Early warnings of ground motion and tsunami: Research development of last 10 years

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During the 2011 Tohoku earthquake (M9.0), earthquake early warning (EEW) was issued from the Japan Meteorological Agency (JMA) 15s before strong shaking hit Tohoku region, as designed. However, strength of shaking was underpredicted at Kanto due to underestimation of the source extent. When multiple aftershocks occurred simultaneously, the EEW system did not identify appropriately the multiple events, which led to false alarms. Tsunami early warning (TEW) was issued based on M7.9 which was estimated just after the mainshock. The underestimation of M caused underprediction of tsunami height. The warning was upgraded rapidly using tsunami data from offshore GNSS buoy, but the data from ocean-bottom pressure (OBP) gauges located far offshore were not used for update of the warning.
We will review the research development of last 10 years regarding EEW and TEW, which were conducted on lessons learned from the above experiences. We will also explain the recent improvements of EEW and TEW of JMA.
To avoid M underestimation during gigantic earthquakes, use of long-period seismic waves is important. Improvements of the M estimation have been investigated by using the data from sophisticated seismometers which enables to monitor the long period waves, and those from GNSS which can record static displacement without oversaturation in real-time (Kawamoto et al, 2017).
Several methods have been proposed for rapid, precise, and robust estimation of source parameters (hypocenter location, M, source extent and so on) for EEW: source-based algorithms. For rapid estimation of source extent, pattern recognition technology is applied by identifying extent of strong-shaking area (Bose et al, 2017). This method is proposed for ShakeAlert (EEW system of California). To address simultaneous multiple events, a new technique has been studied in which not only arrival time of seismic phases but also amplitude is used to determine hypocenter location (Tamaribuchi et al, 2014; IPF method).
Another approach has been investigated: wavefield-based (or ground-motion based) algorithms in which current wavefield is estimated precisely and then future wavefield is predicted using physics of wave propagation (Hoshiba and Aoki, 2015). Because source parameters are not required, this algorithm works well even for large extent of source and multiple simultaneous events.
Smart-phone seismometer is an interesting development of last 10 years. Because acceleration sensor is equipped in smart-phones, seismic observation, data transmission and also warning receiver are realized in a single smart-phone. Some authors have developed an application which is downloaded by general public. Downloads by many people could lead to virtual dense seismic observation network (Kong et al., 2020). More people have reportedly downloaded the application particularly in developing countries.
After the 2011 Tohoku earthquake, dense ocean-bottom observation systems were developed around Japan. Several tsunami-forecast methods using the OBP data have been proposed, such as tsunami-source estimation approach (Tsushima et al., 2009; tFISH) and the tsunami-wavefield estimation approach (Maeda et al., 2015).
JMA introduced IPF method into EEW operation in 2016 for addressing the problem of multiple simultaneous events, and PLUM method (simplified version of wavefield-based algorithm) in 2018 for large source extent. PLUM contributes to reduce underprediction of shaking strength (missed alarm). To enhance observation, cabled ocean bottom seismometers (JMA cables, DONET and S-net of NIED) and borehole seismometers (depth 500-3500m) at southern Kanto have been utilized, which contributes to

rapid EEW.
For improvement of TEW, JMA has installed the method to estimate M using long-period seismic waves (Katsumata et al., 2013) in 2013. In addition, JMA uses dense OBP data in operational tsunami monitoring since 2016. Moreover, tFISH has been used since 2019 for more accurate forecast.

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