language will require modifications in the code of the self-hosting compiler. Another requirement is that the source language should be suitable and advanced enough for writing the compiler[2]. Bootstrapping may distort the design of a programing language that is not otherwise meant to implement compilers or similar programs. Additionally, the bootstrapping approach requires much time and effort, and is hence prescribed only for computer architectures which will be used for software development.

Alternatively, the cross-compilation approach requires less time and effort. An existing compiler can be retargeted to the new computer architecture by modifying its back-end. It is particularly suitable if the new computer architecture is a smartphone, an embedded device or any other battery-powered programable device. Such devices typically have severe processing, memory and power constraints. Using the cross-compilation approach, software for the device can be developed on another computer architecture and copied onto the device. This leads to a lifelong dependence of the device on the other computer architecture. However, it is not a major issue as such devices are not used for software development. A cross-compiler running on a personal computer and generating target code for a battery-powered programable device can employ a large range of code optimization techniques, while a native compiler running on such a device may at most afford to perform peephole optimization because of its various constraints.

It is interesting to note that the final compilers in both the approaches can be represented as $\mathrm{C}_{\mathrm{HLL}}^{\mathrm{HLL\ N.ML}}$ when in their source forms. However, in their executable forms, they become $\mathrm{C}_{\mathrm{N.ML}}^{\mathrm{HLL\ N.ML}}$ in the bootstrapping approach (Figure 1) and $\mathrm{C}_{\mathrm{M.ML}}^{\mathrm{HLL\ N.ML}}$ in the cross-compilation approach (Figure 2).

Although the concepts of bootstrapping and cross-compilation have been known for a long time, they are still in use. Efficient use of these concepts is often helpful in programing language design and compiler construction.

1. Bratman, H., *Commun. ACM*, 1961, **4**, 142.
2. Lecarme, O. and Peyrolle-Thomas, M.-C., *Software: Pract. Experience*, 1978, **8**, 149–170.

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TWINKLE GUPTA
SANYA YADAV
PINAKI CHAKRABORTY*

Division of Computer Engineering,
Netaji Subhas Institute of Technology,
New Delhi 110 078, India
**For correspondence.*
e-mail: pinaki_chakraborty_163@yahoo.com

Prominent precursory signatures observed in soil and water radon data at multi-parametric geophysical observatory, Ghuttu for M_w 7.8 Nepal earthquake

A devastating earthquake (*M* 7.8) occurred in the central part of the Nepal Himalaya on 25 April 2015 at 06:11:26.27 (UTC). USGS reported the epicentre location at 28.147°N and 84.708°E, and focal depth 15 km. The earthquake strongly hit Nepal causing over 7500 deaths and widespread destruction. A historical temple of 19th century was reduced to ruins within a few seconds. More than 55 causalities were reported in the adjoining parts of India, mainly to the south and east of Nepal. The earthquake was followed by 65 aftershocks within a period of three days after the main event. Among these the strongest aftershocks, i.e. *M* 6.7 occurred on 26 April at 07:09:08 (UTC) and *M* 6.6 occurred on 25 April at 06:45:20 (UTC). The moment tensor solution of the main shock suggests thrust fault mechanism with strike 293° and dip 7° (USGS GCMT solution). It caused unilateral rupture of $100 \times 80\ \mathrm{km}^2$ towards east and south from the hypocentre and a maximum slip of 5 m. The dislocation mainly occurred on the Main Himalayan Thrust (MHT), which is a low-angle northerly-dipping boundary between the Indian and Eurasian tectonic plates.

In this communication, we report observation of anomalous radon gas emission measured in a borehole at India's first multi-parametric geophysical observatory (MPGO) located at Ghuttu, Garhwal Himalaya, established by the Wadia Institute of Himalayan Geology (WIHG), Dehradun. MPGO is located in the central part of the seismic gap between the epicentre of the 1905 Kangra earthquake (*M* 7.8) and 1934 Bihar–Nepal earthquake (*M* 8.2) immediately to the south of the Main Central Thrust (MCT) within the High Himalayan Seismic Belt (HHSB). The recent Nepal earthquake occurred 636 km to the east of MPGO (Figure 1). The spatial extent of the so-called seismic gap is slightly reduced towards the west due to occurrence of the recent *M* 7.8 earthquake. The observatory is equipped with simultaneously operated multiple geophysical equipments that can measure radon, magnetic, gravity, seismic, GPS and water level data. The facility also has rain gauge, temperature (atmospheric and underground) and atmospheric pressure observations[1].

The linkage of radon emanation variation with earthquake mechanism reported in many previous studies has prompted the inclusion of radon variation as one of the parameters at MPGO, Ghuttu for earthquake precursory research. Radon is the disintegration product of radioactive uranium and thorium, which was observed for the first time as an earthquake precursor during the great Tashkent earthquake of 1966 (ref. 2). The radon emanation is likely to vary in the crust during earthquake preparation and occurrence period based on the well-accepted dilatancy–diffusion model of earthquake generation mechanism[3]. The model holds some promise for short-term earthquake prediction using radon measurement[4]. However, nonlinear dynamic behaviour

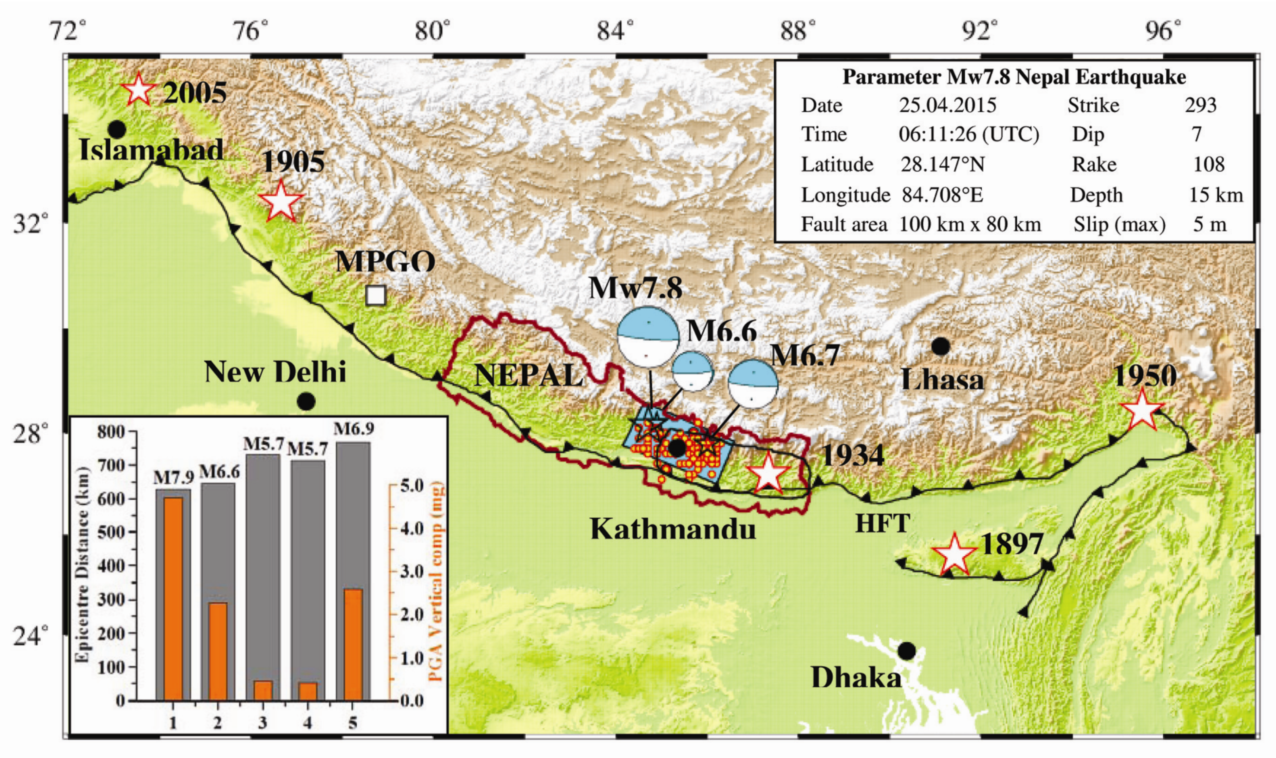

Figure 1. Epicentre locations of M_w 7.8 earthquake and aftershocks, focal mechanisms (main shock and two aftershocks), rupture zone (cyan rectangle), and rupture zone of M 8.2 Bihar–Nepal earthquake of 1934 (black ellipsoid). The multi-parametric geophysical observatory (MPGO), Ghuttu (white rectangle) is situated 636 km west of the Nepal earthquake. (Inset; bottom left) Epicentre distance and Peak Ground Acceleration (PGA) records at MPGO Ghuttu for the main shock (M_w 7.8), first three aftershocks recorded on 25 April, and aftershock with M_w 6.9 recorded on 26 April. (Inset; Top right) Hypocentral parameters and source parameters of the main shock (source: USGS).

of underlying rocks, in addition to geotectonic complexities in the crust, may induce different characteristics that need to be considered in theoretical models. The radon monitoring site of MPGO, Ghuttu is distinctive, as it is located over the Himalayan tectonic fault zones (MCT and MHT), where high seismic activity causes geo-tectonic changes in these fault zones. The main shock of the Nepal earthquake and large aftershocks ($M > 6.0$) occurred on MHT by thrust movement (Figure 1), which have caused permanent displacement of two adjacent sizeable blocks in the hypocentre zone, causing permanent changes.

The radon measurement at MPGO was carried out continuously and automatically every 15 min in the soil and underground water. Study of radon observations since 2007, has shown some anomalous behaviour prior to the occurrence of a few nearby moderate-sized earthquakes[1,5]. However, anomalous changes were negligible and sometimes the data were influenced by environmental and hydrological effects. The M 7.8 Nepal earthquake is one of the biggest earthquakes of the Himalayan region recorded since the installation of MPGO. A careful scrutiny of radon data during April 2015 (Figure 2) as well as other datasets revealed prominent anomalous changes associated with M_w 7.8 Nepal earthquake. Figure 2 shows temporal variation of soil radon, underground water radon, rainfall and water level during April 2015. The soil radon concentration (brown solid line in Figure 2), measured at 10 m depth in a borehole through gamma probe clearly indicated that it had negligible variation during the period 1–15 April 2015. On April 16 at 06:45 (UTC), about ten days before the occurrence of the Nepal earthquake, radon concentration suddenly started increasing, showing an increasing trend up to 28 April. However, the increase in concentration had a sharp enhancement on two occasions. From 16 to 18 April, the concentration suddenly changed with ~7.5% sharp enhancement. This change was followed with a slight decrease up to 20 April and then again an abrupt increase up to 22 April. Then, there was a gradual enhancement during pre-, co- and post-seismic periods till 28 April. Unfortunately, on 28 April the radon probe malfunctioned and thus there is a gap in the data until the instrument was repaired.

In order to consider the influence of hydrological changes (related to rainfall precipitation) and meteorological parameters[1], the variation of rainfall and underground water level are plotted in Figure 2 (blue bar graph and solid blue line respectively). As expected and observed, the water level decreased rapidly with time in summer, except for minor variation associated with occasional rainfall. It may be worth noting that in soil radon emanation, both rainfall and underground water have negligible effect compared to geodynamic deformation due to the occurrence of the Nepal earthquake. During 1 and 15 April, the radon concentration was almost constant despite rainfall occurrences and associated changes in groundwater level. During precursory phase (16–24 April), there was less rainfall and subsequently low variation in water level, but considerably high variation in radon concentration. Therefore, the significant variations

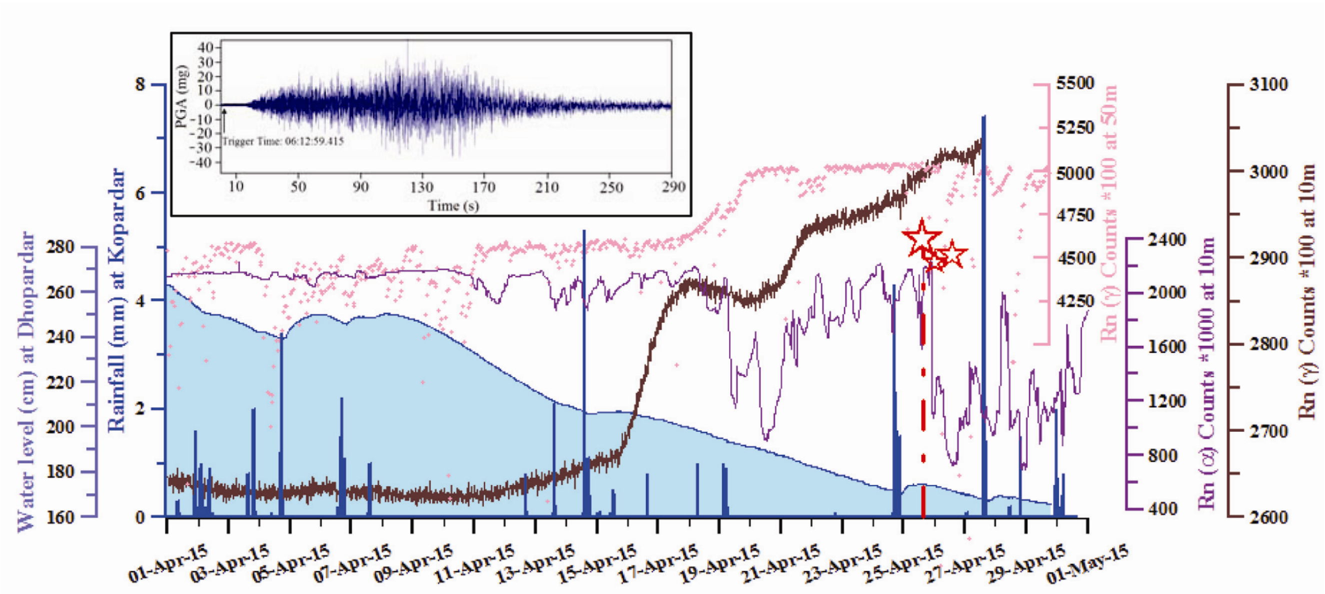

Figure 2. Continuous records of different time series. The variation of soil radon using gamma probe (brown solid line), alpha probe (solid purple line) and underground water radon through gamma probe (pink dots are shown). Rainfall (blue bars) and water level records in 68 m deep borehole (blue solid line) are also shown. (Inset) Vertical component accelerogram of the main shock recorded at MPGO, Ghuttu.

observed during a short span of time indicate that they are largely due to the occurrence of the earthquake with minor influences of meteorological parameters.

Radon emission in underground water measured at 50 m depth using gamma probe showed prominent pre-seismic temporal changes similar to soil radon (pink dots in Figure 2). However, the duration and time of anomalous changes were different. Before 17 April, the concentration was nearly constant. The radon emanation started increasing on 17 April and reached the highest value during 21–26 April followed by minor fluctuations. A careful scrutiny suggests that, there was some fluctuation in groundwater radon during 5–11 and 26–30 April, which was mainly related to the changes in groundwater level within the borehole. In spite of this, the gradual increase during 17–21 April could only be related to the Nepal earthquake. All these changes were not influenced by underground temperature at 50 m depth in the same borehole in which radon measurements were made.

The radon measurement in soil using alpha probe was also utilized, which showed large variations for pre-, co- and post-seismic periods (solid purple line in Figure 2). The changes in radon concentration started on 11 April with slight decrease in base level and a small fluctuation up to 16 April. This was followed by a large fluctuations, a low value observed on 20 April at 04:45 (UTC) and the trend remained the same up to 25 April when the Nepal earthquake occurred. Hence it records strong precursory changes followed by co- and post-seismic variation. Immediately after the occurrence of the Nepal earthquake, the radon concentration suddenly dropped and then a large fluctuation was observed with a shift in base value to lower levels. These variations cannot be related to rainfall, underground water level and other meteorological effects.

The present observations of radon variation related to the Nepal earthquake and the results supplemented with initial observations during the occurrence of nearby moderate magnitude earthquakes signify that the multi-parameter geophysical approach of MPGO, Ghuttu holds good promise for earthquake precursory research.

1. Choubey, V. M., Kumar, N. and Arora, B. R., *Sci. Total Environ.*, 2009, **407**, 5877–5883.
2. Sadovsky, M. A. *et al.*, *Tectonophysics*, 1972, **14**, 195–307.
3. Scholz, C. H., Sykes, L. R. and Agarwal, Y. P., *Science*, 1973, **181**, 803–810.
4. Virk, H. S., Walia, V. and Kumar, N., *J. Geodyn.*, 2001, **31**, 201–210.
5. Arora, B. R., Rawat, G., Kumar, N. and Choubey, V. M., *Curr. Sci.*, 2012, **103**(11), 1286–1299.

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NARESH KUMAR*
VISHAL CHAUHAN
S. DHAMODHARAN
GAUTAM RAWAT
DEVAJIT HAZARIKA
P. K. R. GAUTAM

Wadia Institute of Himalayan Geology,
33 GMS Road,
Dehradun 248 001, India
**For correspondence.*
e-mail: nkd@wihg.res.in