Improved Locations Through Waveform Cross-Correlation Within the Antelope Environment

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Antelope Users Group Meeting
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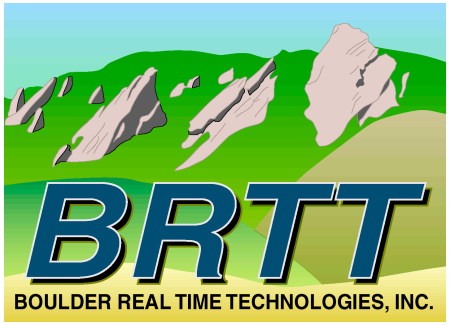


Outline of This Talk

- history and background
- “dbcorrelate” software and utilities
- applications of dbcorrelate
- vision for future network catalogs

Brief History

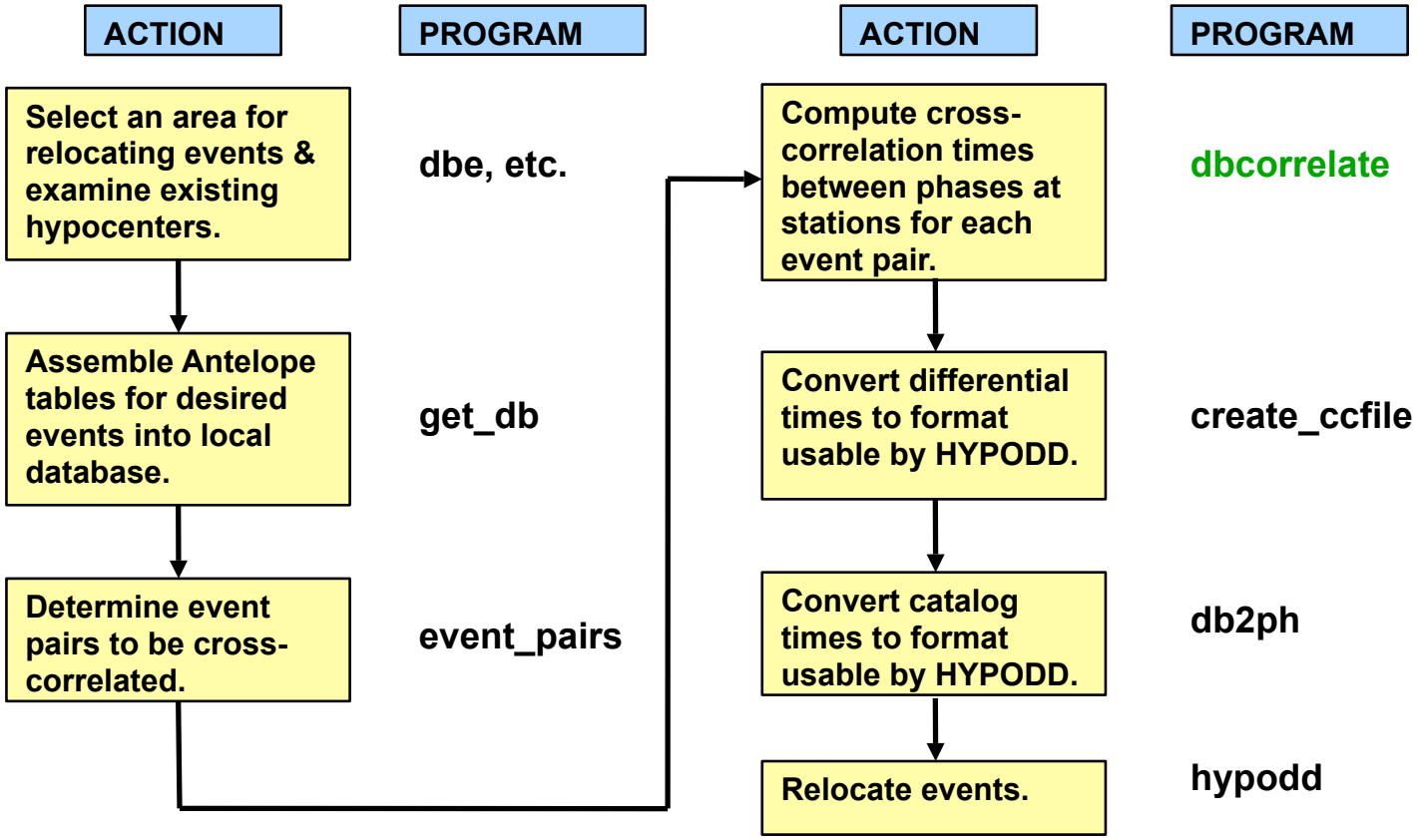
- NSL* started using Antelope software in 1996.
- NSL converted to Antelope for routine operations on 1/1/2000.
- Approximately 10,000 events are located per year within NSL seismic network.
- Started research on waveform cross-correlation in 2004.

*NSL = Nevada Seismological Laboratory

What We Do With Cross-Correlations

- input to HYPODD – catalog refinement
- prototype near-real-time location refinement
- prototype single-station location approximation
- research (structure hetereogeneity, empirical Green's functions, array calibration, etc.)

dbcorrelate Processing Flow



Software Features of dbcorrelate

- ☺ written in C (except two subroutines)
- ☺ uses BRTT Antelope 4.9 libraries
- ☺ tightly coupled to Antelope database
- ☺ synthetic test case provided
- ☺ internal documentation in code
- ☺ User's Guide

Users Guide – Front Page

PROCEDURE FOR CROSS-CORRELATING WAVEFORMS IN ANTELOPE DATABASES AND OBTAINING DIFFERENTIAL TIMES FOR IMPROVED LOCATION ACCURACY USING HYPODD

CONTENTS

Basic Algorithm

- time domain cross-correlation with specified time window and lag time
- refinement of peak time via interpolation of best-fitting 2^{nd}-degree polynomial
- calculation of cross-correlation coefficient (-1 <= CCC <= +1) from non-interpolated peak value
- calculation of relative amplitude of events from cross-variance peak value

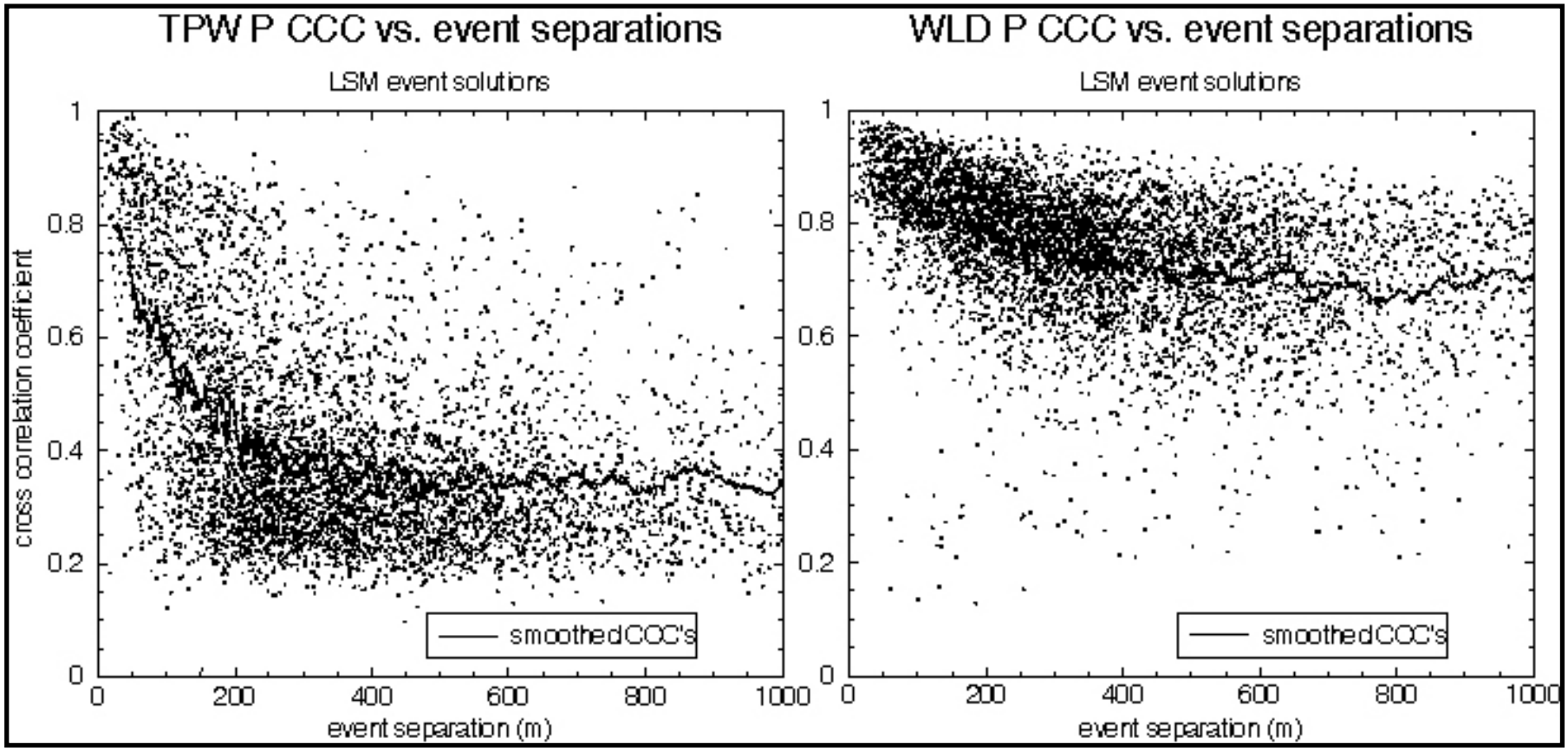
Other Correlation Programs

- cross-correlate waveforms among sensors in arbitrary array of instruments
- cross-correlate waveforms at one station among many events
- auto-correlate noise samples over many contiguous time periods
- cross-correlate master events with other events and stack correlations

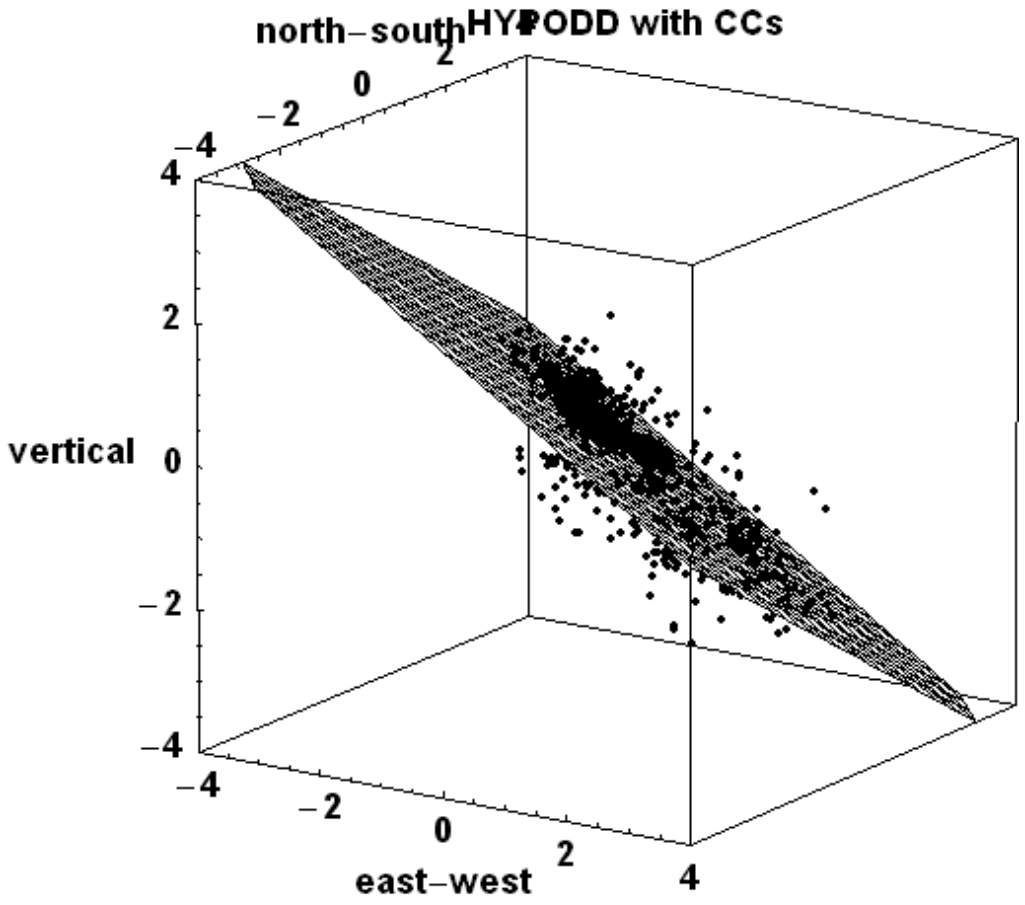
Specific Applications of Waveform Cross-Correlation at NSL

- Yucca Mountain seismic catalog (1996-2005) relocated for site characterization.
- Reno/Carson City/Tahoe area catalog relocated in NEHRP-funded tomography study.
- Seismicity associated with 30-km deep Tahoe magma intrusion relocated (von Seggern et al., BSSA, June 2008).
- Wells (Mw 6) earthquakes of February 2008.
- Mogul earthquakes of Feb-May 2008.

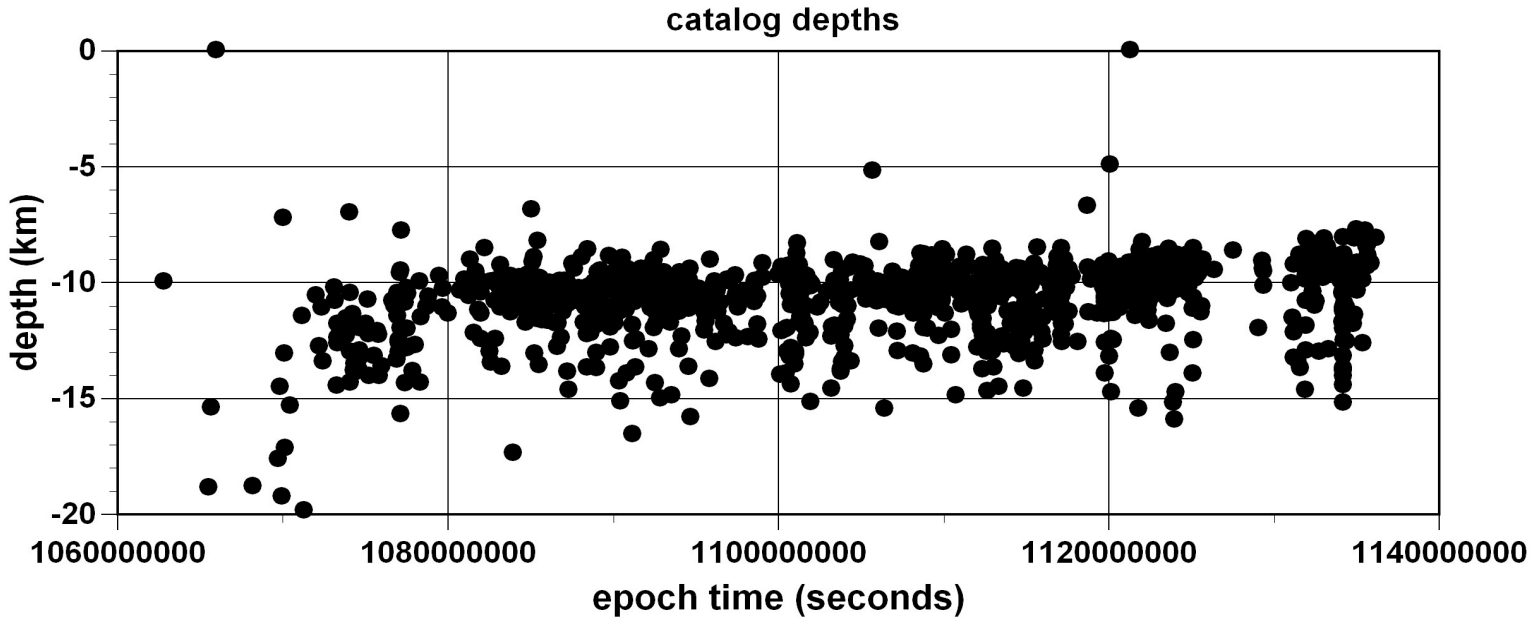
Peak Cross-correlation Dependence on Inter-event Separation

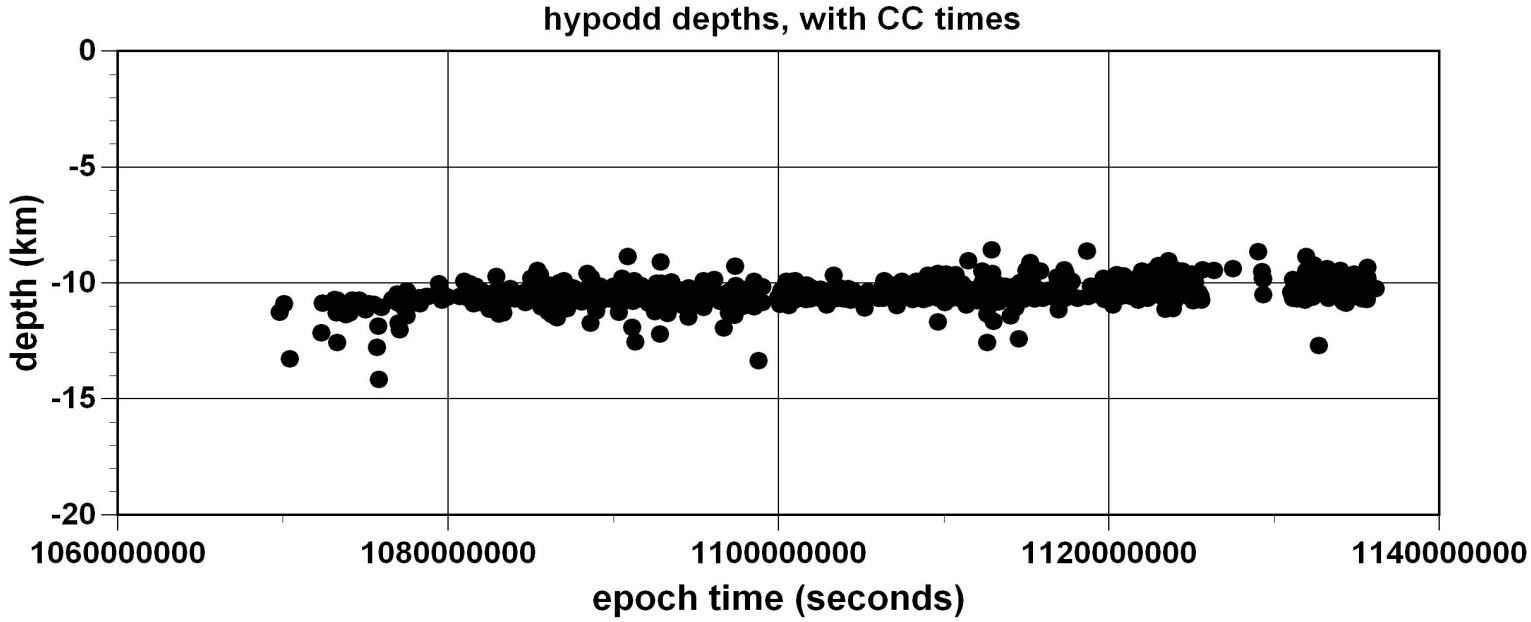


Application to Deep Tahoe Events

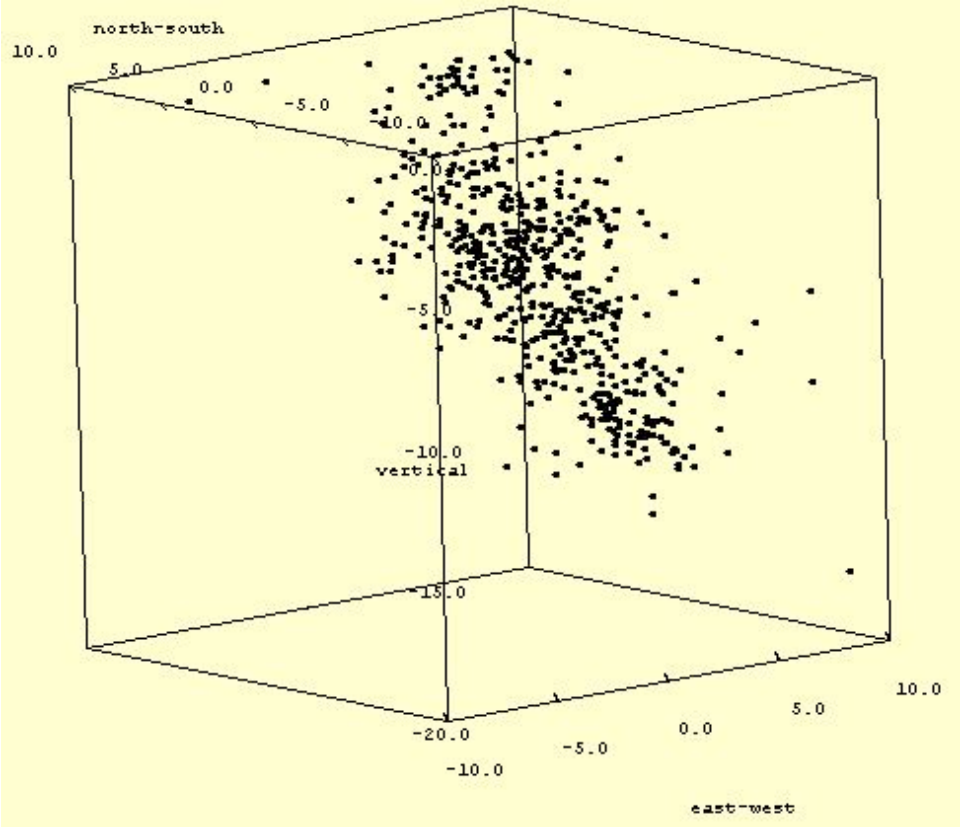


Application to Shallow Tahoe Events





Application to Wells, NV Earthquakes



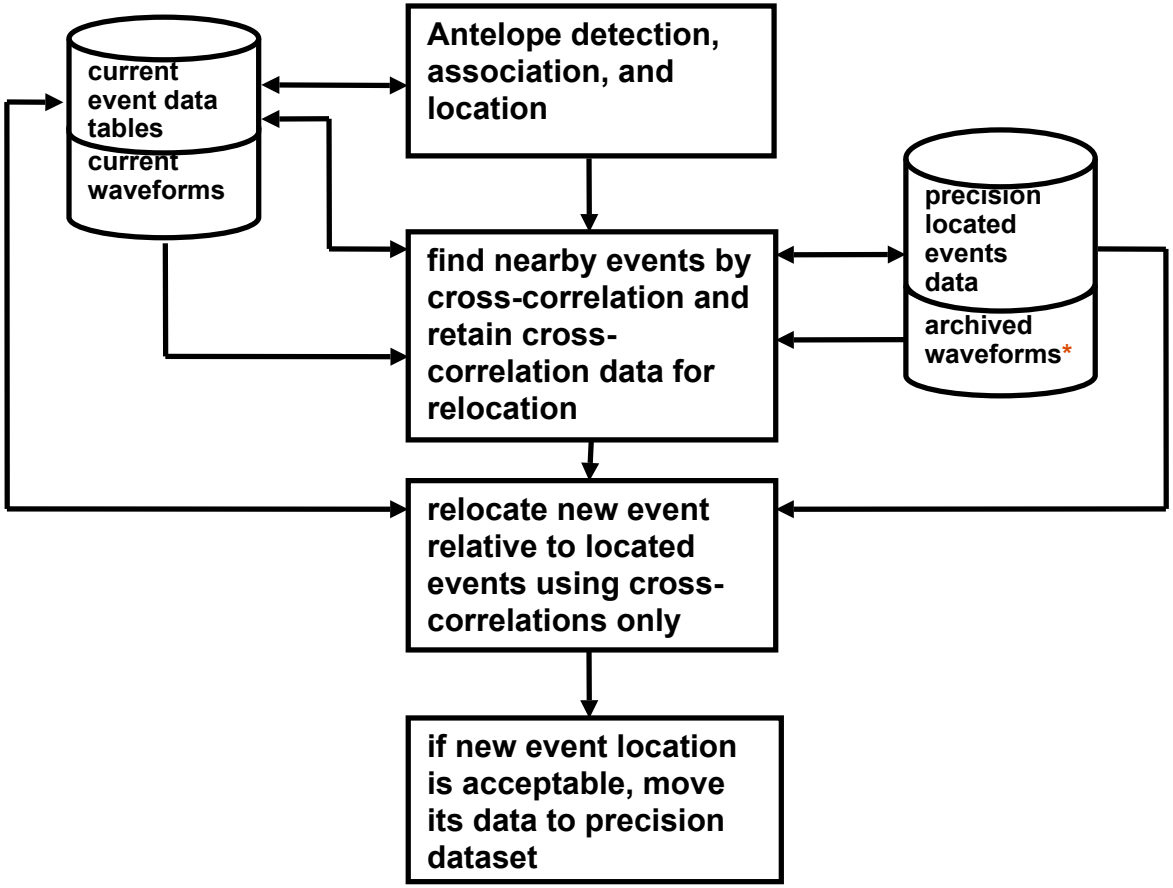
Useful in Near-Real-Time?

Two Possibilities:

1) Compute cross-correlation time delays between current event arrivals and matching arrivals from prior events and apply to relocation.
2) Using one or more stations, simply estimate event location by finding maximum cross-correlation coefficient between current waveforms and waveforms of all prior events.

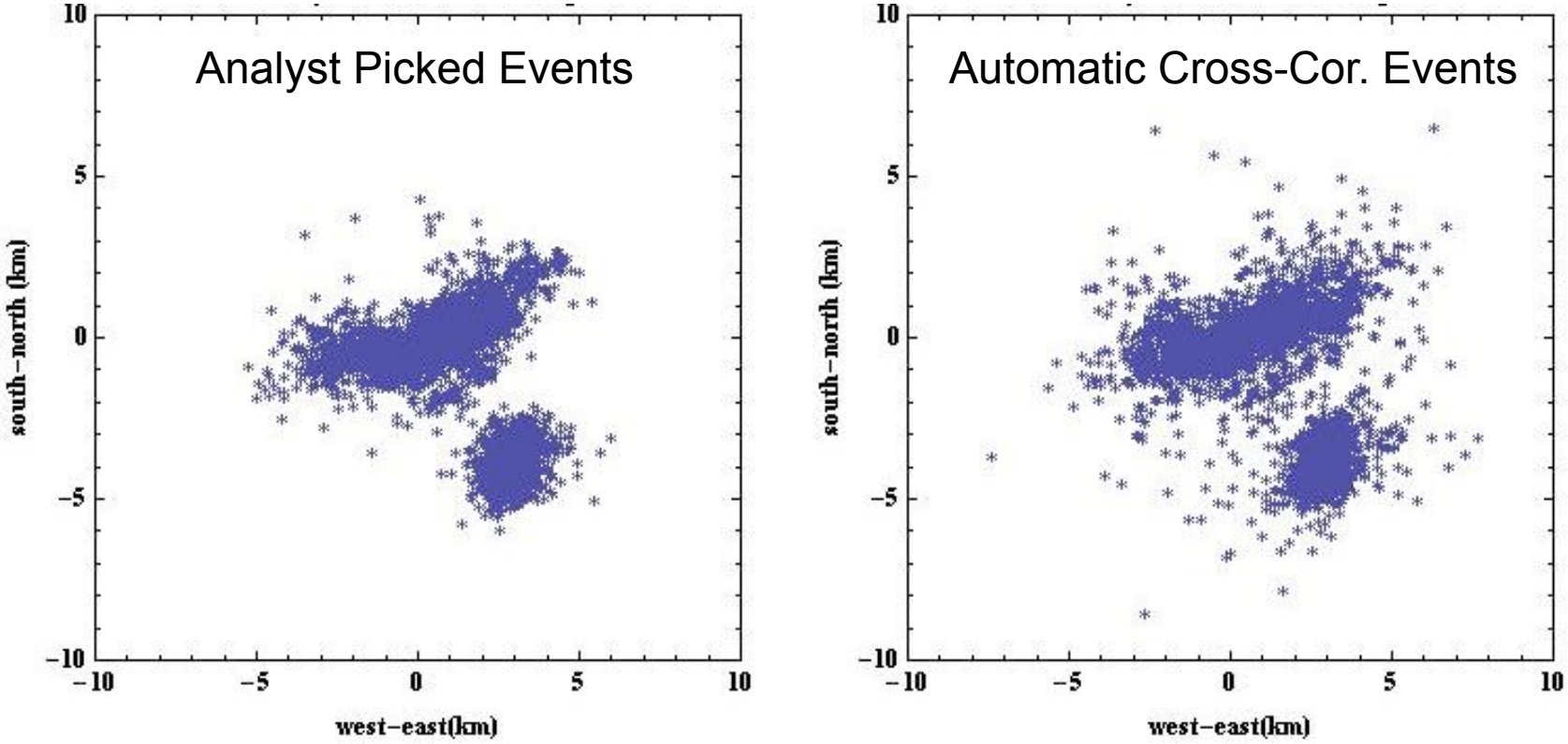
Near-Real-Time nrt_dbcorrelate

Flow Diagram for Relocating Current Events Using Waveform Cross-Correlation Only



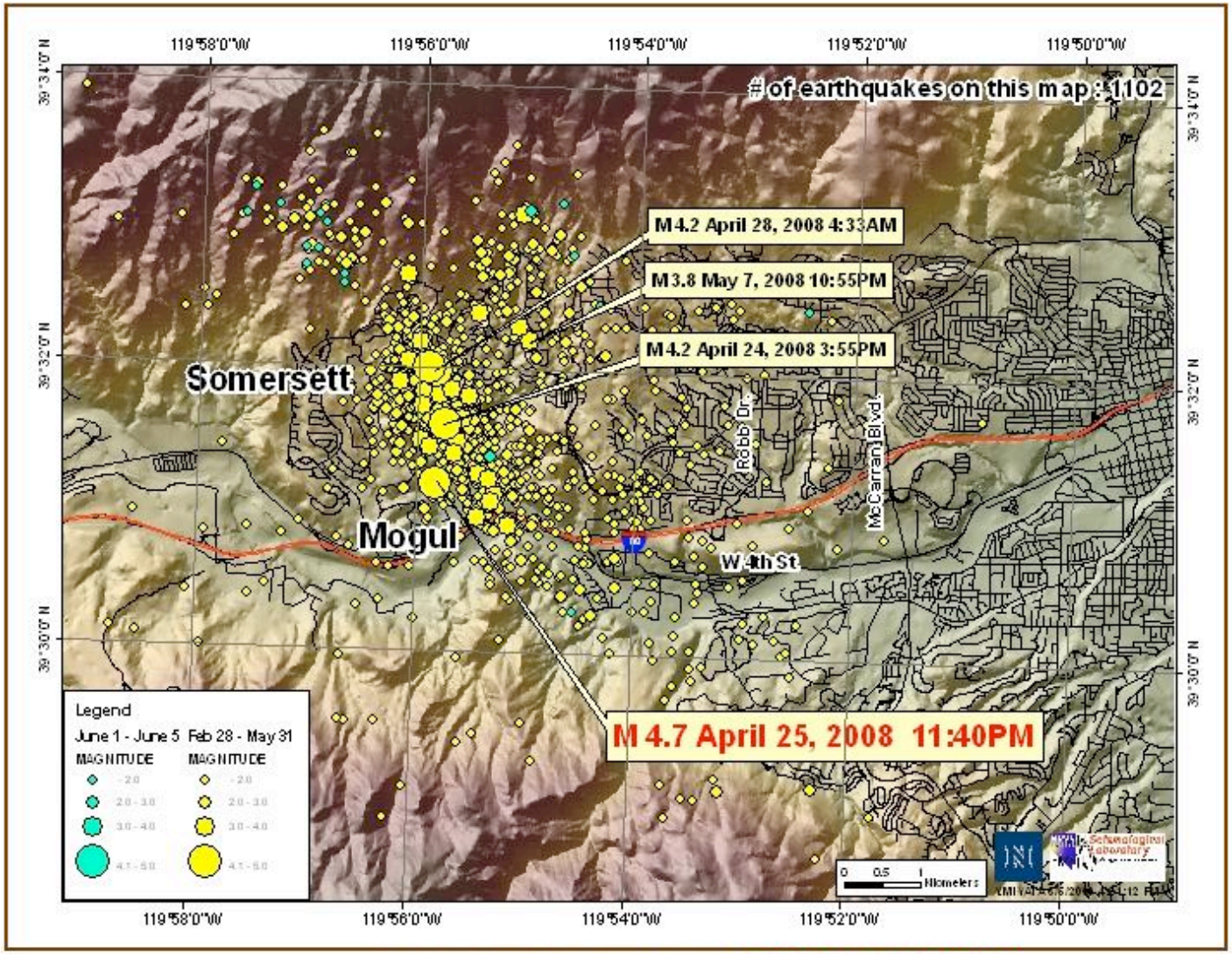
* archived waveforms are short (1-second) snippets stored compactly and input to memory as a block unit indexed by event, station, and phase (P or S)

Application to Adobe Valley Sequence (> 6,000 earthquakes in 2004)



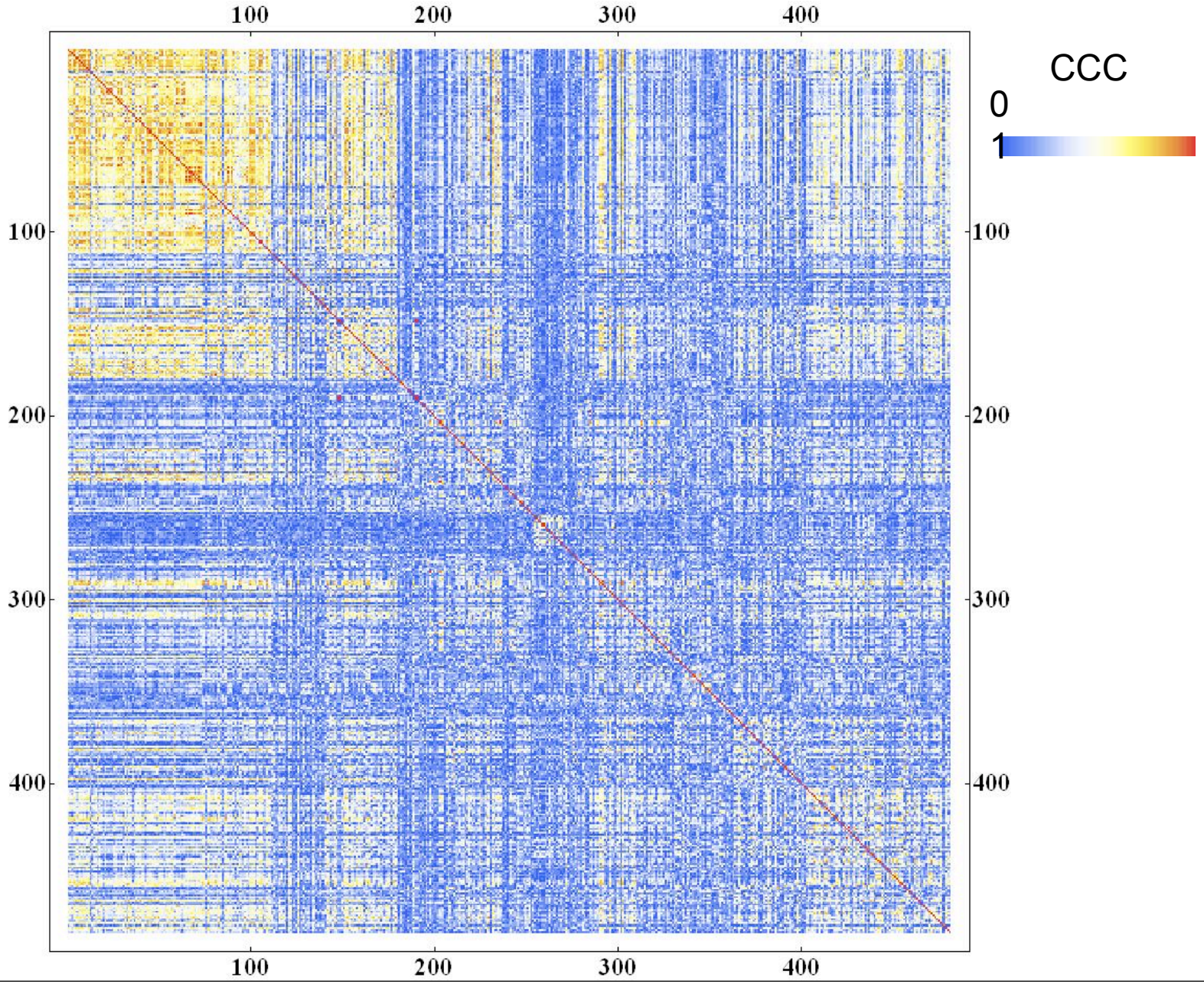
Map View of Epicenters Relative to Main Shock

Mogul Sequence (Feb-Jun 2008)



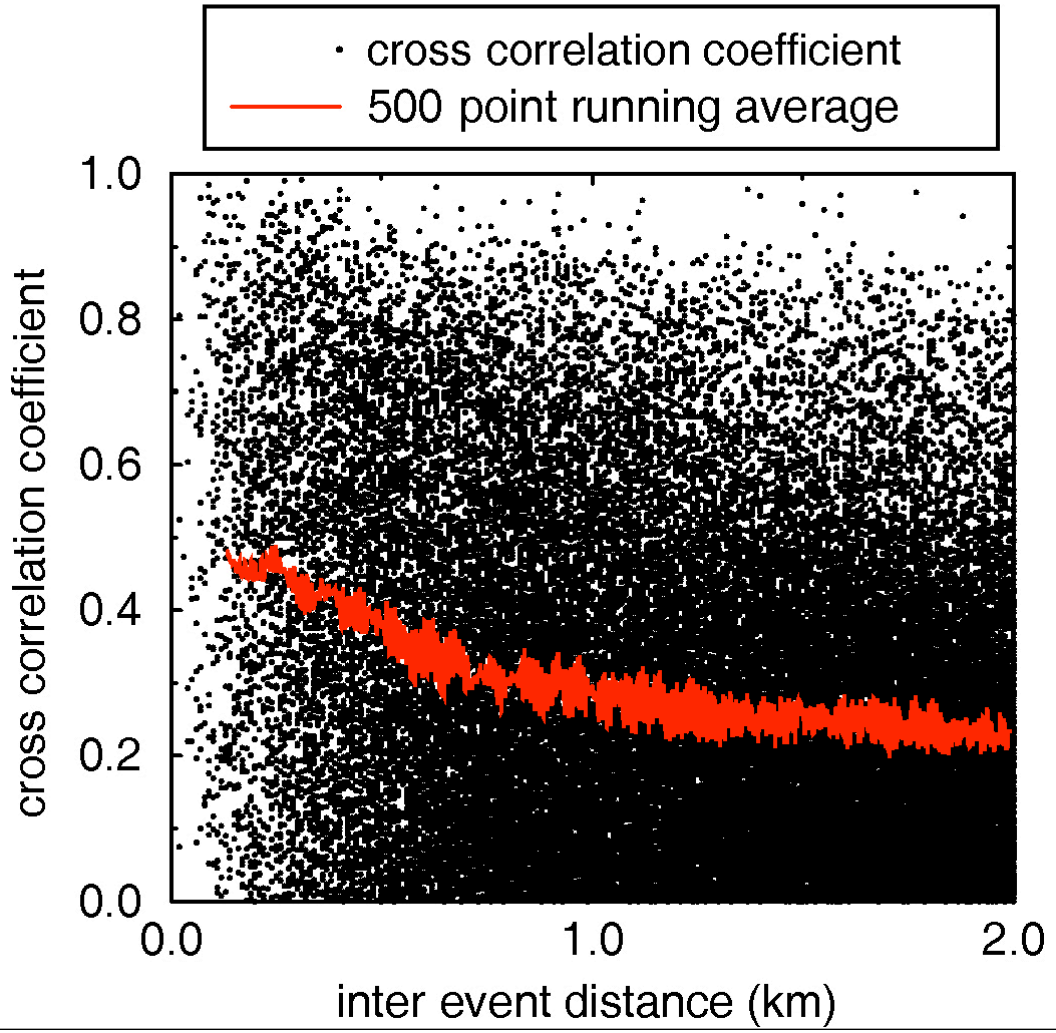
Latest map of aftershocks as of: 06/05/2008 04:22:50 PM

Correlation Matrix (P Waves at PEA)



Peak CCC Versus Event Separation

481 events recorded at PEA =
481^2 cross-correlations of 1-s
window beginning at P-arrival time



Vision Premises

- Routine event location is *time-consuming, tedious, expensive, and frought with inaccuracies* (absolute and relative).
- Earthquake catalog of record should be a *living document*.
- Massive cross-correlation computations need not impact most modern computing environments at network centers.

Vision Realized

- Cross-correlation moves from a research method to routine network operations, with acceptable reliability.
- Large portion (> 50%) of catalog is created by cross-correlation of new events with prior events and automatic relocation.
- Catalog is irregularly updated with new HYPODD solutions, based on cross-correlations.