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MULTI-SCALE MODELING PROGRAMME

Multi-scale modeling program is centered around the data intensive paradigm where numerics and computing strategies relevant for different scales in a dynamical system are combined to arrive at an effective computational solution than the one obtained from the strategy dealing with the most relevant single scale. An ultra-high resolution weather and climate model framework was developed to address multi-scale processes of the atmosphere and analyze the data from observations and these simulations to effectively arrive at inferences. General Circulation Models (GCMs), coupled ocean-atmosphere climate model and earth system model with emphasis on processes such as multiscale organization of deep convection and aerosol-cloud-radiation feedbacks, were employed. Research foci also included multi-scale earthquake dynamics, land-form evolution processes, multi-scale modelling of deformation processes and seismo-ionospheric coupling.

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4.1 Aerosol-climate interaction and Indian Summer Monsoon

Indian Summer Monsoon undergoes vigorous intra-seasonal oscillations (ISOs) in the form of active and break spells, which is essentially the demonstration of similar periodicity of the cloud organization, northward propagation and dissipation. Aerosols can influence monsoons on multiple timescales. During active and break periods, the circulation and precipitation pattern have high variability. The active-weak spells in rainfall area associated with fluctuations in the intensity of the continental tropical convergence zone. Prolonged active and break conditions in monsoon lead to strong and weak monsoon. One of the important components that modulate the variability of ISOs is aerosols, which are tiny solid or liquid particle suspended in the atmosphere. We have analyzed the relationship of aerosols and rainfall for the period 2000-2014. Aerosol-monsoon relationship is highly complex due to the combined effects of microphysical and dynamical impacts of both regional and remote aerosol radiative forcing connected with meteorological forcing.

This study investigates the influence of aerosols on the Indian summer monsoon and characterizes their difference in drought and excess summer monsoon years using satellite data sets. Aerosols and clouds interact strongly in microphysical processes and this interaction depends on meteorological conditions. Data from the MODIS instrument for aerosols and cloud parameters are used. To understand the interaction of aerosol on Indian monsoon, we carried out detailed analysis of variation of atmospheric aerosols. During drought years AOD is found to be higher over Indian region compared to excess monsoon years. The total effect of aerosols causes reduction of summer rainfall but with distinct differences in their impact during strong and weak summer monsoon years. In order to uncover the role of aerosols, further investigation is being done to explain the mechanism of how aerosols modulate the rainfall during the monsoon time over Indian region.

4.2 Aerosols impact on monsoon in an Earth System Model

Atmospheric aerosols can cause significant alteration in the energy balance of the atmosphere and the earth surface by scattering and absorbing the incoming solar radiation (direct effect), and strongly influence the processes of formation of clouds and precipitation (indirect effect).

There are two types of indirect effect: 1) First indirect effect or Twomey effect, 2) Second indirect effect or Albrecht effect. In first indirect effect refers an increase in aerosol concentration can increase the reflectivity of the shallow clouds due to increase in cloud condensation nuclei (CCN); whereas the total liquid water path is constant. In second indirect effect due to increase in CCN the droplet number concentration increases and the effective radius decreases. These effects can increase total liquid water path by reducing the drizzle production.

We have ported and installed an Earth System Model in CSIR supercomputer ANANTA at CSIR-4PI, Bangalore. After successful testing and validation of model, we integrated model for 20 years with active atmosphere, ocean, land, river, sea-ice, land-ice components, which are coupled. The atmosphere component uses an active aerosol module. From the primary analysis of simulated output, the model's ability to capture features of monsoon was found to be appreciable. Further model experiments are progressing and a detailed analysis of the simulations is to be done next.

4.3 Teleconnection of rainfall between India and north-west Pacific

This study is on the dominant factors contributing to variability of monsoon rainfall. A high resolution Atmospheric General Circulation Model (AGCM) forced with observed Sea Surface Temperature (SST), with marked skill compared to IPCC AR5 models, in simulating important features of Asian summer monsoon all-India rainfall (AIR) and all essential aspects of teleconnection with the north-west Pacific, is employed to investigate the mechanism responsible for rainfall variability. Variability of AIR is found to have the strongest link with the variation of rainfall over the northern parts of the West Pacific Ocean (NWTP), with deficits (excess) over India associated with enhancement (suppression) of rainfall over NWTP. This relationship is maintained through the meridional meandering of subtropical westerly jet (SWJ) stream. Consistently, in years with large excess/deficit in June rainfall, the strong link between all-India rainfall in June with convection over NWTP through meandering of SWJ is clearly manifested in the simulation by a high resolution global model.

4.4 Local convection and its relationship to sea surface temperature over warm tropical oceans

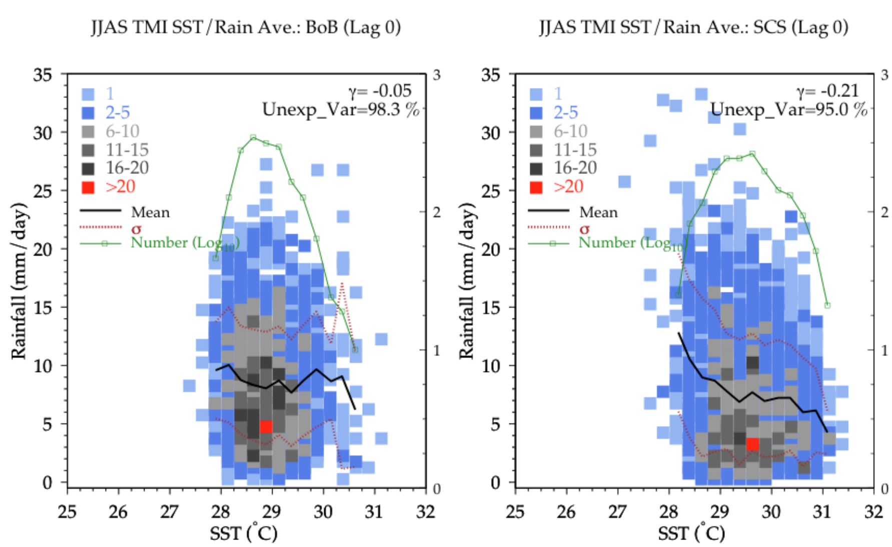

Figure 4.1 Observed relationship between rainfall and SST for June, July, August, September during 1979–2009 for the Bay of Bengal (BoB, left panel) and the South China Sea (SCS, right panel). The number of points, mean and standard deviation for each0.25°C SST and 0.5 mm/day rainfall bin are also shown along with the correlation (ϒ) and unexplained variance

Local SST control on precipitation during monsoon is important for deducing climate change due to global warming for warm oceans. Studies of the relationship of the precipitation over tropical oceans with local sea surface temperature (SST), on the monthly scale, have shown that the propensity for precipitation is high for SST above a threshold of 27.5°C/28°C. However, for warm oceans with SST above the threshold such as the Bay of Bengal (BoB) and South China Sea (SCS), for each SST, there is a large variation of precipitation and the SST-precipitation relationship is weak. When SST is above the threshold, the curve depicting (Figure 4.1) the variation of mean precipitation with SST explains only a small fraction of precipitation variance and hence cannot be considered to be representative of the SST-precipitation relationship, or used to deduce the impact of SST on precipitation. On the other hand, the local control on precipitation is predominantly atmospheric dynamics with the relationship of variation of precipitation to low-level convergence on all timescales, being strong. This suggests that for warm oceans, the limiting resource for precipitation/convection is not SST but dynamics.

4.5 Nested high-resolution dynamical downscaling climate model and regional climate projection

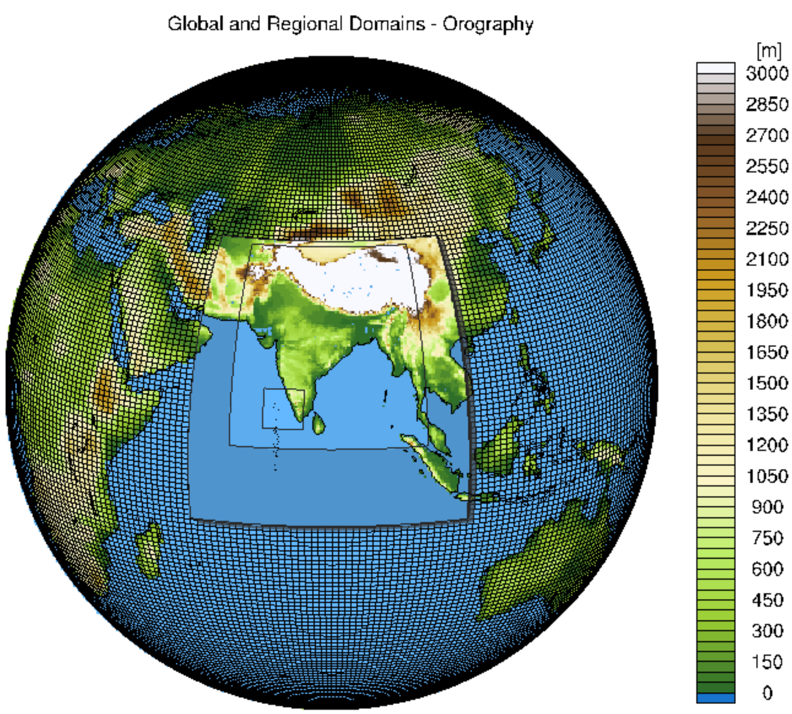

Figure 4.2 Surface orography (shades) representation in the developed dynamical downscaling framework. 3 domains of the RCM (rectangular boxes) are nested in the Global GCM

A nested high-resolution dynamical downscaling climate model is implemented to downscale a coarse resolution general circulation model (GCM) simulations (Figure 4.2). This Global model-regional model nested framework is used to study the projected future changes of Indian summer monsoon (ISM) with special focus over ecologically sensitive, densely populated west coast of India having Western Ghats (WG) Mountains. The performance of high resolution regional climate model (RCM) during present-day period is analyzed, and found that it could realistically simulate the physical and dynamical characteristics of present-day ISM and extreme events, especially the recent trends in ISM rainfall over WG as observed.

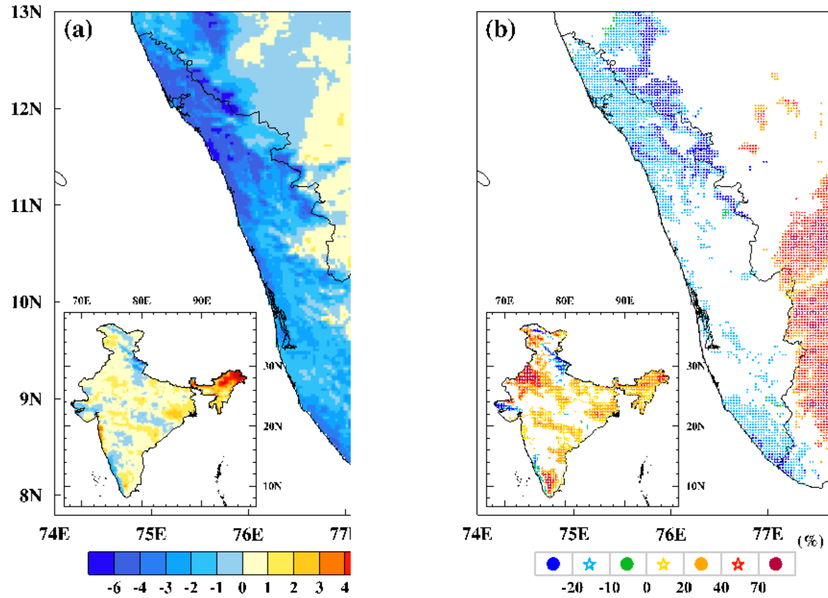

Figure 4.3 a) Projected change in ISMR over WG (WRF CCSM4 FD minus WRF CCSM4 PD) from the innermost domain of the dynamical downscaling model with 3 km resolution. In inset: the same but for all India from the middle domain with 27 km resolution. b) Same as a) but for significant changes in mean summer monsoon rainfall with respect to the climatological JJAS mean rainfall from WRF CCSM4 PD (in percentage)

For obtaining the more realistic boundary conditions, we have selected one of the IPCC AR5 models, that model is reasonably well comparable with the observation in almost all the present day physical as well as dynamical features. Studies have shown that, the high-resolution RCM performs very well given the large-scale forcing by the imposed boundary fields. We prepared historical (for present-day) data as well as the RCP8.5 (for future) data and made ready as the input of the RCM. We have done the longer simulations only after an intensive sensitivity simulations and analysis to obtain the suitable configuration for our RCM to give good simulation of monsoon over the Indian region.

We have analyzed the longer period simulation of RCM to understand the model capability in simulating the present-day climate, which reveals that it is capable of capturing numerous regional details. It has been shown that our RCM can be effectively used to extract very useful high-resolution climate change projection information for summer monsoon over India (Figure 4.3). This skill of the model provides greater confidence in its projection of future climate at regional scale. It is found that, in future, the summer monsoon rainfall over India projects significant increase (reduction) over 50.7% (5.8%) of total grid-points. Also, model projects significant rainfall reduction (10-20% of mean) over WG. The causative mechanism of future WG rainfall reduction is upper-tropospheric warming effect, which stabilizes the atmosphere. Consistent with this, the projected changes in rainfall extremes show widespread increase in very wet days over most of India and reduction over WG.

4.6 Effect of moisture supply from Western Ghats forests on the east coast of India

The mountainous western coast of India, the Western Ghats, is considered to be a biodiversity hot spot, but it is under a constant threat due to human activities. The region is characterized by high orographic monsoon precipitation resulting in dense vegetation cover. Feedback of such a dense vegetation on the southwest monsoon rainfall is not yet explored. Here we perform regional climate simulations with the Weather Research and Forecasting model and find that evapotranspiration from the vegetation of Western Ghats contributes 25–40% of the southwest monsoon rainfall over the water-deficit state of Tamil Nadu. This contribution reaches 50% during deficit monsoon years or dry spells within a season. The recent deforestation in this area will affect not only the biodiversity of the region but also the water availability over Peninsular India, which is already impacted by water scarcity.

Forests over the Western Ghats (WG) region at the west coast of India are suffering from severe deforestation. We find that the vegetation over the WG region contributes moisture to the precipitation of the water-deficit state of Tamil Nadu and it reaches as high as 40% in many of the regions. Tamil Nadu is at present is under severe water crisis due to interstate water sharing and related controversies. We emphasize the urgent need of enforcing strict laws to stop the deforestation of WG not only to retain bio-diversity but also to maintain the water cycle over these semiarid parts of Peninsular India.

4.7 Forecast of summer monsoon-2018 using CFSv2

The Indian Summer Monsoon (ISM) occurring between June to September refers to the summer monsoon that brings bountiful rain to the subcontinent that determines the overall economy of the country. The spatial and temporal progress of monsoon over the subcontinent is important for agricultural planning, food production, hydroelectric power generation and lives of the billions of people of the country. ISM is associated with variability and therefore a good prediction is inevitable for proper management of resources.

Prediction of ISM 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 was described by Edward N Lorenz. Given the fact that high resolution can take care of sub-grid scale processes that include the cloud and convection genesis within a climate model, it is imperative to look into the prediction with high resolution and with the right choice of initial condition. We make use of the NCEP Climate Forecast System Version 2 (CFSv2) general circulation model to look into the overall skill of the model in predicting the monsoon of this year and factors that may affect the monsoon locally and remotely. The initial conditions were derived and forecasts were done using a total of 14 initial conditions in May. The runs were carried out at a resolution, which corresponds to a horizontal grid of approximately 100km. The ensemble mean prediction was for a deficit monsoon for most of India except for south and parts of southeast India (Figure 4.4). Observed all-India deficit was 9.4% and model predicted deficit was 3%. But, the model correctly predicted the excess over the southern peninsular India.

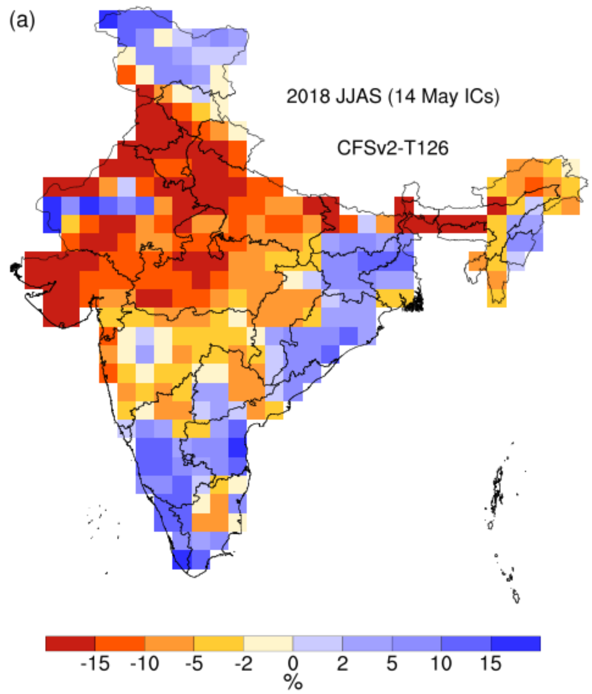

Figure 4.4 CFSv2 predicted rainfall anomaly (change in rainfall with respect to the long-term mean monsoon rainfall in percentage) during the summer monsoon season of 2018. Blue (red) shades denote excess (deficit) rainfall

This ensemble of forecast runs allows us to look into the evolution of various local and remote factors that are responsible for determining the ISM. Individual month's analysis shows a positive rainfall anomaly for the month of June whereas slightly negative anomaly for the months July, August and September. Our analysis shows a neutral El Nino and neutral Indian Ocean Dipole (IOD) during the initial phase of the monsoon season. A slight positive El Nino phase is seen in the end of the year in the 9-month forecast. A prediction is useful if it has maximum lead time in predicting the monsoon season and so our attempt is to look for the best possible prediction with maximum lead time. Further analyses are being carried out to see the intrinsic characteristics of 2018 monsoon.

4.8 A simple algorithm to remove artifacts and aliasing from the ionospheric irregularities

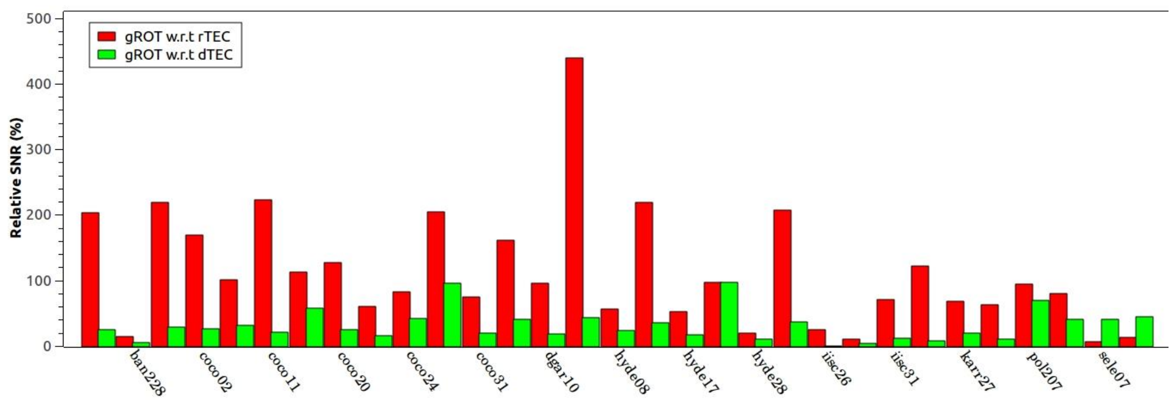

Figure 4.5 Signal to Noise Ratio (SNR) of ionospheric disturbances obtained after the removal of aliasing and artefacts using the new algorithm (gROT) relative to the conventional methods (rTEC& dTEC)

The Total Electron Content (TEC) measurements using an increasing number of GPS ground stations fill the void of conventional ionospheric TEC measurements in both space and time with an unprecedented detail. GPS-TEC measurements are being increasingly used to map the ionospheric irregularities caused by various factors ranging from Space weather (solar, geomagnetic, etc.) to natural hazards (earthquakes, tsunami, thunderstorms, etc.). Monitoring the ionospheric irregularities is essential, on one hand, to assess its impact on the performance of the GPS system and, on the other hand, it provides a plethora of opportunities to study the corresponding causative phenomena in detail. There are three different methods being popularly used to estimate the ionospheric irregularities by the ionospheric researchers. 1. Rate of TEC Index (ROTI) derived from Rate of TEC (ROT) which is popularly used to monitor global distribution of ionospheric irregularities in studies related to space weather. 2. Horizontal TEC gradient derived either by numerically differentiating the Line-of-Sight (LOS) TEC between the cadence of observation (dTEC) or 3. Detrended LOS-TEC considering the higher order polynomial fit as a regular characteristic TEC variation are used to detect the Travelling Ionospheric Disturbances (TID) induced by the tsunami, earthquakes, tropospheric convections, etc. Fixing the order of the higher order polynomial is arbitrary in third method and hence the order varies from case to case. However, the ionospheric irregularities derived using all these three methods are contaminated by signal aliasing and artifacts introduced by the non-linear motion of the Ionospheric Pierce Points (IPP) which eventually picks up sharp static spatial variations as signals. This signal aliasing corrupts both frequency and amplitude of the ionospheric irregularities that eventually limits the certainty of irregularities detected using GPS-TEC. In order to remove such signal aliasing and artifacts a simple algorithm is developed. Adopting the algorithm to derive the ionospheric irregularities in three cases caused by (i) a tsunami (ii) an earthquake and (iii) a space weather event showed that it not only removes successfully the signal aliasing cum artifacts from the ionospheric irregularities and also improves the signal-to-noise ratio (Figure 4.5).

4.9 Influence of source geometry in determining the characteristics of tsunami-induced Travelling Ionospheric Disturbances

Acoustic-Gravity Waves (AGW) generated by tsunamis propagating in the open ocean perturbs the ionosphere and generates Traveling Ionospheric Disturbances (TID). Recent investigations show that continuous monitoring of tsunamigenic TID can be used as a tsunami early warning system provided such TID are properly characterized in order to differentiate it from the TID of other origins. The characteristics of tsunamigenic TID are primarily derived with a point source approximation and thus assuming the wavefronts of the tsunamis are circular. However, in reality, the wavefronts of the tsunamis generated by the submarine earthquakes mimic the shape of the rupturing faults. Hence, such simple approximations while studying the tsunamis generated by rupture of the fault with a length of 1200-1300 km in the case of 26th December 2004 Sumatra-Andaman tsunami and 500 km in the case of 11th March 2011 Tohoku tsunami will severely undermine the characteristics of the resultant TID. The characteristics of TIDs induced by the 26th December 2004 Sumatra-Andaman tsunami were considering the elliptical wavefront mimicking the entire fault geometry. Results show that the magnitude of horizontal velocities of TID increase from 3.5% to 65% with respect to the direction of propagation of the tsunami when the actual geometry is considered in place of simple point source assumption. This establishes the significance of considering the actual geometry of the fault rupture while deriving the TID characteristics.

4.10 Multi-scale simulation framework for earthquake physics studies: Seismic-cycles at plate-boundary zones

We tested the accuracy and performance of a multi-scale simulation framework for earthquake physics using the CSIR ANANTA cluster through a rigorous benchmarking process. This 3D numerical code is a portable, scalable software for simulation of crustal deformation involving spatial scales ranging from meters to hundreds of kilometres and temporal scales ranging from milliseconds to thousands of years. We tested these codes for quasi-static crustal deformation and evaluated the relative performance of different types of basic functions, numerical integration schemes, and model discretization for multi-scale crustal deformation modelling applications. In addition, we evaluated the efficiency and scaling of the numerical codes. These benchmarks were good test problems, in which we performed simulations comparable to actual seismo-tectonic settings. These benchmarks were performed at various resolutions using different element types.

By comparing the runtime and efficiency for different resolutions and element types, we evaluated the combination which will be the best representative of the tectonic problems of our interest. We considered a quasi-static interseismic and coseismic deformation in 2D for a subduction zone benchmark problem which computes the coseismic relaxation of stresses based on the 2011 M9.0 Tohoku earthquake, off the east coast of Japan. We modelled the earthquake rupture involving coseismic slip along the interface between the subducting slab and the continental crust and uppermost portion of the mantle below the continental crust. We used standard analytical solutions to apply the boundary conditions and to compare against the numerically-computed elastic solution.

4.11 Energy release of selected Sumatra-Andaman earthquakes

Outer-rise earthquakes occur as a consequence of bending of thin elastic subducting lithosphere down in to a trench at a plate boundary zone. Dynamic stress perturbations due to giant plate boundary ruptures can trigger these types of earthquakes. We analyzed the outer arc deformational constraints of the Andaman Nicobar arc and computed the energy budget of some of the selected outer-rise earthquakes so as to understand the source process characteristics. This study shows that the outer-rise earthquakes of Andaman Nicobar region do have higher fracture energy release, an indication that the seismogenesis is associated with newer fault formation than failure on existing planes.