Japan Geoscience Union Meeting 2010
(May 23-28 2010 at Makuhari, Chiba, Japan)

SGD001-P12 Room: Convention Hall Time: May 27 17:15-18:45

A New Analysis Method Using the Particle Filter Algorithm Applicable to Long-Period Tide Gauge Records

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Sea level along the coast line of Japan has been observed for more than 100 years at ~150 tide gauges operated by Geographical Survey Institute (GSI), Japan Meteorological Agency (JMA), Japan Coast Guard (JCG), and other institutes. The day-to-day tidal records clearly show the stationary oceanic tides sometimes including transient events such as tsunamis. On the other hand, the long-term sea level variations for years are considered to demonstrate oceanic variations and/or tectonic deformations. In particular, a secular trend up to several millimeters per year is caused by tectonic process such as subduction of oceanic plates, and sometimes shows a sudden baseline jump due to interplate earthquakes. Kato and Tsumura [1979] improved the analysis method of Tsumura [1963] that enables us to extract evidences of tectonic deformation from the long-period tidal records through determination of a trend variation from monthly means with modeling both seasonal variation and spatial correlation with nearby observatories. One of the important results they derived is that the coasts of Japan can be classified into 10 segments according to features of the spatial correlations. GSI has adopted this powerful tool as an official analysis method for more than 10 years, but it should be improved at this moment especially in parts relying on subjective experiences.

We propose a new analysis method using the particle filter algorithm, which decomposes long-term tidal records into trend, seasonal, autoregressive (AR), and observation noise components. In order to extract sudden trend jumps caused by interplate earthquakes, we assume a Cauchy distribution function for the system noise of the trend component. Such trend jumps usually so small that we should obtain a large signal-to-noise ratio (SNR) as possible with better modeling. We adopt here a multivariate AR model for the purpose to extract the spatial correlation components among observatories in the same coastal segment. The model parameter vector A to be determined consists of the AR coefficient matrices, the scale value of the Cauchy distribution, variances of system and observation noises, and initial state vectors. The procedure to estimate these parameters is as follows: (1) give a prior distribution p(A) for each model parameter, (2) calculate log-likelihood function p(Y|A) for each particle sampled from the prior giving observation data Y, (3) obtain a posterior distribution p(A|Y) proportional to p(Y|A)p(A) by the Markov Chain Monte Carlo (MCMC) algorithms, and finally (4) obtain the maximum a posteriori (MAP) solution A_{opt}. We apply our method to monthly means of tidal records observed at 144 tide gauge stations for more than 40 years with a parallel computation using ~200 Intel Xeon CPUs, and confirm that a larger SNR is obtained comparing with the case of using an univariate AR model. We also obtain spatial and temporal distributions for each component showing remarkable features in the tidal records such as the tectonic deformation and the oceanic variations.

Keywords: tide gauge, earthquake, particle filter, AR model, posterior distribution, MCMC