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Detection of earthquake induced radon precursors by Hilbert Huang Transform

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ABSTRACT

Continuous measurement of radon-222 concentration in soil was carried out across duration of one year at a geologically faulted area having high regional heat flow to detect anomalies caused by seismic activities. The data reveals a range of periodicities present in the radon time series. To identify seismic induced radon changes we treat the time series data through various filtering methods to remove inherent periodicities. The Ensemble Empirical Mode Decomposition (EEMD) is deployed to decompose the signal into its characteristic modes. Hilbert Huang Transform (HHT) is applied for the first time on the physically significant modes obtained by EEMD to represent time–energy–frequency of the recorded soil radon time series. After removing the periodic and quasi-periodic constituents from the original time series, the simulated result shows a forceful correlation in recorded radon-222 anomalies with regional and local seismic events.

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1. Introduction

The incidence of large changes in soil radon preceding earthquakes has been known for long (King, 1980; Mogro-Campero et al., 1980; Birchard and Libby, 1980; Shapiro et al., 1981; Rastogi et al., 1986; Wakita et al., 1980; Zmazek et al., 2002, 2003; Walia et al., 2005; Hartmann and Levy, 2005). However, one of the important problems of Earth Science is to understand the relationship between an observed radon anomaly and the subsequent time and location of earthquake occurrence (King, 1986). Several forms of changes in the earth's crust take place across various time scales preceding an earthquake. These precursory changes are noticeable as interlinked deviations or “anomalies” in wide ranging geological, geophysical and geo-chemical parameters. In the present case we take concentration variations of radon-222 in soil, in a time series observation and exploit them to indicate probability of regional earthquake occurrences.

The solid earth is geologically a complex entity with many soil related features such as grain size, mineralogy, porosity, density, permeability, moisture, and radium and uranium content of the soil correlating to changes in the relative concentration of helium and radon in soil gases (Price et al., 1994). Besides, the diffusion and advection of radon out of soils are controlled by several geophysical and geochemical factors such as (i) geomorphology of the study area, (ii) existence of geological fault in the vicinity of the study area, (iii) soil porosity, (iv) ground water movement, (v) distribution of uranium and radium in the bed rock, and (vi) micro seismicity in the region (Holub and Brady, 1981; Chaudhuri et al., 2010, 2012; Ramola et al., 2008; Das et al., 2006a; Walia et al., 2003; Abumuard and Tamini, 2001; Ball, 1994; Virk and Singh, 1993; Igarashi and Wakita, 1990; Nazaroff and Nero, 1988). Furthermore, several other factors such as gravitational changes causing earth's tides, meteorological parameters such as humidity, temperature, pressure and rainfall affect soil gas emanation (Chaudhuri et al., 2010, 2011; Weinlinch et al., 2006; Prasad et al., 2006; Barnet et al., 1997). Due to a single or compound effect of these influences it becomes difficult to assign a recorded anomaly as arising beyond doubt to be due to earthquake related change.

Notwithstanding the contribution to radon changes on account of the above influences, earthquake related stress–strain changes play the dominant role in influencing soil gas concentration changes, especially during the final stages of earthquake preparation phase prior to rupture (Planinic et al., 2004; Wakita, 1996; Hauksson and Goddard, 1981; King, 1980). To understand the behavior underlying soil radon and its relation to tectonic activities, numerous attempts were made across the world over the last three decades to obtain a common framework to the problem (Toutain and Baubron, 1999; Cicerone et al., 2009; Ghosh et al., 2009; Chaudhuri et al., 2013a, 2013b). Several workers proposed a number of mathematical models (Fleischer, 1981, Walia et al., 2005; Kumar et al., 2012; Omar et al., 2013). However, as our present understanding indicates it is hard to evaluate meaningfully the complex phenomena of seismic induced radon emanation process restricting to conventional mathematical models and statistical analysis. Nonlinear methods such as power spectrum analysis, wavelet analysis,

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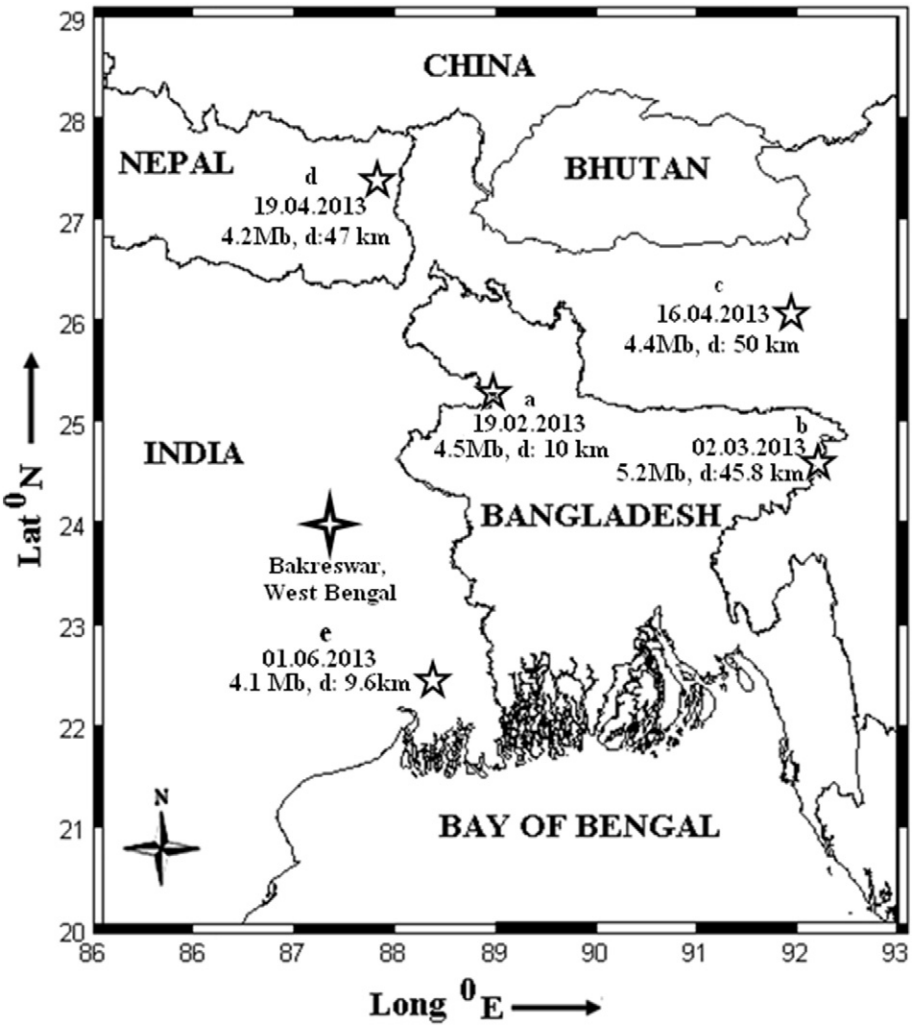

Fig. 1. Seismological data of the earthquakes that occurred within a radius of 500 km from the Bakreswar, West Bengal observatory during the period of January 01–June 01, 2013.

and fractal analysis may assist to reveal nonlinear characteristics of the under-earth physico-chemical mechanism involved in radon emanation process (Das et al., 2006b; Chaudhuri et al., 2013a, 2013b). In the present work, we have extended the analyzing technique by applying EEMD based Hilbert Huang Transform to soil gas radon time series data recoded at Bakreswar Geochemical Monitoring Laboratory, West Bengal, India. The essence of applying this method lies in the fact that for the first time soil radon-222 data set is being analyzed taking into consideration its non-stationary features.

2. Geological setting of the study area — 'Bakreswar Geothermal Region'

The Bakreswar (23°52′30″N, 87°22′30″E) geothermal area is about 250 km north-west of Kolkata in West Bengal. It is located within a region that witnessed widespread volcanic activity for about 60 million years between ~120 and 60 Ma (Rajmahal volcanism). Close to Bakreswar is the spectacularly long ENE–WSW trending mega lineament called Narmada–Sone Lineament (Gupta et al., 1975; Shankar, 1991; Majumdar et al., 2005).

Over geologic time scale this geothermal zone has been subjected to different cycles of plate movements with intervening periods of iso-static readjustments during the Precambrian to Cenozoic era (Sarkar, 1982; Shankar, 1991). Geologically, the region lies in an area abounded by Precambrian granitic rocks and basalt lava flows hiding several buried faults that may accommodate a significant amount of seismic strain. The place where radon measurements were carried out was far from locality in flat ground with permeable laterite soil. The area supports sparse vegetation cover.

Table 1
Data of magnitude, epicentral distance and the precursor time of the considered earthquake occurrences.

Event no	Magnitude (Mb)	Epicentral distance (in km)	Precursor time (in days)
a	4.5	236	4
b	5.2	500	1
c	4.4	520	11
d	4.2	387	2
e	4.1	188	5

3. Method of analysis

Many research disciplines are exploiting time series analysis to evaluate, understand and interpret outcomes. However, most of the methods are based on Fourier analysis and hence confined to analysis of linear systems only. The available methods have been appropriately reviewed by Huang et al. (1998a). They focused to the inability of these methods to be applied to analysis of non-stationary data. During 1998 they introduced a two step method for the analysis of time series data. The first step was to decompose the data into a number of intrinsic mode function (IMF) components by means of empirical

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