

## Natural time analysis on the ultra-low frequency magnetic field variations prior to the 2016 Kumamoto (Japan) earthquakes

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### Highlights

- ULF magnetic fields prior to 2016 Kumamoto earthquakes (EQs) are considered.
- ULF parameters are analyzed by the natural time method.
- Criticality in the ULF radiation characteristics is revealed prior to the EQs.

### Abstract

On 15 April 2016 a very strong and shallow earthquake (EQ) ( $M_W = 7.0$ , depth  $\sim 10$  km) occurred in Southwest Japan under the city of Kumamoto, while two very strong foreshocks ( $M_W = 6.2$  and  $M_W = 6.0$ ) preceded by about one day. The Kumamoto EQs being very catastrophic, have already attracted much attention among the scientific community in a quest for understanding the generation mechanism, as well as for reporting any preseismic anomalies in various observables and assessing the effectivity of the current early warning systems. In the present article we report precursory behavior of the ground-based observed ultra-low frequency (ULF) magnetic field variations before the Kumamoto EQs. By analyzing specific ULF magnetic field characteristics in terms of the recently introduced natural time (NT) analysis method, we identified that ULF magnetic field variations presented critical features from 2 weeks up to 1 month before the Kumamoto EQs. Specifically, the ULF magnetic field characteristics  $F_h$ ,  $F_z$ ,  $D_h$  and  $\delta Dep$  were analyzed. The first two represent variations of the horizontal and vertical components of the geomagnetic field. The third and fourth characteristics correspond to the depression (decrease) and a relative depression of the horizontal magnetic field variations, respectively. The latter depends on the degree of ionospheric disturbance. All of them were found to reach criticality before the Kumamoto EQs; however, in different time periods for each characteristic.

### Graphical abstract