Modeling effect of time delay for large network of seismic monitor

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Abstract

1 Introduction

2 Methods

We have a network of seismic monitors recording ground vibrations. The monitor records compression and decompression as discrete values -1 and 1, respectively, every second. The GPS coordinate position of each monitor in the network is known (Figure !!!TODO: insert map of monitors).

The network of monitors can be modelled as a complete graph !!!TODO: schematic representation of the graph. The signal of each monitor is cross-correlated with other monitor signals, finally yielding time-delay data between each monitor. The time delay between the monitors comprise information on the real time the signal travels between the monitors, the inaccuracies of the clock (time drift), and other noise affecting the measurement.

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Let $\boldsymbol{\delta}_t \in \mathbb{R}^n$ be the measured pairwise time delays of the system, $\boldsymbol{\Delta_t}$ the actual time delays, and $\mathbf{D}_t$ an error term describing the difference between the actual and measured time delays

$$\boldsymbol{\delta}_t = \boldsymbol{\Delta}_t + \mathbf{D}_t. \tag{1}$$

Each of the monitors are equipped with a clock which runs independent of others. It is synchronized via GPS system once a month and then runs independently. The drift, D_i in clock i is described by

$$D_i(t) = \varepsilon c_i(t) + t_i^0, \tag{2}$$

in which ε accounts for the (non-linear) drift of the clock, c_i is the clock counter, and t_i^0 the reference time at synchronization.

In the case of the complete network, the equation 2 becomes

$$\mathbf{D}_t = \boldsymbol{\varepsilon}_t \mathbf{c}_t + \mathbf{t}_0, \tag{3}$$

in which $\mathbf{D}_t \in \mathbb{R}^n$, $\boldsymbol{\varepsilon}_t \in \mathbb{R}^{n \times n}$ sparse matrix, and $\mathbf{c}_t$, $\mathbf{t}_0 \in \mathbb{R}^n$.

Combining Equations 1 and 3 yields

$$\boldsymbol{\delta}_t = \boldsymbol{\Delta}_t + \boldsymbol{\varepsilon}_t \mathbf{c}_t + \mathbf{t}_0. \tag{4}$$

The position of each seismic monitor in the network is known. As the monitors are spread across a large area, it is assumed that local tremors are detected by stations that are close by, and therefore the correlations found in the pairwise cross-correlations and time delay data between them have higher likelihood to be linked. Therefore, a weight matrix $\mathbf{A}$ is constructed with a weight measure based on the distance between the stations: the closer the stations are together, the higher the weight assigned to the measurement. The weight elements a_{ij} in the matrix $\mathbf{A}$ are calculated by

$$a_{ij} = \frac{1}{r_{ij}}, \tag{5}$$

in which r_{ij} is the distance between the stations i and j. The values a_{ij} are then normalized to $[0, 1]$ to obtain weights.

!!!TODO: how to incorporate the weight matrix to model