Infrasonic Source Location Using The Neighbourhood Algorithm

D. Brown

Retired. (Formerly: Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO))

INTRODUCTION AND MAIN RESULTS

The Neighbourhood Algorithm is a grid search method that optimizes a user-supplied objective function over a computational domain using Voronoi cell tesselation. The algorithm is a method for solving geophysical inverse problems with the additional benefit of not requiring the estimation of travel-time derivative information (Sambridge, 1999). In this application a misfit function for infrasound detections, defined in terms of observed and predicted values of travel time and backazimuth, is minimised using the neighbourhood algorithm with a hypocentral source location hypothesised. The method is applied to several noteworthy infrasound events

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Introduction

Signal detection and characterization strategies are used to form an observation vector $d_j = (T_j, \theta_j, s_j)$ for a set of *1 ..j .. N* SHI stations that have recorded signals from a common source .

For an hypothesized initial source location X^0 the source location is typically refined through an iterative procedure $X^0 \rightarrow X^1 \rightarrow X^2 \rightarrow \cdots \rightarrow X^k$ where at each iteration a correction vector Δx^k is specified such that:

$$x^{k+1} = x^k + \Delta x^k \quad \text{where} \quad \Delta d_i^k = \sum_{j=1}^{N} \left(\frac{\partial d_i}{\partial x_j} \right)_{x=x^0} \Delta x^k \quad \text{or} \quad p = \mathrm{G}q$$

Singular Value Decomposition is used to solve for **q** where a *generalized* inverse $\mathfrak{S}$ is determined such that **q** = $\mathfrak{S}\mathfrak{p}$ where $\mathfrak{S} = V\Sigma^{-1}U^T$ for unitary matrices *V* and *U*, and diagonal matrix $\boldsymbol{\Sigma}$. The main issues with this method are:

- it is generally over-determined, and the eigenvalues contained in Σ are often manipulated to guarantee inversion
- certain smootheness propeties on the travel-time curves are assumed in order to determine the derivative

The Neighbourhood Algorithm method

-Sambridge: 1999-

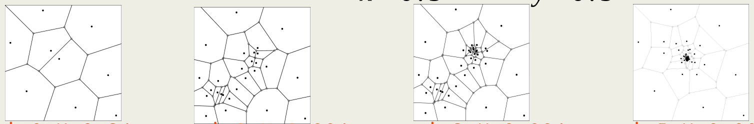
The Neighbourhood algorithm is a iterative grid-search method that uses Voronoi Tesselation to search a sample space.

Voronoi Tessellation is a method of tiling a space with

- a random chosen set of *seed* points
- a tile consisting of all points closer to their seed than any other seed
- the value of an objective function can be determined at each seed point

An iterative procedure can be developed that re-seeds the tile containing the seed with the minimum function value generating a new set of tiles, e.g. for the objective function

$$z = 1 - \frac{\sin(x-0.5)}{x-0.5} \times \frac{\sin(y-0.5)}{y-0.5}$$



i=0 M=0.24 at (0.0) | i=2 M=0.004 at (0.46,0.57 | i=3 M=0.004 at 0.46,0.57) | i=5 M=0.002 at (0.51,0.45)

For infrasound source location the following objective (misfit) function is used:

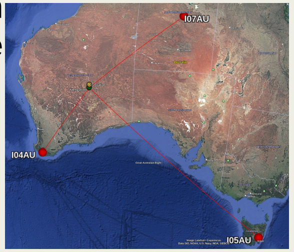
$$M(\vartheta, \varphi) = \sum_{i=1}^{N} \left[\frac{ W_T \left(\frac{T_i^{(obs)} - T_i^{(pred)}}{\sigma_i^{(T)}} \right)^{1.0} + W_\theta \left(\frac{\theta_i^{(obs)} - \theta_i^{(pred)}}{\sigma_i^{(\theta)}} \right)^{4.0} }{ W_T + W_\theta } \right]$$

-where T is time, θ is azimuth, (obs) the observed detected value, (pred) the predicated value based on a forward modelling estimate, σ the uncertainties and *W* the weightings

processing

- detections provided by Hough Transform detector (Brown 2008)
- analyst determined dominant stratospheric return
- constant velocity assumed: 295 m/s
- no conflict resolution employed in source location
- deltim: 30 sec delaz 3 deg
- azimuthal weighting: 95% time weighting: 5%
- adapts work of Brown (2007), Brown et al. (2013),

Australia: explosion of mining truck carrying ANFO

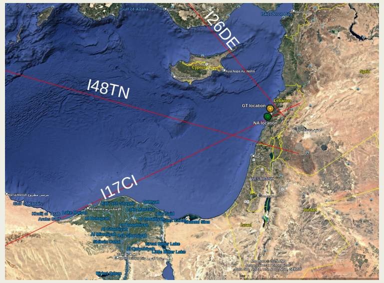



```
GT0 location:
  (-27.92298,123.47106)
  @ exact time unknown

NA location:
  (-28.2313,123.4297)
  @ 24-Oct-2022 03:38:05

Misfit: 34.3 km
no uncertainty analysis
```

Beirut: fertilizer storage silo

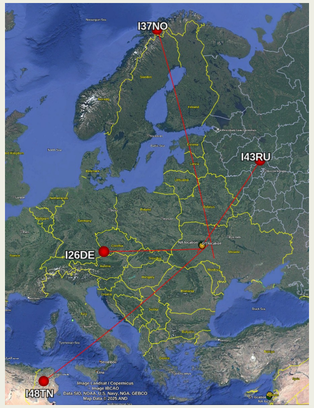



```
GT0 location:
  (33.90039,35.51834)
  @ 4-Aug-2020 15:08:18

NA location:
  (33.6898,35.4428)
  @ 4-Aug-2020 15:04:41
  no uncertainty analysis

Misfit: 24.4 km  227 sec
no uncertainty analysis
```

Ukraine: ammunition depot explosion




```
GT0 location:
  (49.45165,26.876136)
  @ 13-May-2023 03:10:14
                (seismic)

NA location:
  (49.5390,26.8086)
  @ 13-May-2023 03:11:54

Misfit: 10.9 km 100 sec
no uncertainty analysis
```

Conclusions

- The Neighbourhood Algorithm provides a useful tool to do source location at IMS operational distances
- the inclusion of meteorological info to back out the azimuthal deviation is required
- needs to be supplemented by an error analysis
- need to sort conflict resolution for auto processing

References

Sambridge, M., Geophys. J Int., **138**, 1999 . NA code used with permission of Prof. Sambridge
Brown, D. et al., J. Geoph. Res., **113**, 2008
Brown, D. **ITW** 2007
Brown, D. et al, **SnT** 2013