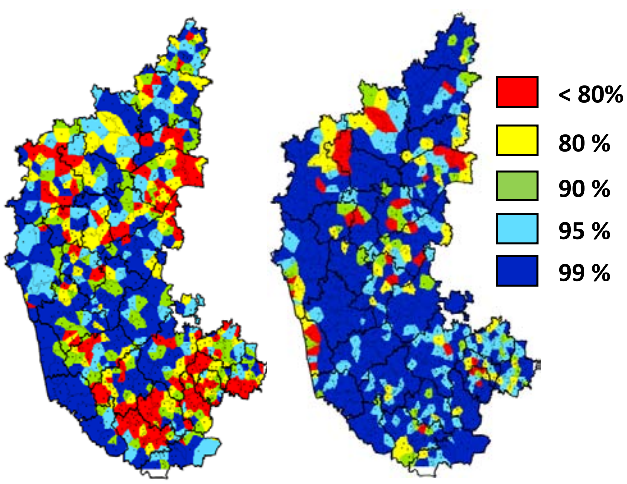

Figure 2.4 Significance of Correlation between the observed and forecasted daily rainfall for SWM (left panel) and NEM (right panel) season for 2011.

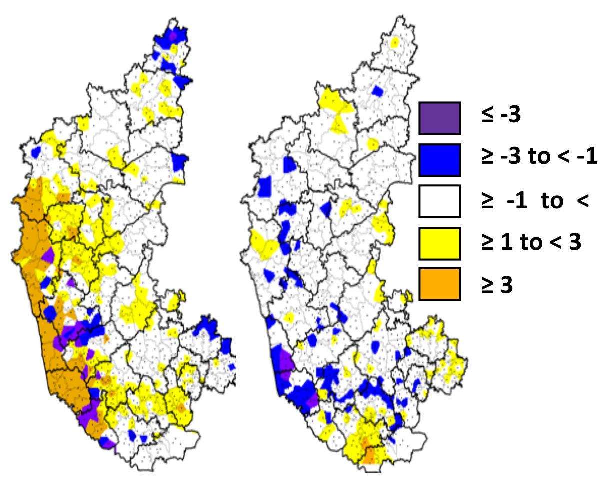

Figure 2.5 The average bias in daily rainfall (mm/day) for SWM (left panel) and NEM (right panel) season 2011.

Efforts are now on to increase the accuracy of the forecasts further through assimilation of data from CSIR COMoN as well as from the KSNDMC observation network. An initiative to generate forecasts at Panchayat level (a few Km scale) has also begun.

Rakesh V, Goswami P and Prakash V S[1]
Meteorological Applications, 2013
[1]Director, KSNDMC, Bangalore

2.6 Dynamical Model for Air Pollution: Interfacing with GCM

Species like suspended particulate matter (SPM), respirable suspended particulate matter (RSPM), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) not only act as atmospheric pollutants but also affect long-term climate through radiative and chemical forcing. Earlier work has shown that the daily variations in these species over a location could be simulated quite well by considering daily meteorological fields from NCEP–NCAR reanalysis data in combination with models for natural and anthropogenic sources over Delhi, India. In the present work this possibility is explored by simulating the pollutant concentrations by using forecast fields from an atmospheric general circulation model (AGCM); this takes the model closer to a forecast model. Because of the coarse resolution, however, the present work considers an air basin rather than a detailed spatiotemporal distribution.

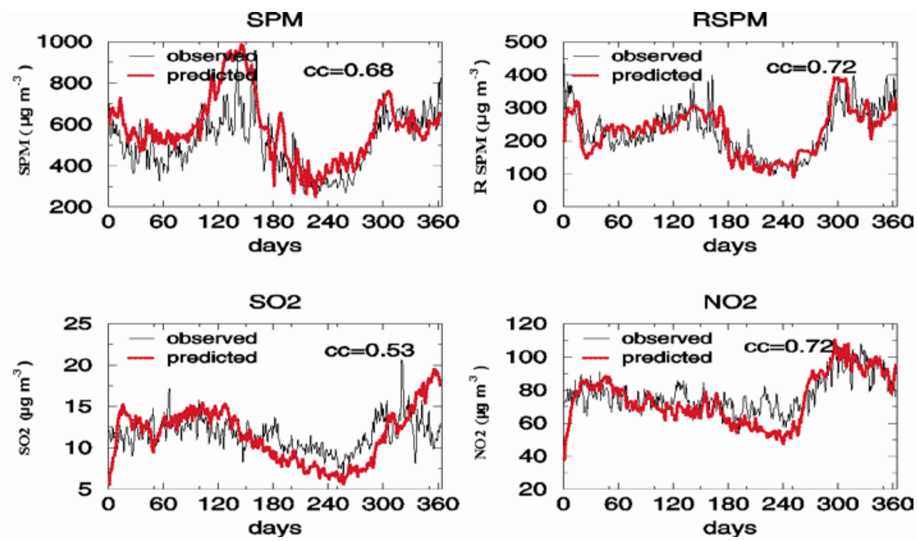

Figure 2.6 Climatology (2000-2005) of observed (black line) and simulated (red line) values for different pollutants over Delhi as indicated. The meteorological variables have been taken from debiased prediction of gridded model output with the centre of zoom at 77° E and 28° N (Delhi). The observed data is from Central Pollution Control Board.

One of the objectives of the present work has been to compare and assess the impacts of a GCM-generated field with reference to NCEP–NCAR reanalysis data used in earlier work. In the present work the interaction is one way, and active chemistry for the species is not considered; thus the work should be regarded as a minimal forecast model, especially for SO_2 and NO_2. It is shown that the GCM-driven model has skill comparable to skill obtained when using NCEP–NCAR reanalysis data. However, much higher skill can be expected with incorporation of techniques like data assimilation and objective debiasing.

Goswami P and Barua J
J Meteor. Climatol., 2013

2.7 Impact of Domain Size and Parameterization Scheme on Simulation of Tropical Cyclones

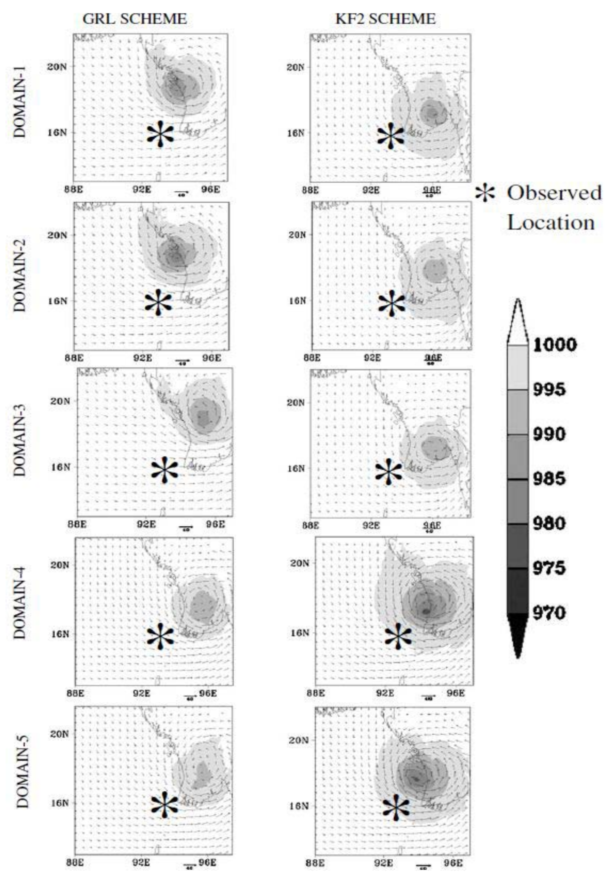

Figure 2.7 Surface pressure (hPa) and vector wind for cyclone Mala at 18 h on 28 April 2006 for different domains and parameterization schemes. All the simulations were carried out with initial condition extracted from NCEP FNL (1° × 1°) 06 h data on 25 April 2006. The observed minimum surface pressure is 954 hPa.

Accuracy of forecasts of tropical cyclones is still below the user requirement, especially over the north Indian Ocean. In case of dynamical forecasting, a large number of processes and factors control the quality of simulations with a numerical weather prediction model and especially with mesoscale models; identification and optimization of these processes are critical for improving forecast skill. The importance of cumulus parameterization schemes in simulation of tropical cyclones was recognized early, and a large number of studies have addressed this issue. However, certain other aspects have received relatively less attention. In particular, unlike simulation with a global circulation model, a mesoscale simulation is characterized by a limited domain and hence inhomogeneous lateral boundary conditions that strongly affect the quality of the simulation. In this work, we investigate the relative impact of size of the model domain and the cumulus parameterization scheme on simulation of 10 cyclones over the Bay of Bengal during the period 1999–2009. For five domains with different spatial extents, simulations were carried out for three different cumulus parameterization schemes (Anthes-Kuo, Grell, and Kain-Fritsch2) for each of the 10 events (using the mesoscale model MM5). Our results show that the size of the domain also plays an equally critical role as the parameterization scheme in simulation of maximum intensity, track, and spatial structure of the cyclones. The impact of domain size is not linear; while each domain chosen is large enough, neither the largest nor the smallest domain provides the best simulation. However, there is consistency in the sense that a single domain emerges as best for intensity and track among the five considered. While the specific conclusions may depend on the ocean basin, the methodology is generic and can be applied to any ocean basin of cyclogenesis. The result provides a basis and methodology for improving skill in forecasting tropical cyclones over the north Indian Sea.

Goswami P and Mohapatra G N
Journal of Geophysical Research: Atmospheres, 2014

D. Climate Change Assessment, Impact and Mitigation

2.8 Efficient, Non-disruptive and Sustainable C Sequestration with Vetiver

The increase of atmospheric CO2 concentration is a major cause of global warming. This issue may be effectively addressed through sequestration of carbon in plants and soils. Here we studied the potential of vetiver, Vetiveria zizanioides L., to sequester carbon in field plots in Bangalore, India. Vetiver is a perennial and economically viable crop growing in tropical and subtropical regions. Vetiver has medicinal and aromatic properties. Vetiver shoot and root C amounts were measured. Results show that vetiver sequesters 15.24 Mg C ha−1 year−1 in shoot and roots, much higher than that for lemongrass with 5.38, palmarosa with 6.14, and trees with 2.92. In addition the benefit/cost ratio of vetiver, 2.3, is higher than that of rice, 1.97.We estimate that vetiver cropping could sequester 150 Tg per year in India, which is nearly 46 % of C emissions in India.

Table 2.2 Comparative economics of production of three aromatic plants and rice

Crop	Fresh biomass (mega grams ha^{-1} $year^{-1}$)	Essential oil (%)	Benefit cost ratio
Vetiver	4.25 (roots)	0.8	2.3
Lemongrass	27.7	0.8	1.97
Palmarosa	30	0.5	2.75
Rice	-	-	1.97

India has approximately 6.63m ha salt effected soils, 17.9 m ha acid soils and 83.3 m ha land affected by soil erosion. Even if 10% of the degraded soils affected by erosion, acidity, salinity and sodicity in India (which comes to nearly 10 m ha) is employed for a vetiver-based carbon sequestration system (vetiver and vetiver based agro-forestry systems), a potential exists to sequester more than 50 Tg C $year^{-1}$ in soil and 150 Tg C $year^{-1}$ in the biomass over a 5- year period. This potential is much higher than some earlier estimates for restoration of degraded soils in India. The potential C-sequestration by vetiver could be nearly 46% of the C emissions of 434 Tg $year^{-1}$ in India. It should be noted that as only a small fraction (~10%) of potential area is considered in the estimate. the plantations of vetiver can be rotated, allowing SOC to decline below saturation value, so that the cycle can be repeated. Thus vetiver can provide a sustainable, non-disruptive solution to sequester carbon in soil along with societal benefits.

Munnu Singh[1], Neha Guleria[1], Prakasa Rao E V S and Goswami P
Agron. Sustain. Dev, 2013.
[1]CIMAP, Bangalore

2.9 Modeling of Vulnerability of an Urban Groundwater System under Combined Impacts of Climate Change and Management

Climate change impact on a groundwater-dependent small urban town has been investigated in the semiarid hard rock aquifer in southern India. A distributed groundwater model was used to simulate the groundwater levels in the study region for the projected future rainfall (2012–32) obtained from a general circulation model (GCM) to estimate the impacts of climate change and management practices on the groundwater system. Management practices were based on the human-induced changes in the urban infrastructure such as reduced recharge from the lakes, reduced recharge from water and waste water utility due to an operational and functioning underground drainage system, and additional water extracted by the water utility for domestic purposes. An assessment of impacts on the groundwater levels was carried out by calibrating a groundwater model using comprehensive data gathered during the period 2008–11 and then simulating the future groundwater level changes using rainfall from six GCMs [Institute of Numerical Mathematics Coupled Model, version 3.0 (INM-CM.3.0); L'Institut Pierre-Simon Laplace Coupled Model, version 4 (IPSL-CM4); Model for Interdisciplinary Research on Climate, version 3.2 (MIROC3.2); ECHAM and the global Hamburg Ocean Primitive Equation (ECHO-G); Hadley Centre Coupled Model, version 3 (HadCM3); and Hadley Centre Global Environment Model, version 1 (HadGEM1)] that were found to show good correlation to the historical rainfall in the study area. The model results for the present condition indicate that the annual average discharge (sum of pumping and natural groundwater outflow) was marginally or moderately higher at various locations than the recharge and further the recharge is aided from the recharge from the lakes. Model simulations showed that groundwater levels were vulnerable to the GCM rainfall and a scenario of moderate reduction in recharge from lakes. Hence, it is important to sustain the induced recharge from lakes by ensuring that sufficient runoff water flows to these lakes.

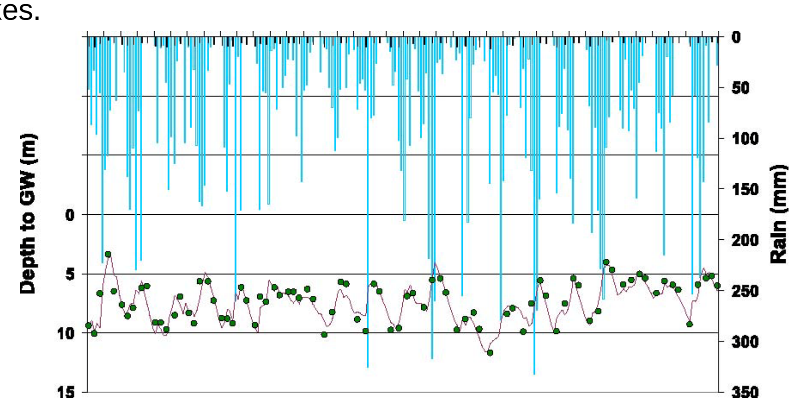

Figure 2.8 Comparison of observed and simulated groundwater levels monitor data station during 1978–97. The line represents simulated and circle represents observations.

Efforts are now on to develop a comprehensive simulation platform for ground water demand and availability in different socio-economic scenario.

Sekhar M[1], Shindekar M[1], Tomer Sat K [1]and Goswami P, Earth Interactions, 2013
[1] Indian Institute of Science, Bangalore, India

E. Sustainability Policy Analysis and Modelling

2.10 Quantitative Assessment of Agricultural Sustainability over India

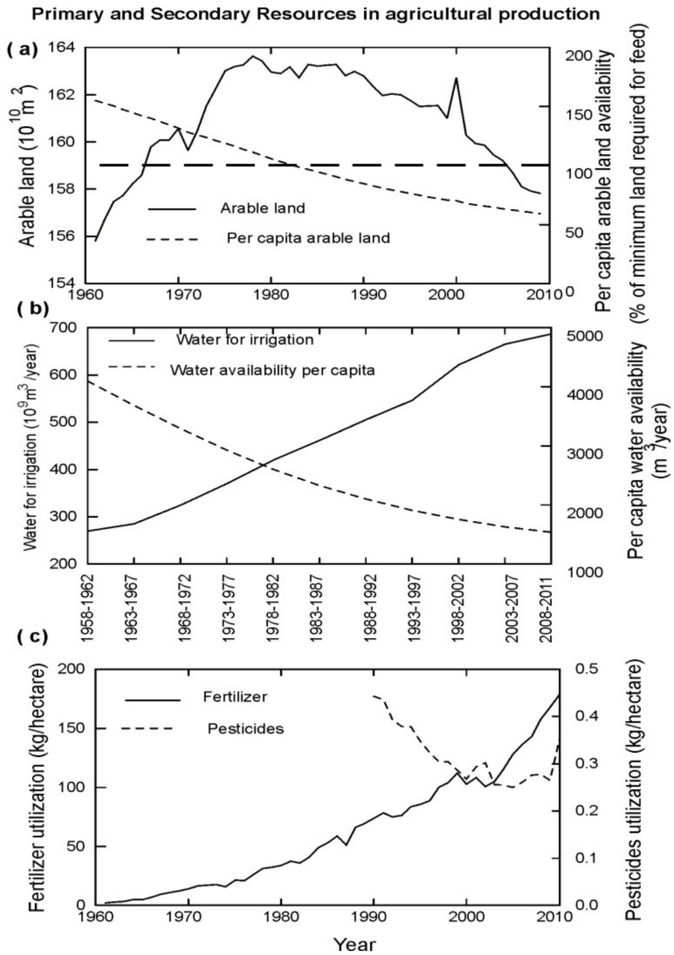

Figure 2.9 Availability and status of the primary resources for India. Top panel: Total arable land (left y axis, solid line) and per capita land availability (right y axis, dash line); expressed as the % of minimum land needed to produce food for one person (0.22 hectares: http://www.gdrc.org/sustdev/fao-100.pdf). Middle panel: Water use for irrigation (solid line, left y axis) and the per capita water availability (dash line, right y axis) for different epochs. Bottom panel: Fertilizer utilization per hectare (left y axis, solid line) and pesticides utilization per hectare (right y axis, dash line). The observed data for fertilizer utilization and arable land is taken from FAOSTAT; the data on pesticides is adopted from Dept. of Agricultural and Corporation http://agricoop.nic.in/Agristatistics.htm).

Agricultural sustainability is an important parameter for policy design. Sustainability is a complex function of many variables and has to follow a constrained dynamics due to limited resources, increase in demand and factors like climate change; thus quantitative estimation and projection of sustainability pose significant scientific challenge. With respect to food sustainability, saturation and even decline of agricultural land along with growing consumption in many parts of the world can make surpluses unavailable for redistribution through trades. Thus agricultural self-sustainability, defined as the ratio of the total food producible to the total food demand of a people, is going to be increasingly relevant. However, a quantitative, dynamical framework for regional agricultural self-sustainability is often missing. We present an assessment of agricultural self-sustainability in terms of primary resources like arable land and water for India with its changing population and consumption for a case study. It is shown that India is at the threshold of losing sustainability in the primary resources, with extreme vulnerability to any adverse change in climate.

These results can provide important inputs for long-term policy planning in areas like food sustainability, water sustainability and export.

Goswami P and Shiv Narayan Nishad,
Current Science, 2014

F. Climate Observation and Modelling Network (COMoN)

2.11 Soil Moisture Analysis with COMoN Data

Accurate soil moisture data is critical for many applications like agriculture and estimate of ground water. However, reliable climatology of soil moisture is limited by the absence of high-frequency, multi-site observations, especially over India. A long term sustained soil moisture observation at four vertical levels (5cm, 15cm, 50cm and 100cm) is now available at several locations over India under a multi-institutional program Climate Observations and Modelling Network (COMoN) led by CSIR, India. At the same time, a high resolution (0.1°x0.1°) daily (moving 5-day mean) surface relative soil moisture data set has now become available from the Advanced Scatterometer (ASCAT). However, there is a need to compare remotely sensed data and in situ observations to ensure consistency and quantify uncertainties. This is particularly true for India characterized by diverse climatic zones. We present a comparative analysis of gridded ASCAT soil moisture data and in situ COMoN station data over six locations in India during the period 2010-2013. The comparisons are carried out at daily, weekly, monthly and seasonal time scales at each location. Analyses in terms of a number of statistical parameters show that the two data sets are generally consistent, although there are seasonalities in the agreement. In general, the correlation coefficient is higher for the wet season (summer, autumn), and moderate for dry season (winter, spring). Our results show consistency between the remotely sensed and in situ soil moisture in spite of the inherent differences in their methodology, resolution etc.; however, the results also show certain differences that introduce uncertainties in the climatology of soil moisture.

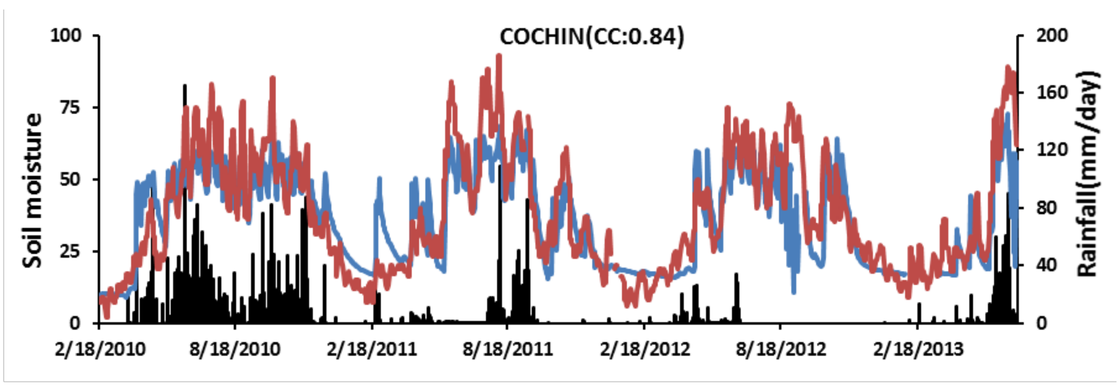

Figure 2.10 Daily time series plot of soil saturation from ASCAT and COMoN observations associated with concurrent rainfall episodes. The primary y-axis represents the soil saturation and secondary y-axis represents the Rainfall values.

Trends in soil moisture also provide important and quantitative measure of change in aridity; thus accurate spatial distributions of soil moisture are critical inputs for many applications. Our study provides the first quantitative multi-scale comparison of in situ and remotely measured soil moisture over India.

Bhimala K R and Goswami P

2.12 Validation of the Simulation of Heavy Rainfall Event over Delhi using WRF model and data assimilation system with CSIR COMoN observations

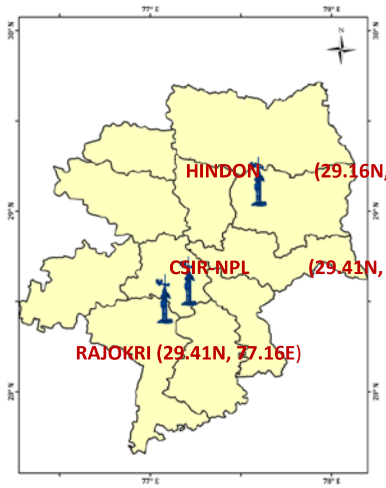

Figure 2.11 Location of 32-meter meteorological profilers under Mesoscale Observation Network for Urban System (MONUS) over the study area of Delhi.

Hourly data from three MONUS profilers were used for the comparison and analysis of simulations. In addition, horizontal wind and temperature from MONUS were also examined. Simulated rain (both control and test experiments) was compared with station and TRMM data.

Figure 2.12 shows the comparison of the time evolution of the simulated rain at each station with the observation (TRMM and COMoN data) and also the comparison of the time evolution of the simulated rain averaged over the three stations with the observation averaged over the same grid points or stations. Looking at each station it may be said that there was a high degree of rainfall variability (onset, intensity and duration) amongst the neighboring stations that are a few kilometers apart.

The simulated rain, despite some discrepancies, when compared to observations (with regards to time-lag, intensity and onset of the event) could have been useful in issuing an alert. Another important observation was that TRMM data showed excess rain before the event at all the stations that is not reflected in the observed rain (COMoN) at these stations. Thus our results indicate that satellite-based quantitative precipitation estimates might not be reliable during heavy rainfall events because of their limitations in resolution.

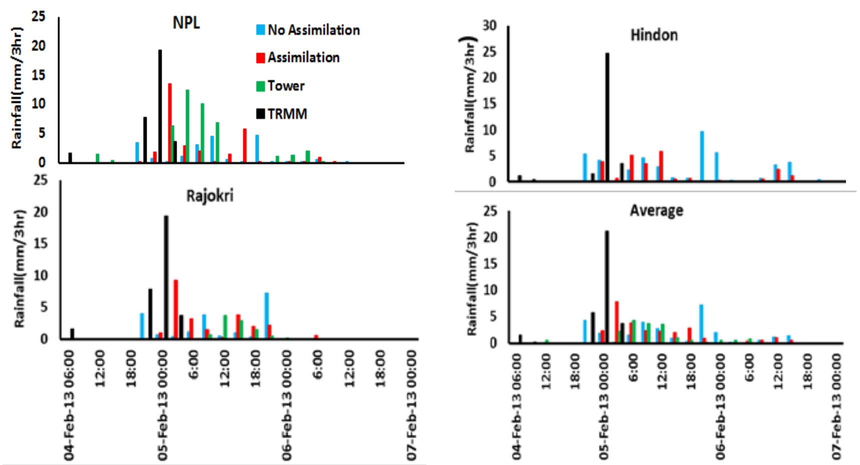

Figure 2.12 Comparison of the time evolution of simulated and observed (COMoN) rain in Delhi during the heavy rainfall event. The peak of the event was on 5th Feb 2013, 00.30 hour. Large variation in neighboring stations just few km away is evident from tower observation but is not reflected in TRMM data. It is also evident that assimilation improved the simulation in terms of intensity which is in phase with tower observation, except at Hindon.

These results are being used to calibrate and validate a disaster forecast platform over the National Capital Region.

Himesh S, Rakesh V, Ramesh K V, Mohapatra G N, Bimala K R, Gouda K C and Goswami