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MULTI-SCALE MODELING PROGRAMME

This is a data intensive paradigm which addresses multiscale problems ranging from weather and climate, century-scale climate projections, space-based geodesy, computational geodynamics, surface processes and climate aspects from surface to ionosphere. Development of system models and carrying out the simulations, formulation of algorithms for analysis of simulations and deriving inferences in the field of climate sciences, lithosphere-hydrosphere-atmosphere-ionosphere interactions and computational geodynamics, are the major foci of the group. In weather and climate studies, General Circulation Models (GCMs), coupled ocean-atmosphere climate model and earth system model with emphasis on processes such as multiscale organization of organized convection and aerosol-cloud-radiation feedbacks, are employed. Computational geodynamics and space-based geodesy research are on multi-scale earthquake dynamics, land-form evolution processes, multi-scale modelling of deformation processes and seismo-ionospheric coupling.

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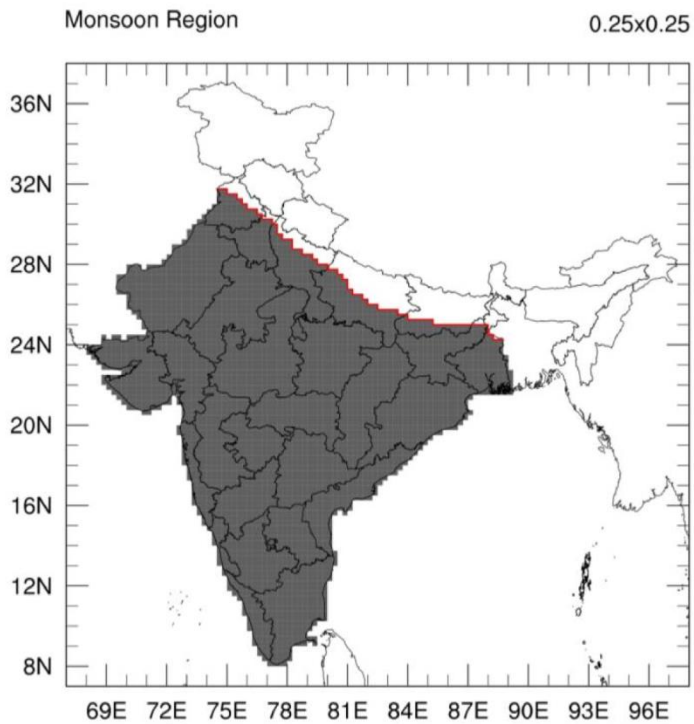
4.1 A new rain-based index for the Indian summer monsoon rainfall

Most of the studies of the observed variability of the Indian summer monsoon rainfall (ISMR), have involved analysis of an index for ISMR. In 2006 India Meteorological Department (IMD) derived a gridded rainfall data set at a resolution of 1^0 for the Indian region and subsequently in 2014, IMD has derived a finer resolution (0.25^0) rainfall data set for the same region. At present, these data sets are widely used by modelers to generate the 'observed' ISMR for assessment of the skill of their models. However, in different studies, different regions are used for averaging the grid data to obtain the 'observed' ISMR. For proper assessment and standardized comparison of the skill of the simulations/predictions by different models/versions, it is important that a standard region under the sway of Indian summer monsoon system be used for averaging the rainfall to obtain the observed ISMR.



We suggest what we consider as the appropriate regions for averaging the rainfall in terms of the 1° and 0.25° (Figure 4.1) to derive/represent ISMR, on the basis of the present understanding of the monsoonal regions and the Indian summer monsoon. We show that the interannual variation of the ISMR thus derived (by averaging rainfall over the regions identified in this study) from gridded data sets is largely consistent with the interannual variation of the indices used earlier studies.

Figure 4.1 Newly defined seasonal rainfall based Indian summer monsoon region for monsoon variability studies, at 0.25° resolution (shaded)

4.2 Future projections of Indian Summer Monsoon under multiple RCPs using a high resolution global climate model multiforcing ensemble simulations

Greenhouse gases (GHGs) act as an external factor that affects Indian summer monsoon climate. Different Representative Concentration Pathways (RCPs) introduced in the Inter-governmental Panel for Climate Change Assessment Report 5 (IPCC AR5) viz. RCP 2.6, 4.5, 6.0 and 8.5 based on the emissions of GHGs in the atmosphere. Present climate simulations (1983-2003) of the model with three deep convection schemes and three initial conditions are analysed to choose the best scheme for simulating the mean ISM rainfall (ISMR) and its variability. Multiforcing ensemble projections are carried out with the selected convection scheme, forced with four spatial patterns in future sea surface temperature (SST) changes under each scenarios. Further, multiforcing ensemble simulations of a global climate model at 60km horizontal resolution, under future (2079-2099) scenarios corresponding to RCP 2.6, 4.5, 6.0 and 8.5, are examined for ISM projections. Future changes in surface air temperature and rainfall show an overall increase over India (although with some spatial inhomogeneity for rainfall).

4.3 Aerosol-monsoon relationship on subseasonal timescales

Over India, low rainfall amounts during the droughts are found to be associated with high AOD as compared to decreased AOD in excess monsoon years. This is consistent with the understanding that increased wash out of aerosols occurs in wet regions, and aerosol life times are longer in dry regions. Given the rather short life time of aerosols, it is imperative to understand how the aerosols can possibly impact the prominent component of Indian summer monsoon (ISM) intraseasonal variability (ISV) by analyzing recent ground-based and satellite observations of aerosol and cloud properties, and India Meteorology Department (IMD) rainfall. Our analysis confirms the indirect effect of dust aerosols on intraseasonal time scales. These results are crucial and it is required to incorporate aerosol induced heating in models for proper simulation of ISV and thereby improved prediction of ISM.

4.4 Indian summer monsoon climate change projections: CSIR-4PI WRF RCM for dynamical downscaling versus CORDEX-SA RCMs

The high-resolution regional climate model (RCM) simulations are found to be an important to provide realistic climate change information at regional scale, which is useful for climate change impact assessments. We use the high-resolution dynamical downscaled simulations from CORDEX South Asia (SAS) domain to assess their skill in reproducing present-day mean and extremes of Indian summer monsoon (ISM). Although a few CORDEX RCM simulations exhibit improved regional characteristics of mean ISM, many fail to outperform their parent CMIP5 GCM and could be due to the low skill of the parent GCM. The climate change projection of mean ISM rainfall at the end of 21^{st} century is estimated using RCP8.5 scenario simulations of CORDEX RCMs. Along with consistent surface temperature increase, the models project a future increase in ISM rainfall with large inter-model spread, which is similar to that seen CMIP5 models. The CORDEX RCMs are of the order of 50 km resolution, which still is not sufficient to resolve the small-scale features especially at highly complex orographic areas such as Western Ghats (WG) over the southern peninsular India.

4.5 Forecast of monsoon-2018 using CFSv2

Indian summer monsoon (ISM) forecasting has always been associated with sensitivity to initial conditions pertaining to the capricious behavior of climate system. This can be regarded as a classic example of prediction problem as first pointed out by E N Lorenz. Given the fact that high resolution can take care of sub-grid scale processes which include the cloud and convection genesis within a climate model, it is imperative to look into the prediction with the right choice of initial condition as well. At CSIR-4PI, we took into account these factors and did an experimental forecast for the summer monsoon season of 2018 using the available computing facility at CSIR-4PI. A total of 14 initial conditions were derived and forecasts were carried out at a resolution which corresponds to a grid resolution of approximately 40km. A prediction is useful if it has sufficient lead time in predicting the monsoon season and so we took May initial conditions. Figure 4.2 shows the ensemble mean of 14 runs, June to September (summer monsoon) predicted rainfall (top panel) and the seasonal mean departure of monsoon rainfall (bottom panel). Forecast indicates below normal monsoon.

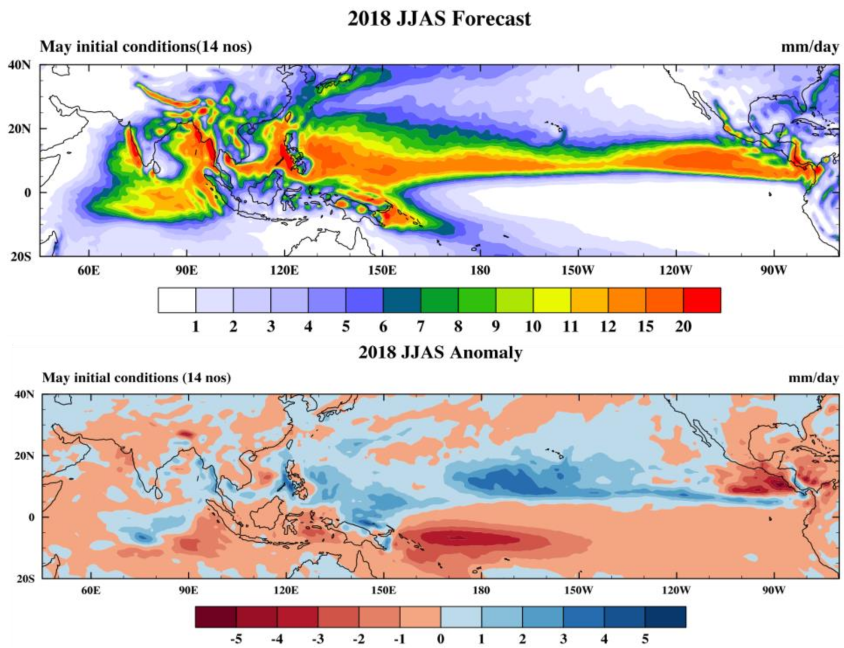


Figure 4.2 June to September mean (JJAS, summer monsoon) rainfall (top panel) and the seasonal (JJAS) mean departure of rainfall (bottom panel) for 2018, as predicted by the ensemble mean of runs with 14 May initial conditions

4.6 Global spread of ionospheric irregularities during the 17th March 2015 the St. Patrick's day geomagnetic storm

The St. Patricks day geomagnetic storm was triggered by an Earth directed Interplanetary Coronal Mass Ejection (ICME) associated with c9.1 class solar flare erupted from the active region of the Sun (AR 2297 at S22W29) on 11/03/2015 between 00:45 UT and 02:00 UT. This was the first geomagnetic storm of the 24th Solar cycle which reached a level of G4 on the NOAA scale (severe).

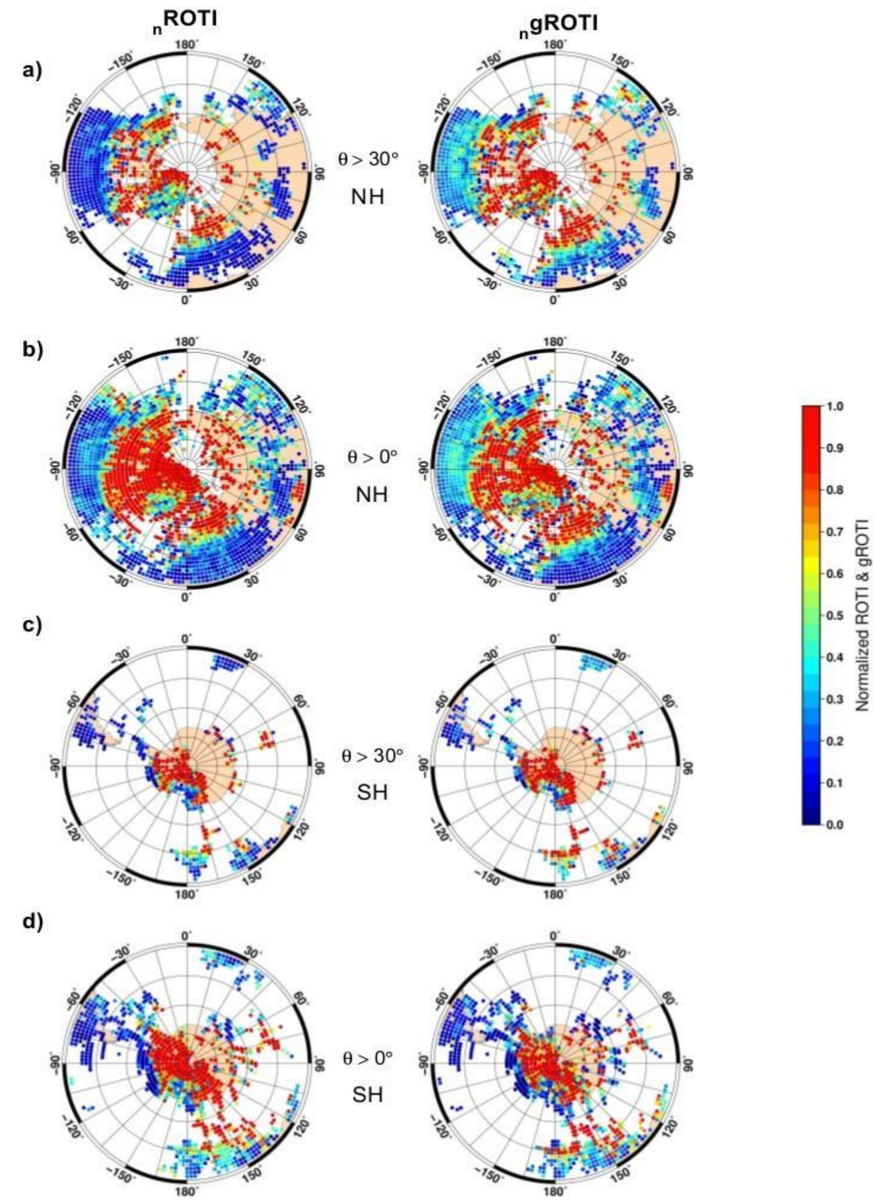


Figure 4.3 The variation of normalized value of ROT and gROT in the northern and southern hemisphere for a latitude range of 30° - 90° gridded with 1°x1° at 17-18hr of St. Patrick's day storm

The impact of the ionospheric irregularities caused by the St. Patrick’s day storm was studied using dual frequency microwave soundings at ~13.7 million Ionospheric Pierce Points (IPP), which are intersections of GPS signals observed by 2,365 ground based dual frequency GPS receivers spread across the globe as part of IGS, CORS, and Australian networks during the St. Patrick’s storm. De-aliased ROTI (Rate of TEC Index) maps were prepared using the gradient Rate of change of TEC (gROT) and conventional ROT (Rate change of TEC). The comparison of ROTI and gROTI shows that de-aliased ROTI maps can be used to increase the area of coverage by >60% by including observations from all elevations without altering the signal. The de-aliased gROT map (Figure 4.3) with 1 degree x 1 degree resolution during 17-18 UTC on St' Patrick's day, the 17th March 2015, shows the strong ionospheric irregularities in both southern and northern hemisphere. The irregularities were intense at 17-18 UTC and it spread beyond the mid-latitude.

4.7 Establishing multi-scale modeling frame work for LAIC studies: Ionospheric General Circulation Model

The TIEGCM (Thermosphere Ionosphere Electrodynamics General Circulation Model) developed by High Altitude Observatory at the National Center for Atmospheric Research, USA was installed at CSIR-4PI MSMP computing platform as part of the Multi-scale modelling frame work for LAIC (Lithosphere-Atmosphere-Ionosphere Coupling) studies. TIEGCM is a three dimensional, time-dependent numerical simulation model of the Earth's upper atmosphere, including the upper Stratosphere, Mesosphere, Thermosphere and Ionosphere. This also includes a self-consistent aeronomic scheme for the coupled Thermosphere/Ionosphere system. The performance of the model was assessed by carrying out standard tests and benchmarking. The global ionospheric Total Electron Content (TEC) on 21st March 2012 simulated using TIEGCM with a spatial resolution of 0.25x0.25 degrees is given in Figure 2. The Equatorial Ionization Anomaly spread over the Indian region is well captured by the TIEGCM simulation (Figure 4.4). This newly established computing facility will enhance the capability to study the ionospheric coupling processes in detail.

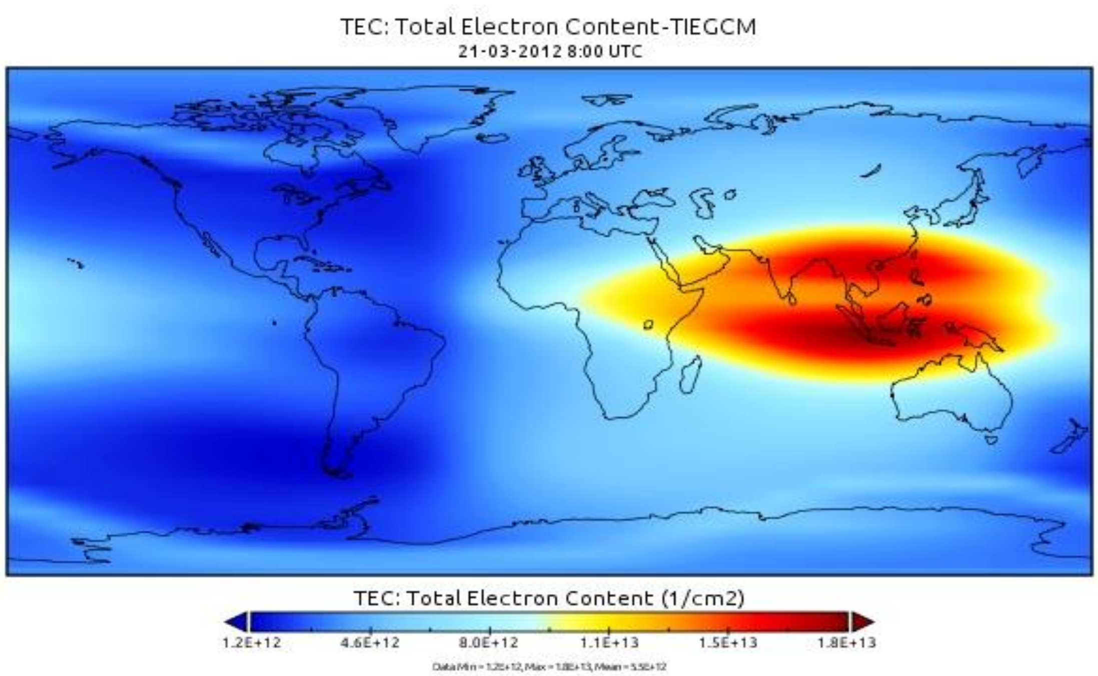


Figure 4.4 Total Electron Content on 21st March 2012 at 8 UTC simulated by TIEGCM

4.8 Noise characteristics of GPS time series and their influence on velocity uncertainties

Accurate geodetic crustal deformation estimates with realistic uncertainties are essential to constrain geophysical models. A selection of appropriate noise model in geodetic data processing based on the characteristics of the geodetic time series being studied is the key to achieving realistic uncertainties. The noise characteristics of a 12-yr long global positioning system (GPS) geodetic time series (2002–2013) obtained from 22 continuous mode GPS stations situated in north-east India, Nepal and Bhutan Himalayas, which are one of the most complex tectonic regimes influenced by the largest hydrological loading and impacted with a load of the largest inland glaciers, were studied. A comparison of the maximum log likelihood estimates of three different noise models – (i) white plus power law (WPL), (ii) white plus flicker law (WFL) and (iii) white plus random walk noise – adopted to process the GPS time series reveals that among the three models, ~74% of the time series can be better described either by WPL or WFL model. The results further showed that the horizontals in Nepal Himalayas and verticals in north-east India are highly correlated with time. The impact analysis of noise models on velocity estimation (Figure 4.5) shows that the conventional way of assuming time uncorrelated noise models (white noise) for constraining the crustal deformation of this region severely underestimates rate uncertainty up to 14 times. Such simplistic assumption, being adopted in many geodetic crustal deformation studies, will completely mislead the geophysical interpretations and has the potential danger of identifying any inter/intra-plate tectonic quiescence as active tectonic deformation. Furthermore, the analysis on the effect of the time span of observations on velocity uncertainties suggests 3 years of continuous observations as a minimum requirement to estimate the horizontal velocities with realistic uncertainties for constraining the tectonics of this region.

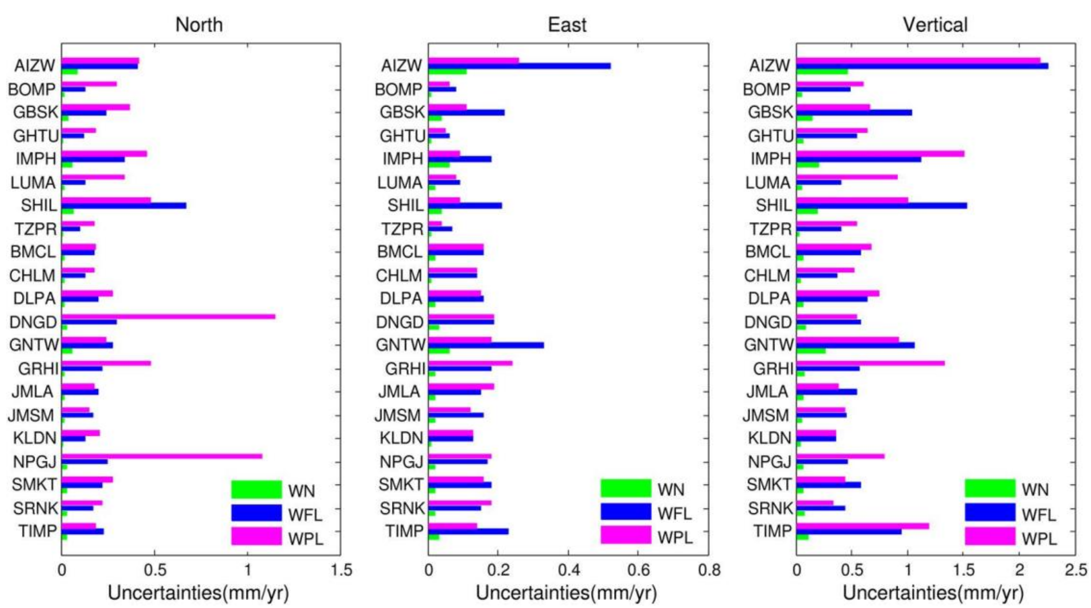


Figure 4.5 Velocity uncertainties obtained when adopting WN (white noise), WFL and WPL noise models

4.9 A reappraisal on the present-day stress field of the Indo-Burmese ranges: seismo-tectonic insights from faulting mechanisms

Contentious arguments are present in the available literature on the Indo-Burmese arc tectonics, which places the subduction there as relict, ceased, a seismically creeping or even fully locked. This leaves large uncertainties on the associated seismic hazard. Through this work, we re-examine the state of stress-field using available faulting mechanism data from this region. These data mostly represent the slab deformation of the sinking Indian lithosphere and the slip partitioning along the Sagaing fault. Our results show that the shallower slab features NNE compression, concurrent with the Indian plate convergent direction. Whereas, an EW active subduction can be observed at the southern segments. Over all, our results favour a weakly coupled active subduction, which could be capable of generating segmented plate boundary ruptures.