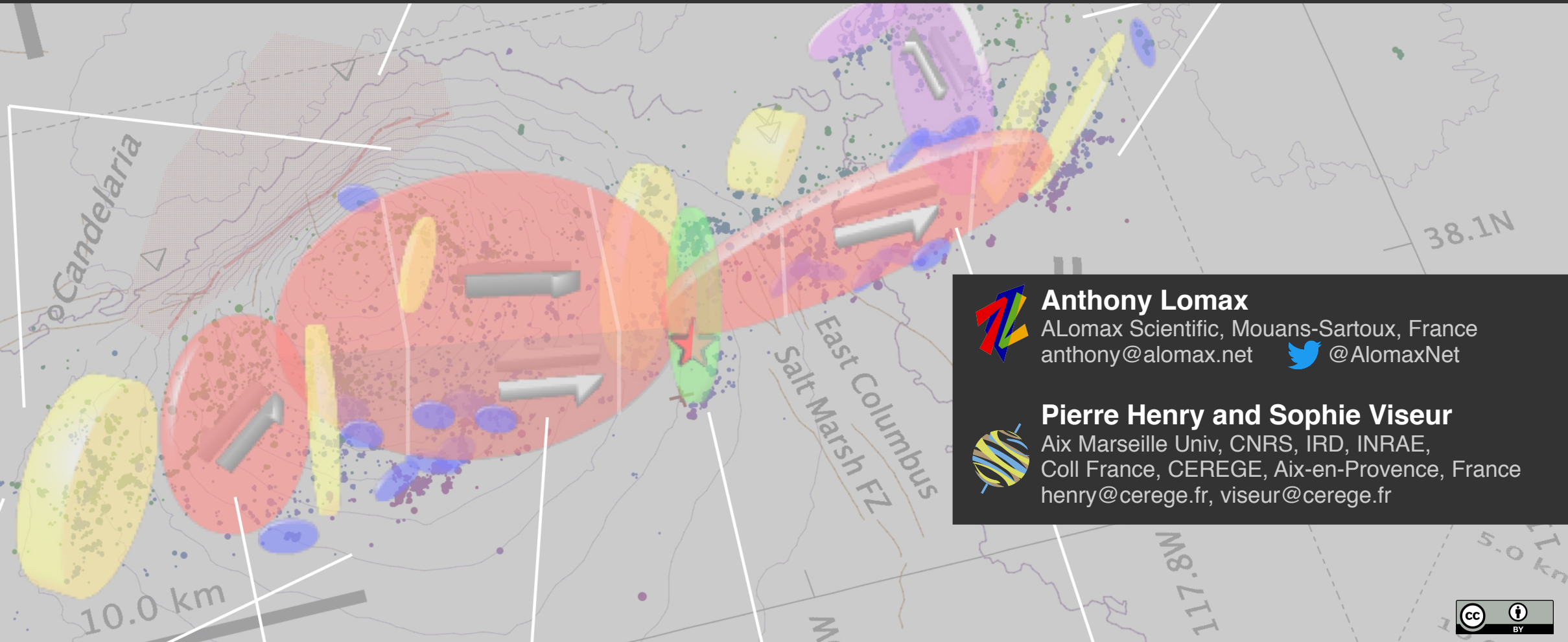


High-precision, absolute earthquake location based on waveform similarity between events

application to imaging foreshocks, fault complexity and
damage zones for recent western US earthquakes



High-precision, absolute earthquake location based on waveform similarity between events

application to imaging foreshocks, fault complexity and damage zones for recent western US earthquakes

Presentation outline

Here we show:

- a new procedure for high-precision, absolute earthquake location (**NLL-SSST-coherence**) based on source-specific station terms (SSST) and waveform similarity (coherence) between events
- **NLL-SSST-coherence** approaches the precision of cross-correlation, relative location, with possible higher precision and depth constraint when few nearby seismic stations
- **NLL-SSST-coherence** relocations for recent western US earthquakes reveal foreshocks, fault complexity and damage zones

Key references:

Lomax & Savvaidis, 2021, High-precision, absolute earthquake location using source-specific station terms and inter-event waveform similarity, *in preparation*.

Lomax, 2020, The 2020 Mw 6.5 Monte Cristo Range, Nevada earthquake: relocated seismicity shows rupture of a complete shear-crack system. <https://eartharxiv.org/repository/view/1904>

See also: EGU21-13447 Imaging damage zones and fault growth processes with high-precision relocations of earthquake sequences.

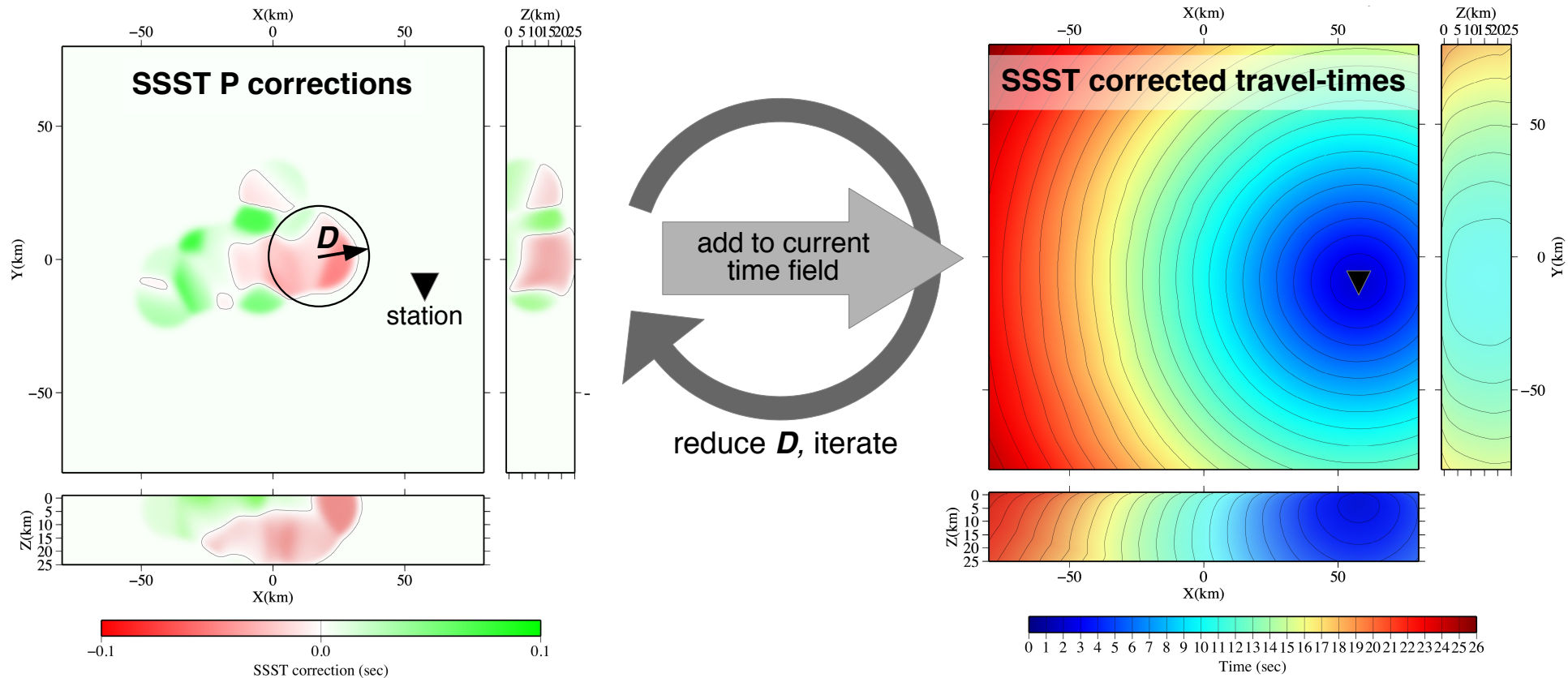
Absolute earthquake location forms a foundation and framework for earthquake response and basic seismological studies, including relative location.

NLL-SSST-coherence: a procedure for *high-precision, absolute* relocation including:

- probabilistic, global-search location: robust to model and arrival-time error
NonLinLoc algorithm (Lomax et al., 2000, 2005, 2008, 2014)
- source-specific, station travel-time corrections (NLL-SSST) → 3D maps of perturbed times
(Richards-Dinger & Shearer, 2000; Nooshiri et al., 2017)
- high-precision relocation based on waveform similarity between events (NLL-coherence)
(Lomax, 2020, 2021)

Source-Specific, Station Term travel-time corrections (NLL-SSST)

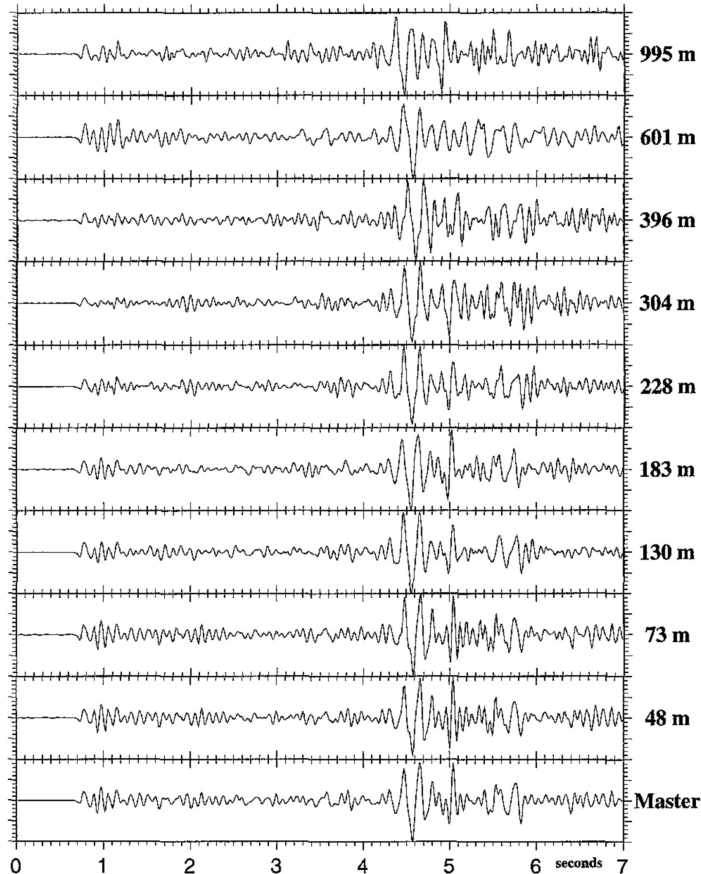
NLL-SSST performs an iterative accumulation of mean travel-time residuals for a station over smaller and smaller source areas of size $\sim D$.



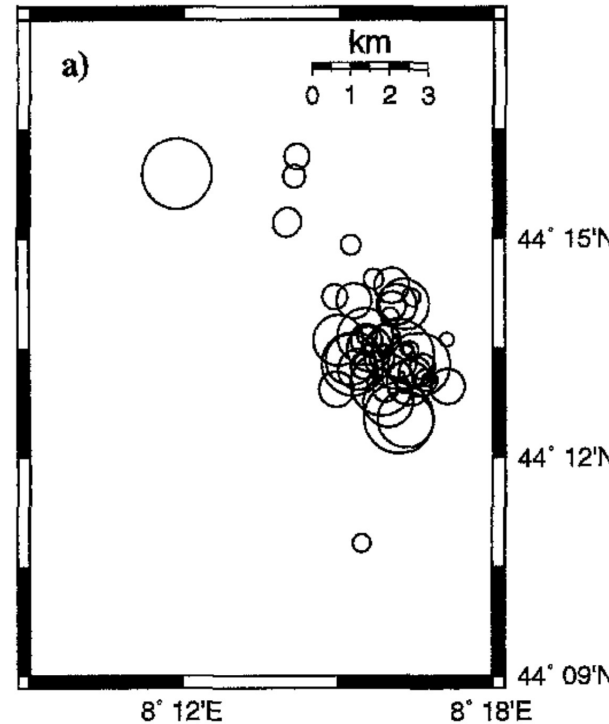
High-precision relocation based on waveform similarity between events (NLL-coherence)

If the waveforms at a station for two or more events are very similar (have high coherency) up to a given frequency, then the distance separating these “multiplet” events is small relative to the seismic wavelength at that frequency (e.g. Geller & Mueller, 1980)

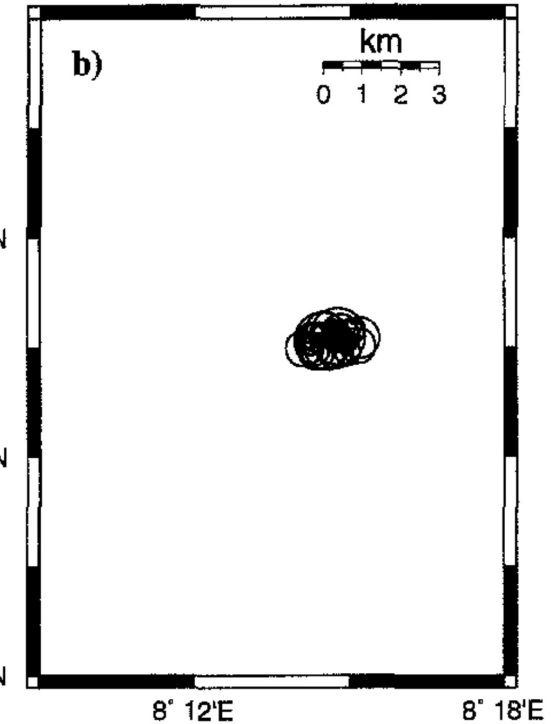
similar, multiplet event waveforms



routine locations



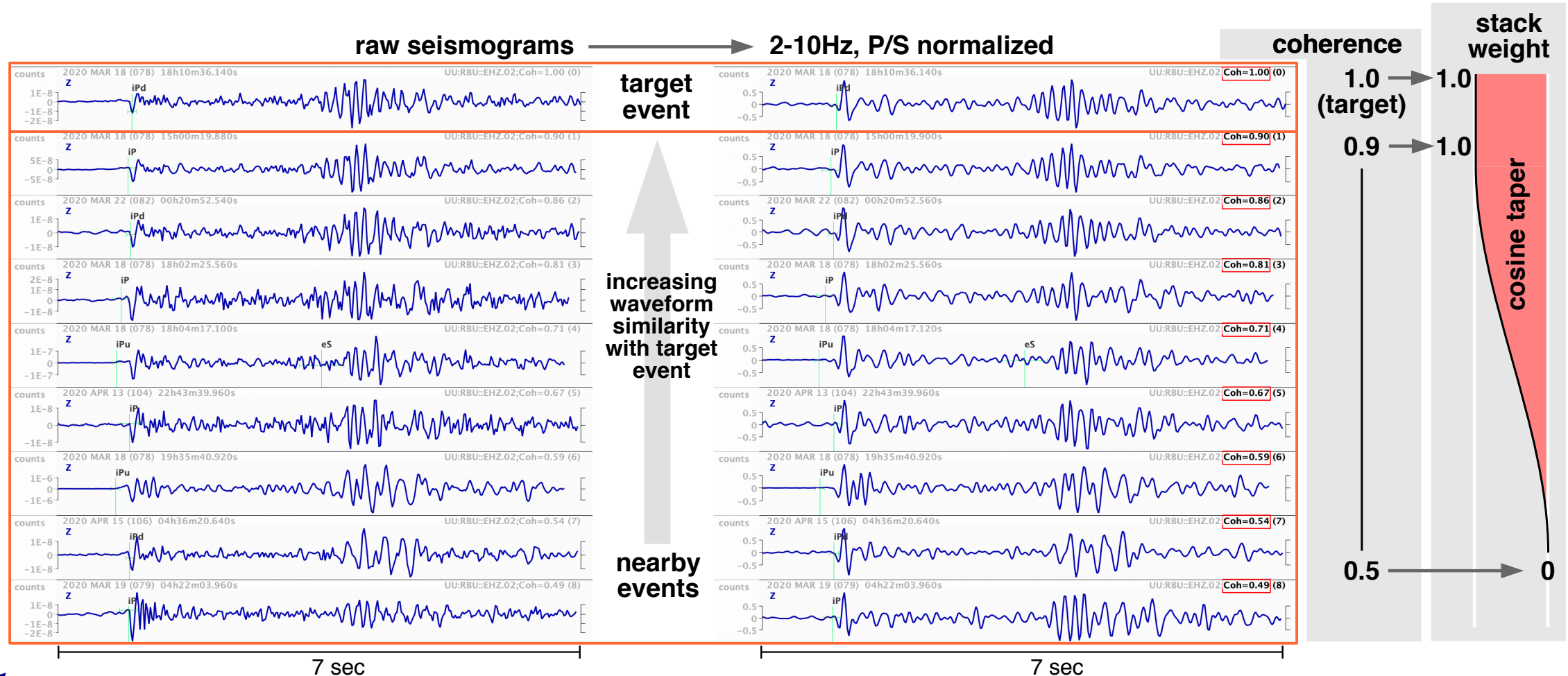
waveform similarity based, relative location



Cattaneo et al. 1997

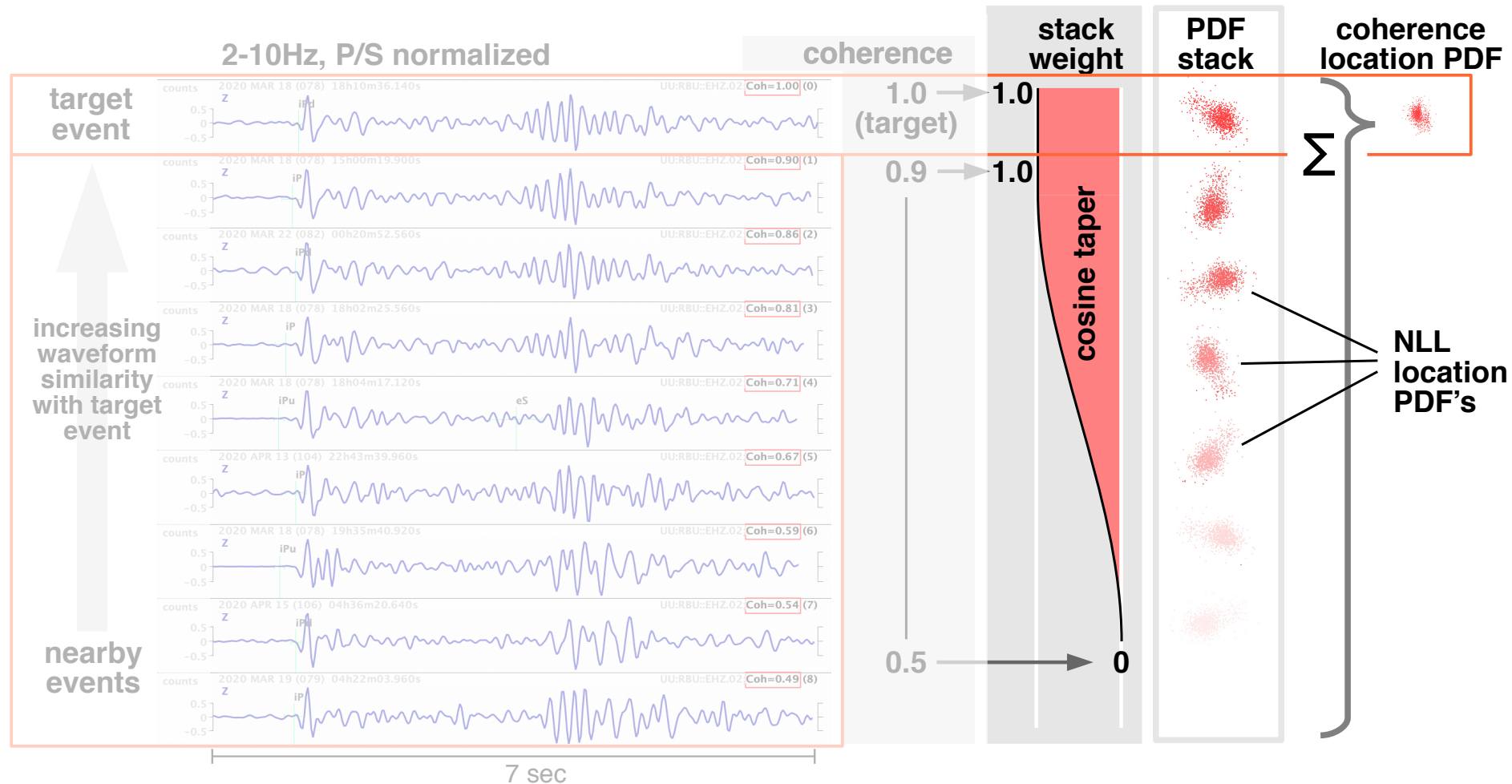
High-precision relocation based on waveform similarity between events (NLL-coherence)

Coherence is the maximum of cross-correlation between two waveforms.
NLL-coherence: Coherences from a minimum cutoff (e.g. 0.5) to 1.0 are mapped to 0 → 1 weights, which will be used for stacking of NLL locations over events.



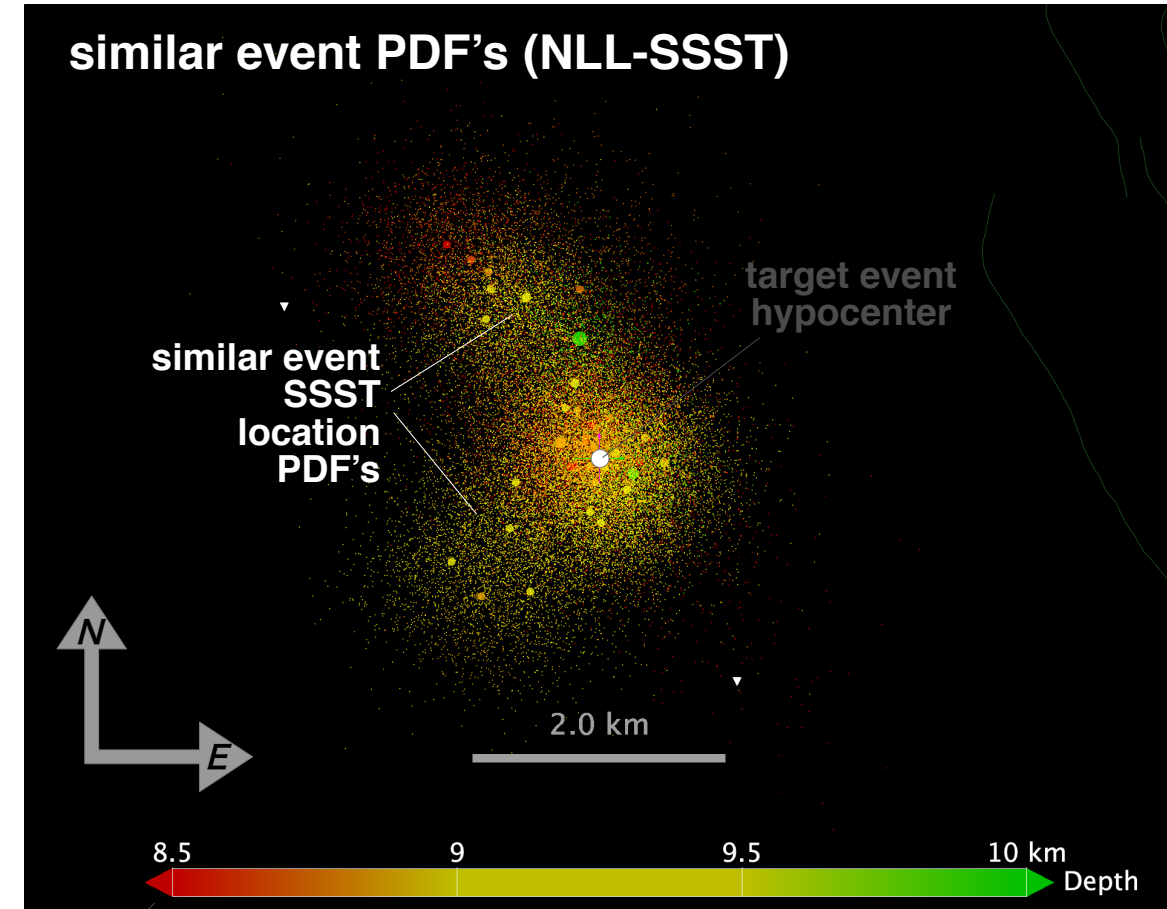
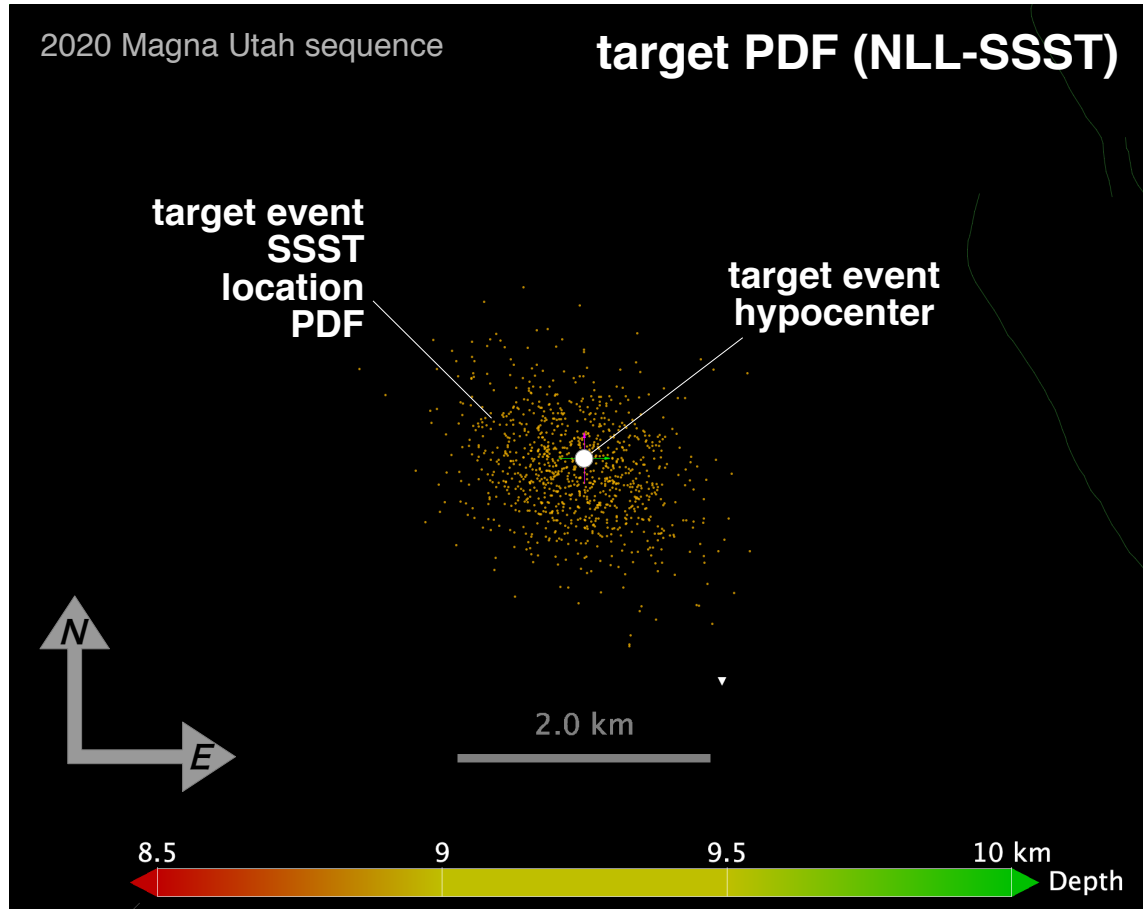
High-precision relocation based on waveform similarity between events (NLL-coherence)

NLL coherency relocation stacks the NLL-SSST location PDF (uncertainty cloud) for a target event with the PDF's for other nearby, similar events.



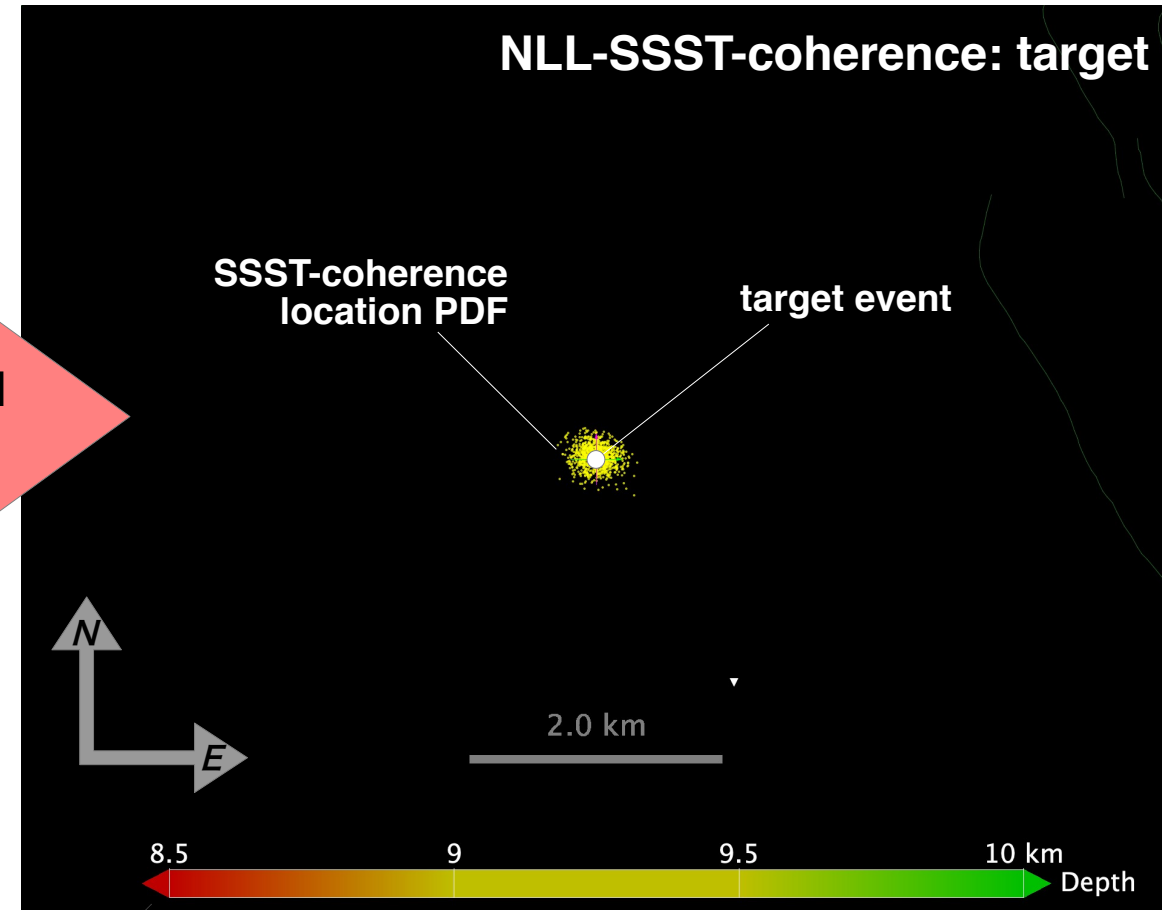
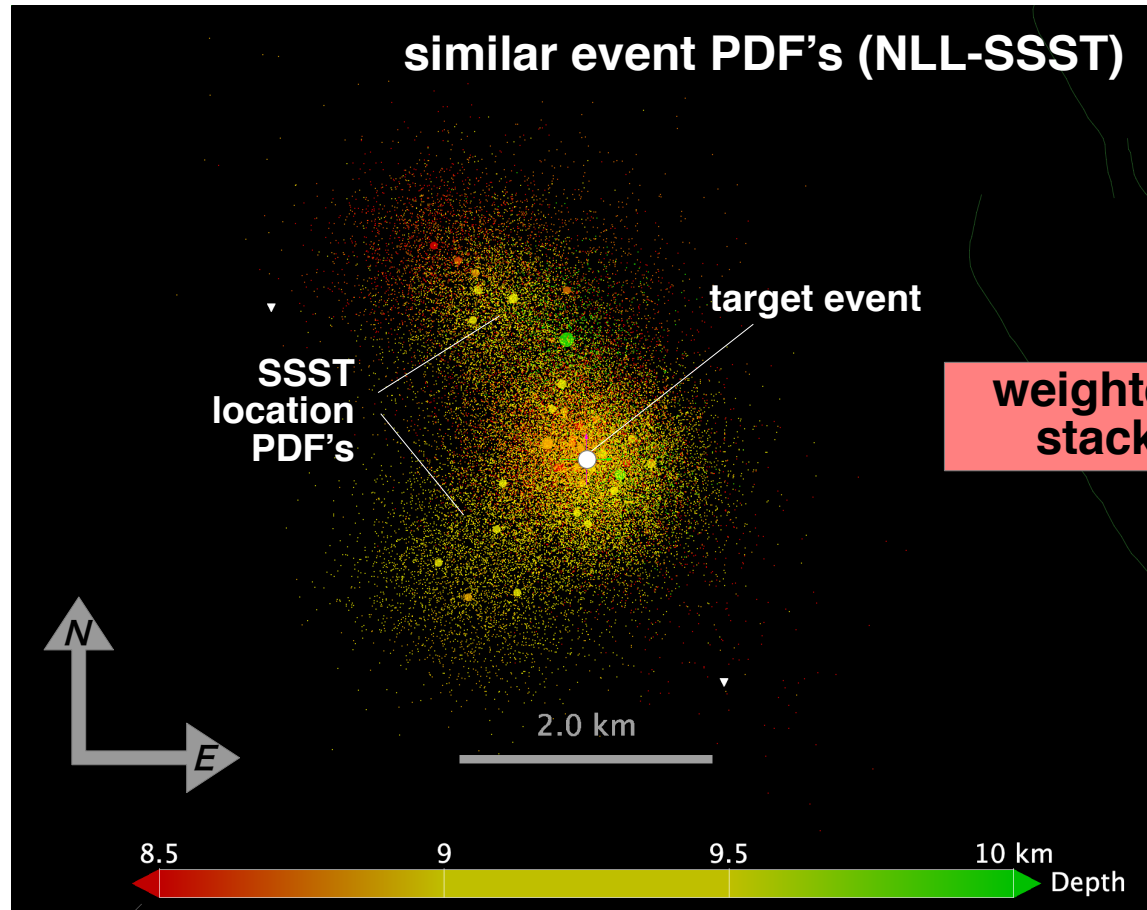
High-precision relocation based on waveform similarity between events (NLL-coherence)

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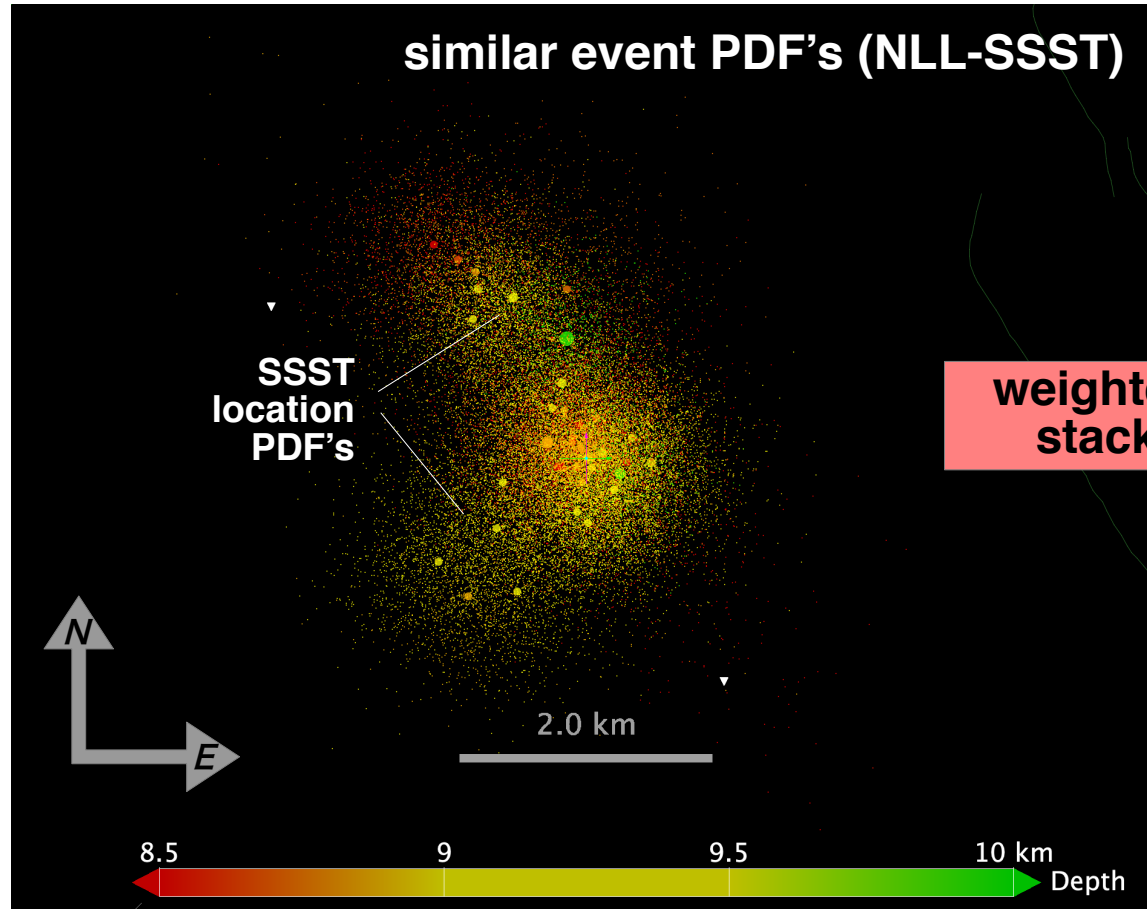
High-precision relocation based on waveform similarity between events (NLL-coherence)

NLL coherency relocation for a target event is a stack over 3D space of the event's location PDF with the PDF's for other events, weighted by the waveform coherency between the target event and the other event.

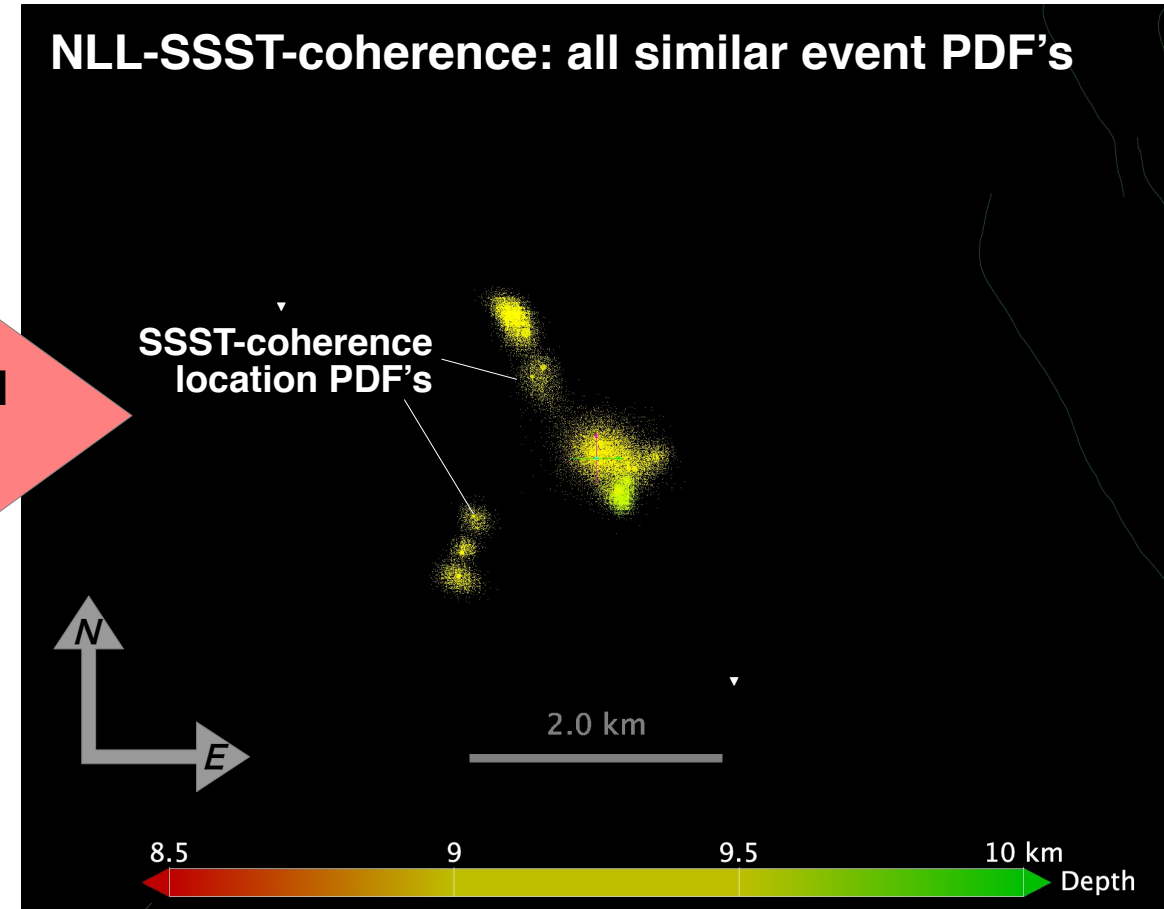


High-precision relocation based on waveform similarity between events (NLL-coherence)

The hypocenters and PDFs for a set of similar events show NLL-coherence location produces clustering and organization of locations, and greatly reduced PDF extent (formal location uncertainty).



**weighted
stack**



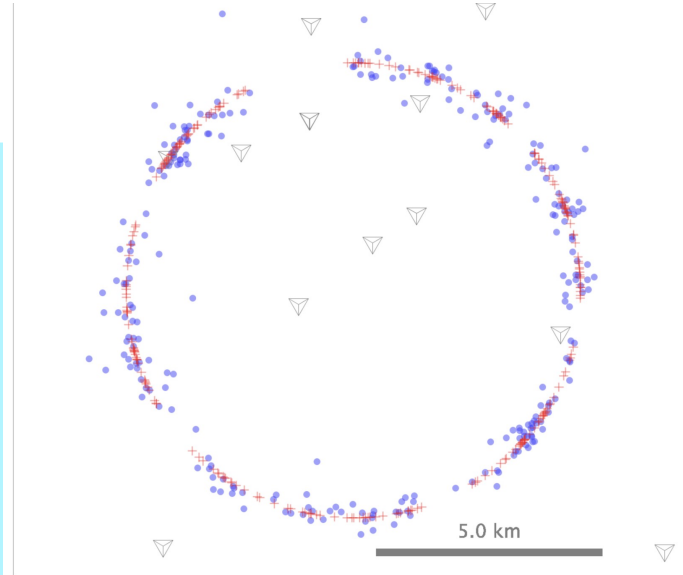
Synthetic test of absolute, coherency relocation

NLL-coherence: correctly reduces hypocenter scatter, removes outlier hypocenters and clusters nearby events. But tends to over-tightly cluster events.

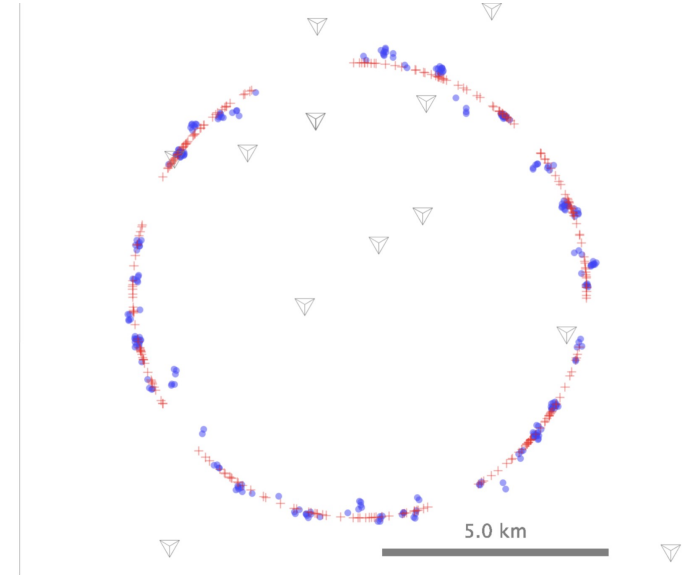
generate P&S arrivals
for clustered synthetic
events on a circle (red)

locate with P&S arrival noise (blue)

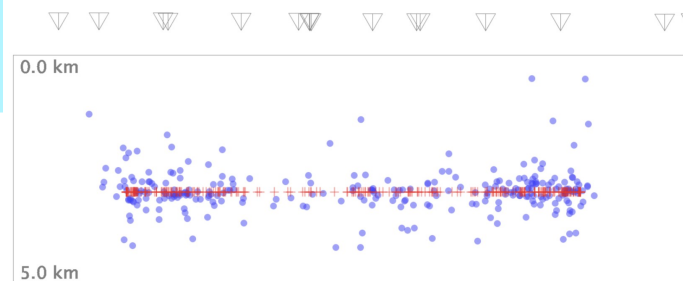
then relocate with NLL-coherence (blue)



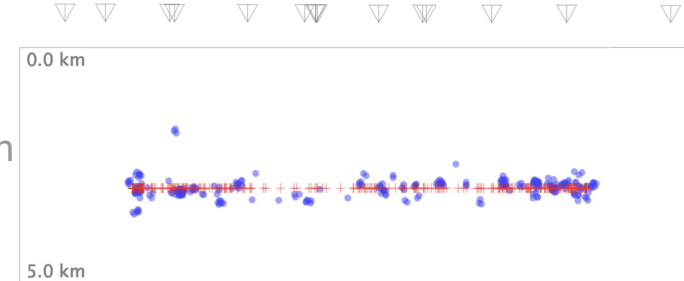
map
view



synthetic coherence is
derived from the true
separation of original
synthetic events

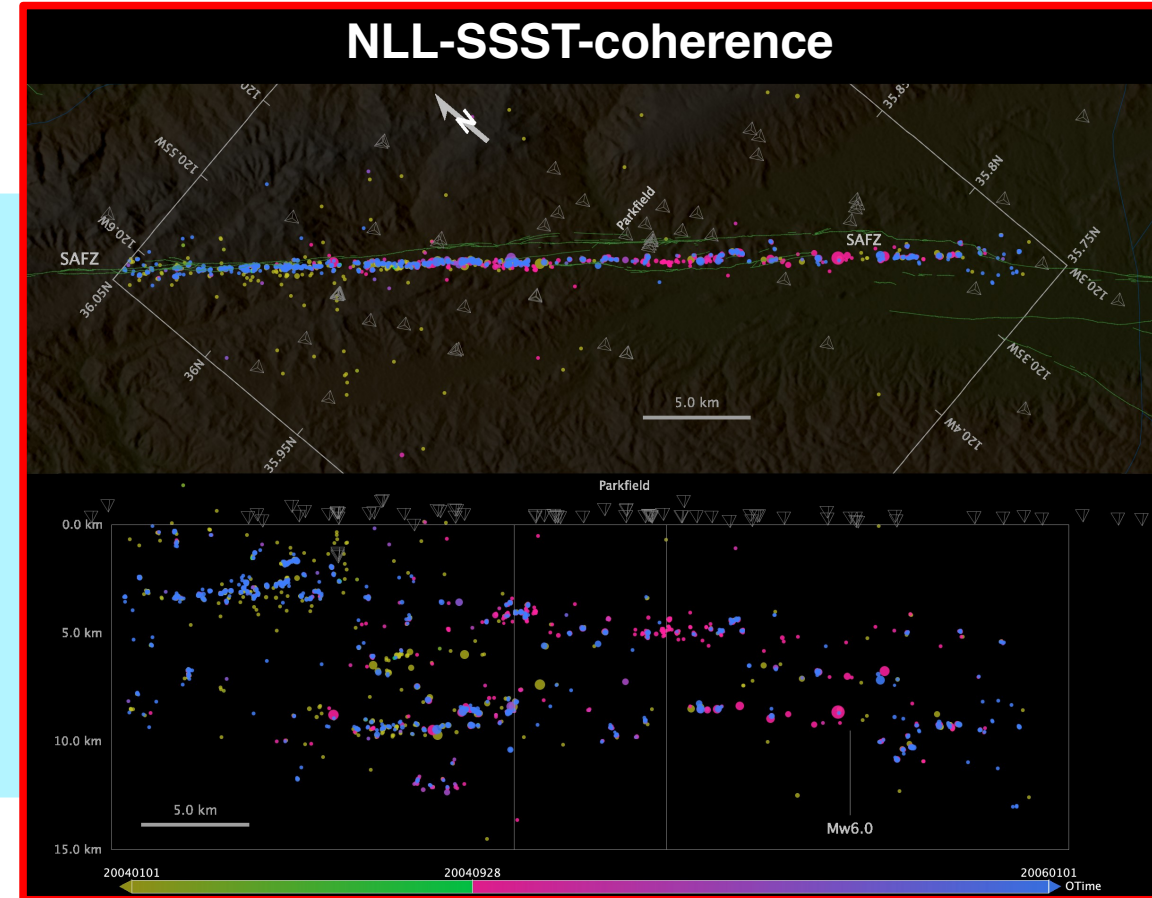
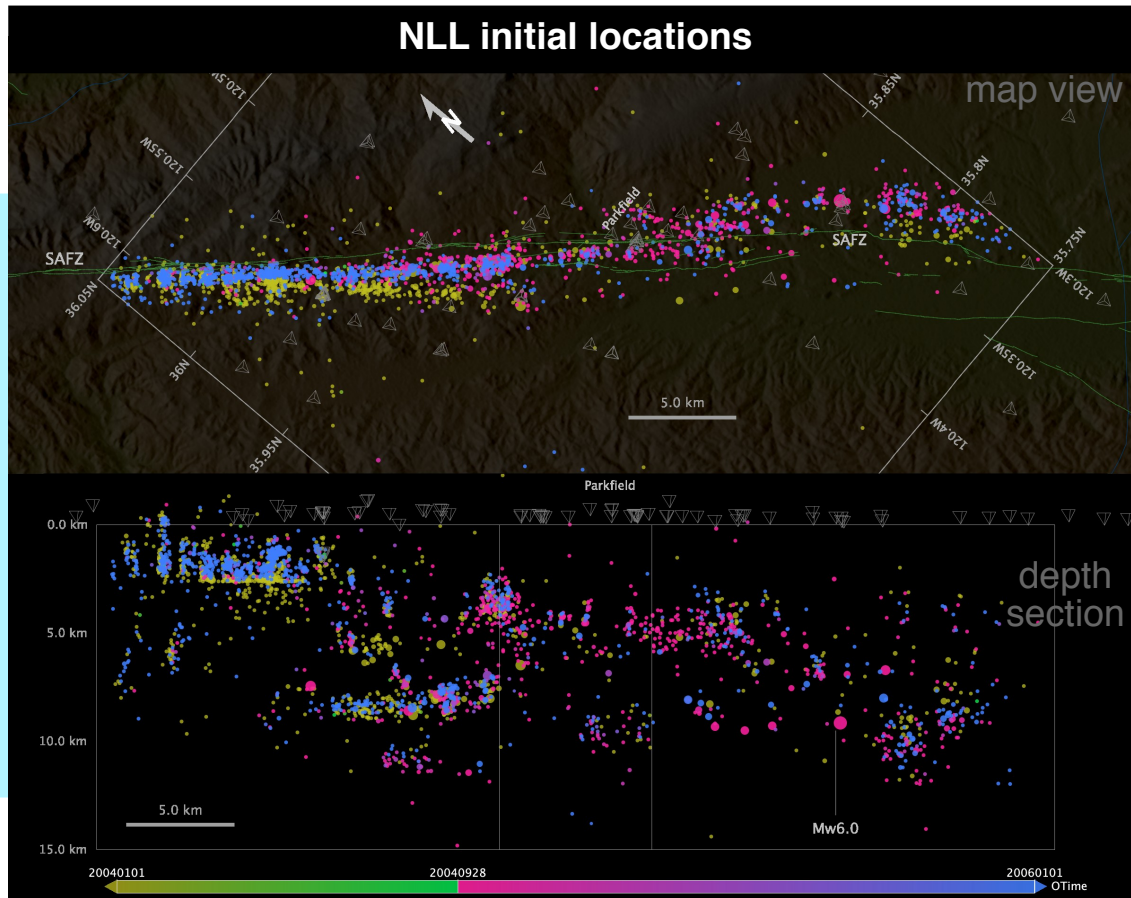


depth
section



2004 Parkfield California sequence: excellent station coverage

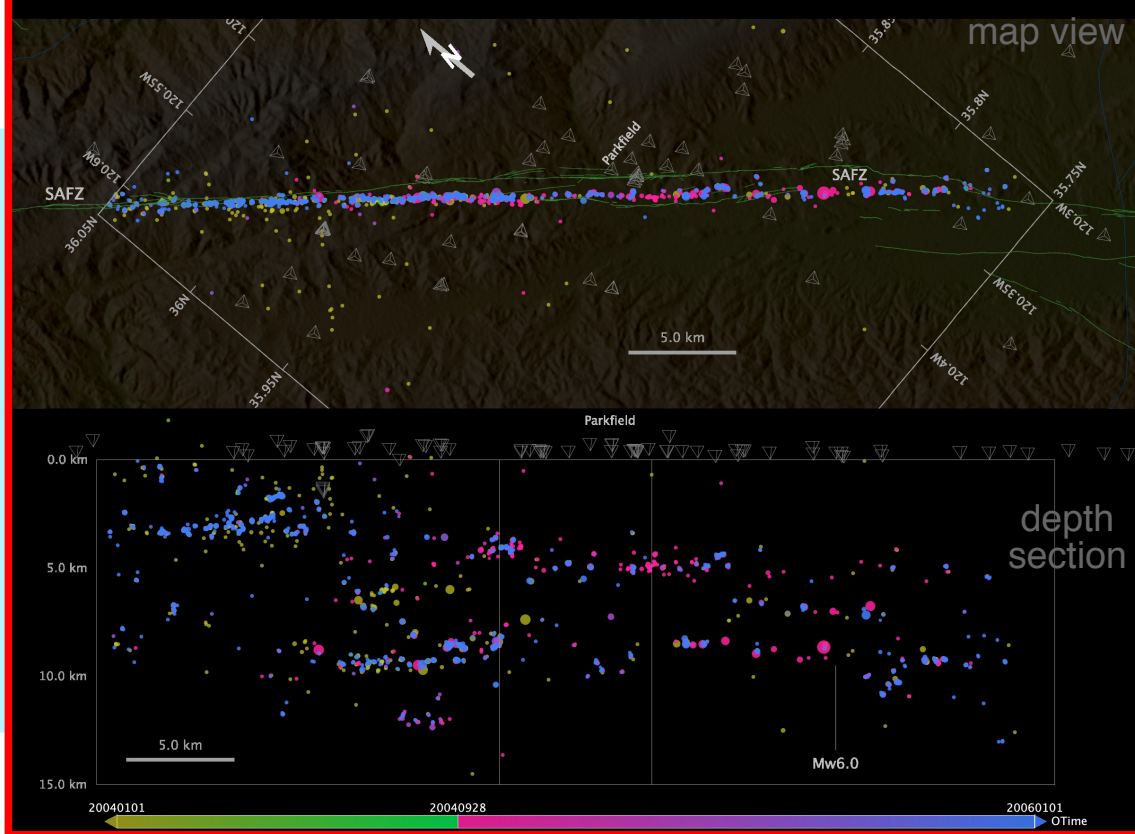
NLL-SSST-coherence absolute location show greatly increased organization, clustering and depth resolution relative to routine, initial locations.



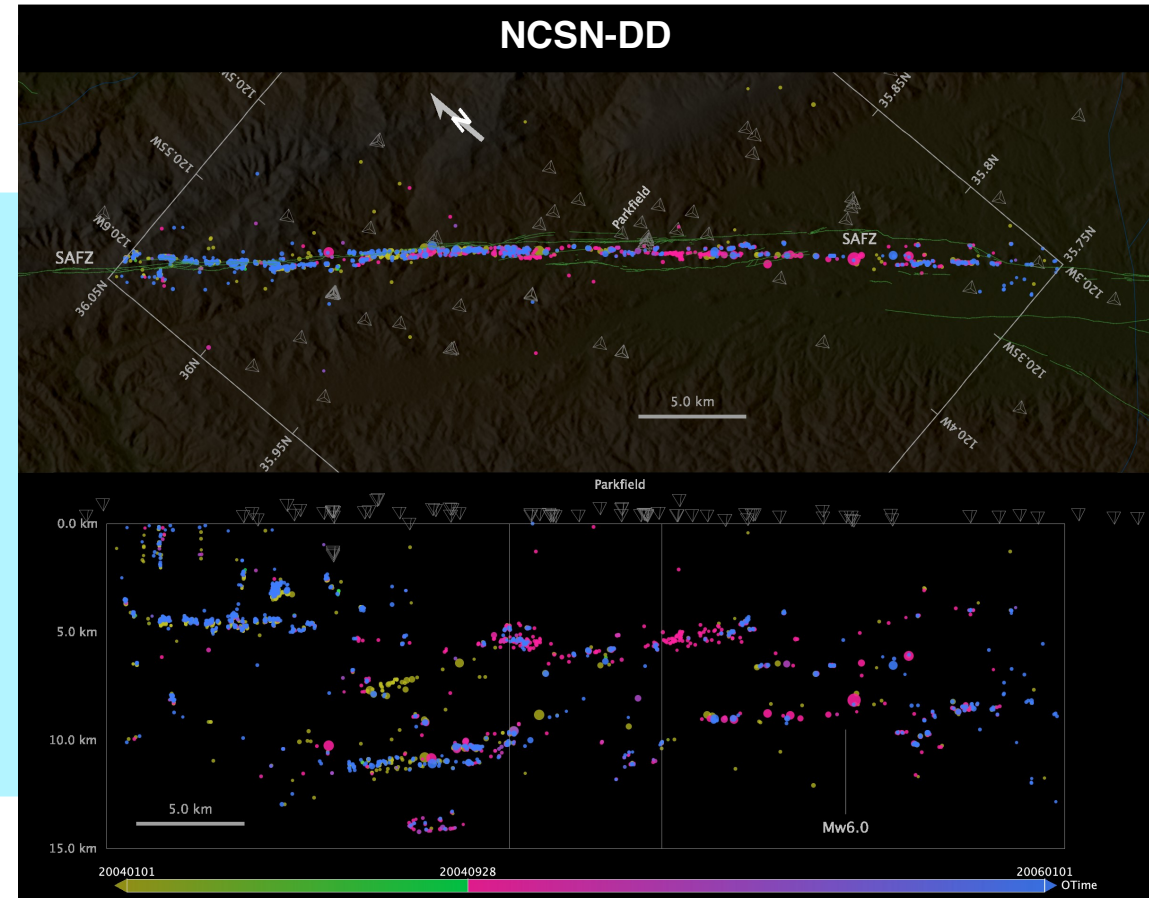
2004 Parkfield California sequence: excellent station coverage

NLL-SSST-coherence absolute location approaches the precision of relative location using cross-correlation arrival differences (NCSN-DD).

NLL-SSST-coherence



NCSN-DD

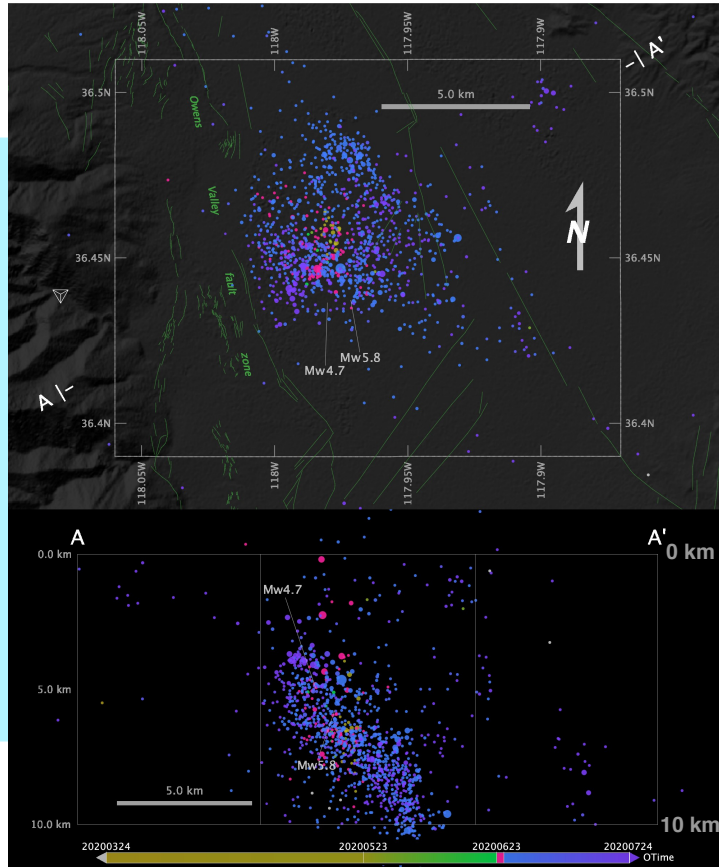


NCEDC (2014), doi:10.7932/NCEDC

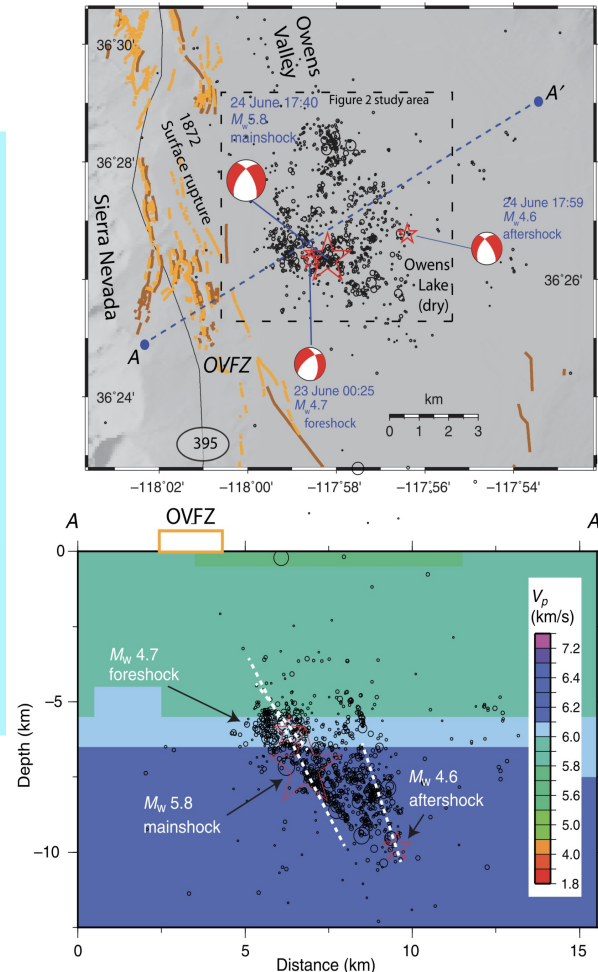
2020 Mw 5.8 Lone Pine sequence: complex normal faulting, few nearby stations

NLL-SSST-coherence locations show increased organization, clustering and depth resolution over USGS catalog and Hauksson et al. 2020 relative locations.

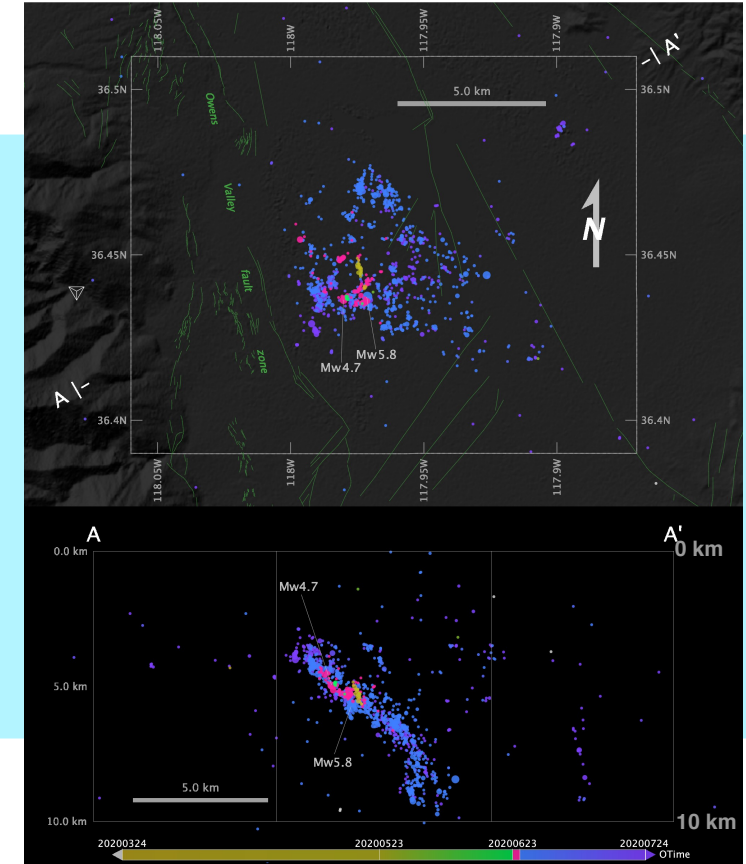
USGS-SCSN catalog absolute



Hauksson et al. 2020: relative



NLL-SSST-coherence

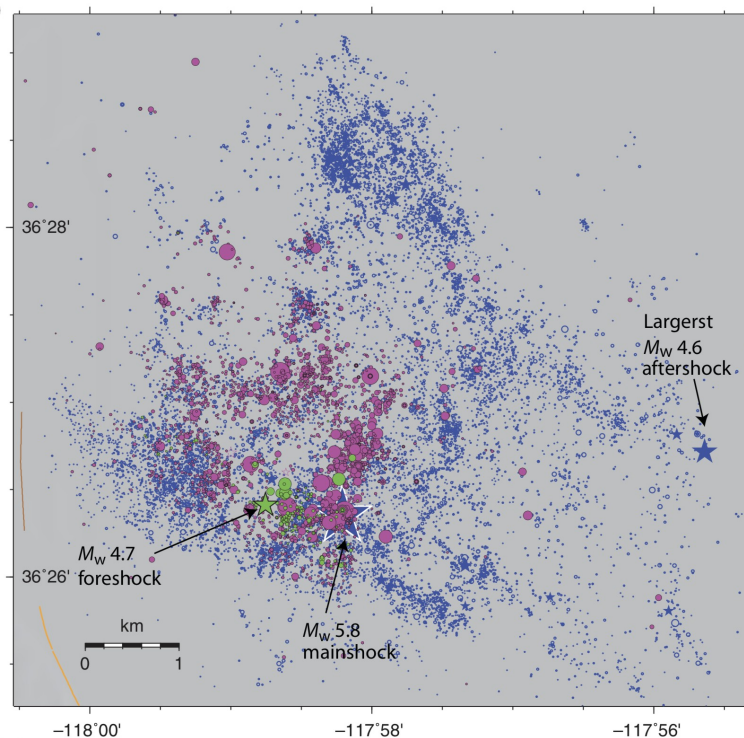


2020 Mw 5.8 Lone Pine sequence: complex normal faulting, few nearby stations

NLL-SSST-coherence shows clusters and lineations that roughly match those in the QTM catalog, but NLL-SSST-coherence clusters are typically sparser and more concentrated.

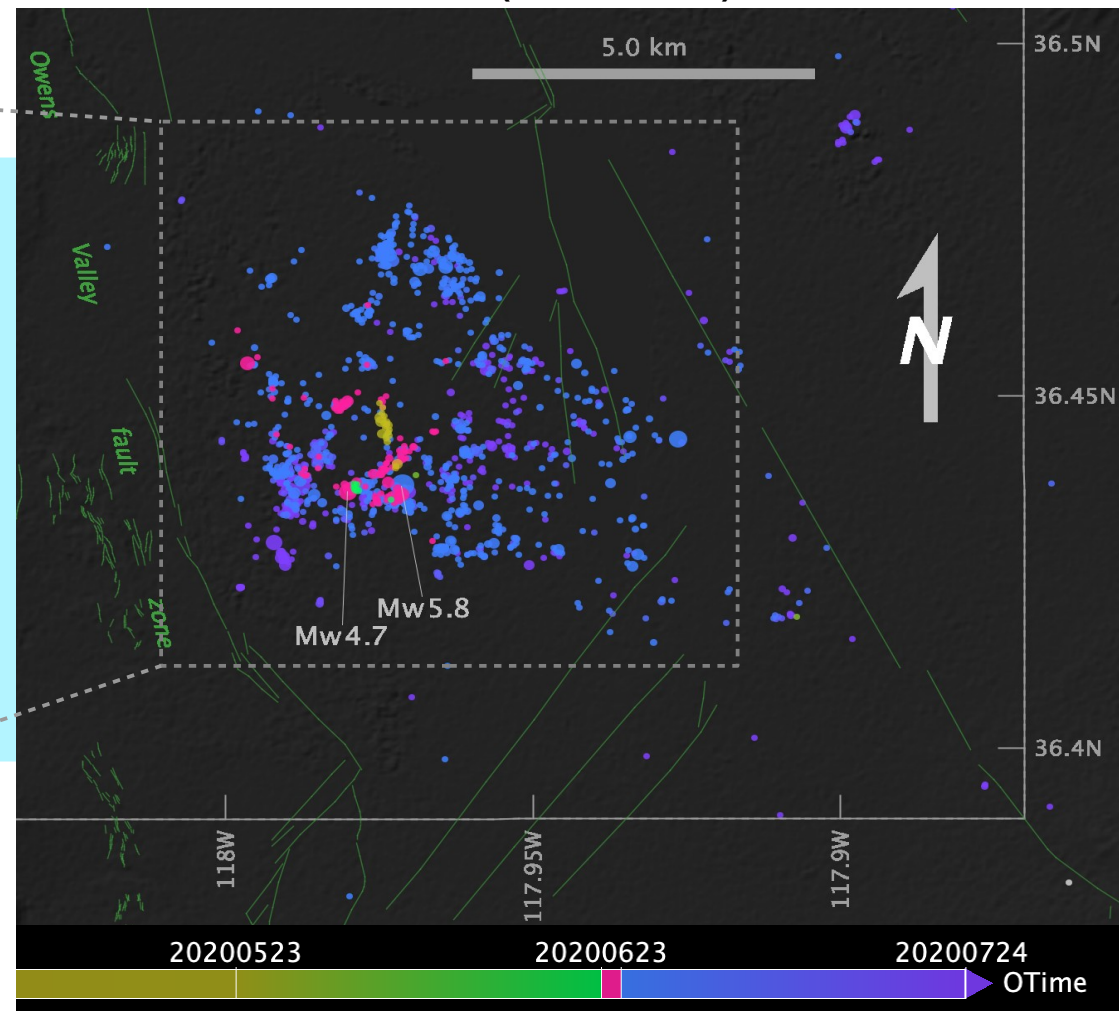
Hauksson et al. 2020

QTM template matching – GrowClust relative relocation
(~24,000 events)



“inconsistent depth distribution”

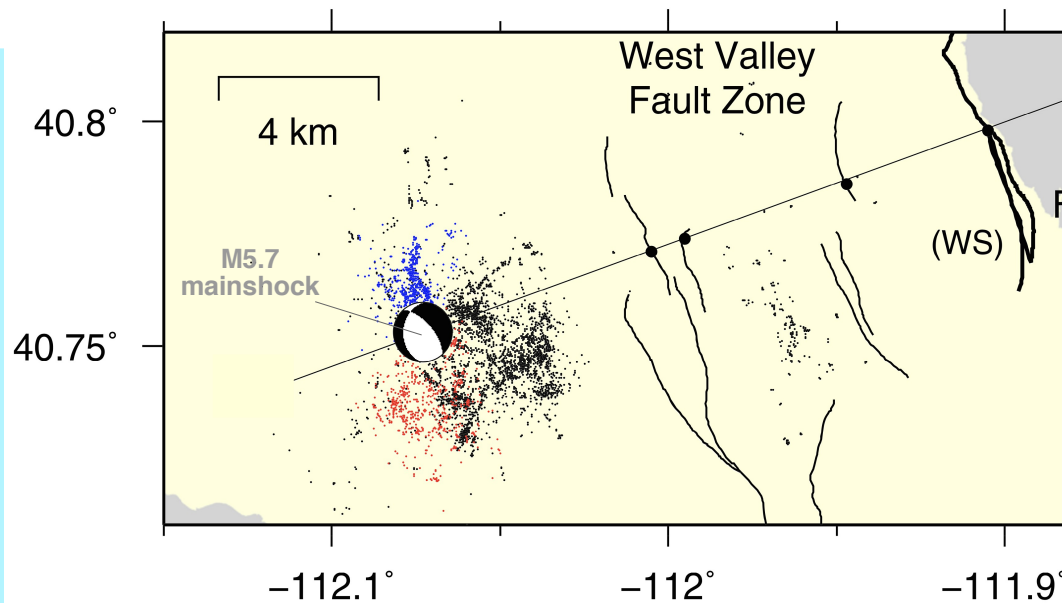
NLL-SSST-coherence (1044 events)



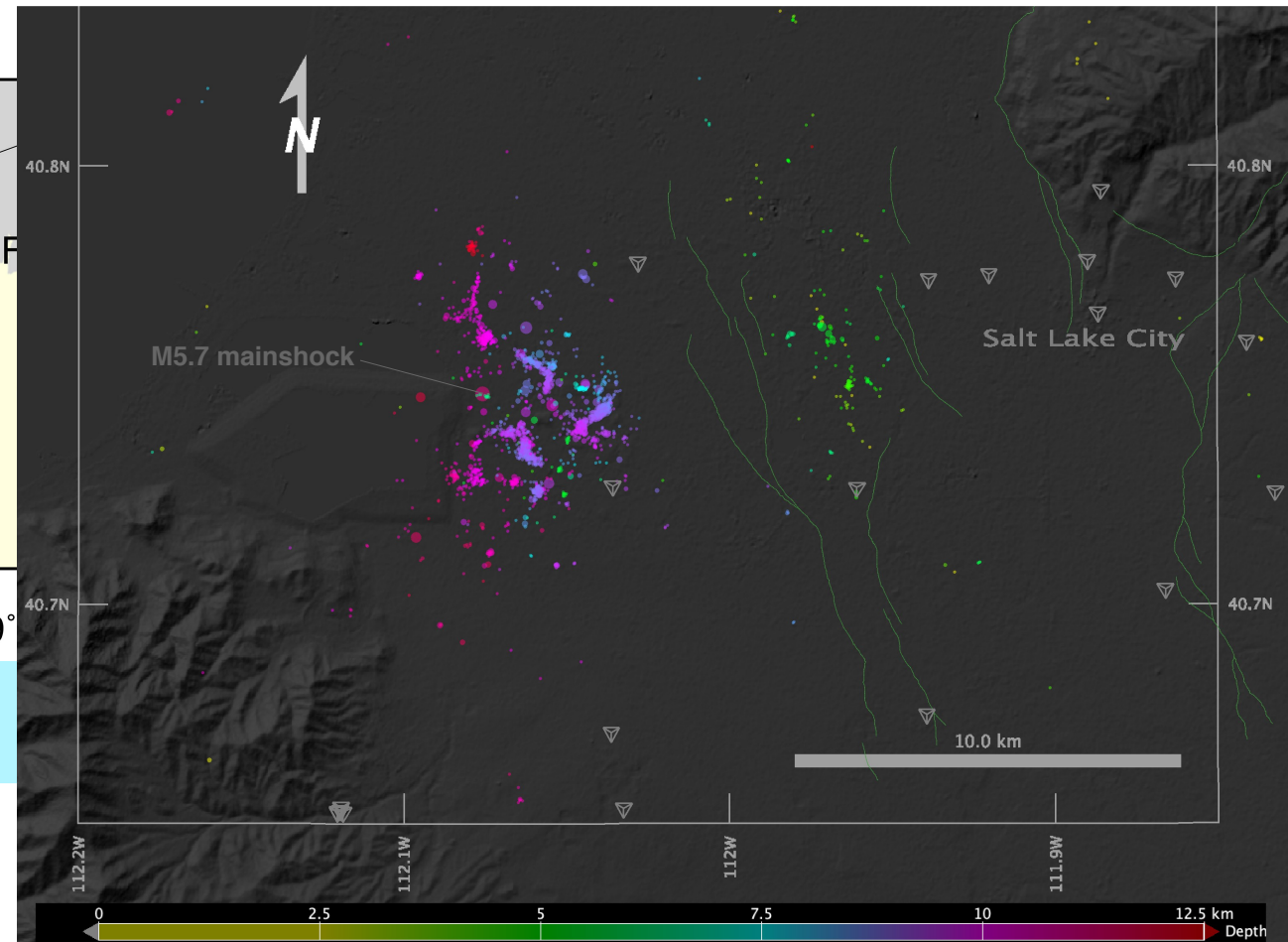
2020 Mw 5.7 Magna Utah sequence: complex normal faulting, good station distribution

NLL-SSST-coherence clusters and lineation are similar to those in the relative location catalog, but again NLL-SSST-coherence clusters are typically sparser and more concentrated.

Pang et al. 2020
template matching – GrowClust relative relocation
(5623 events)



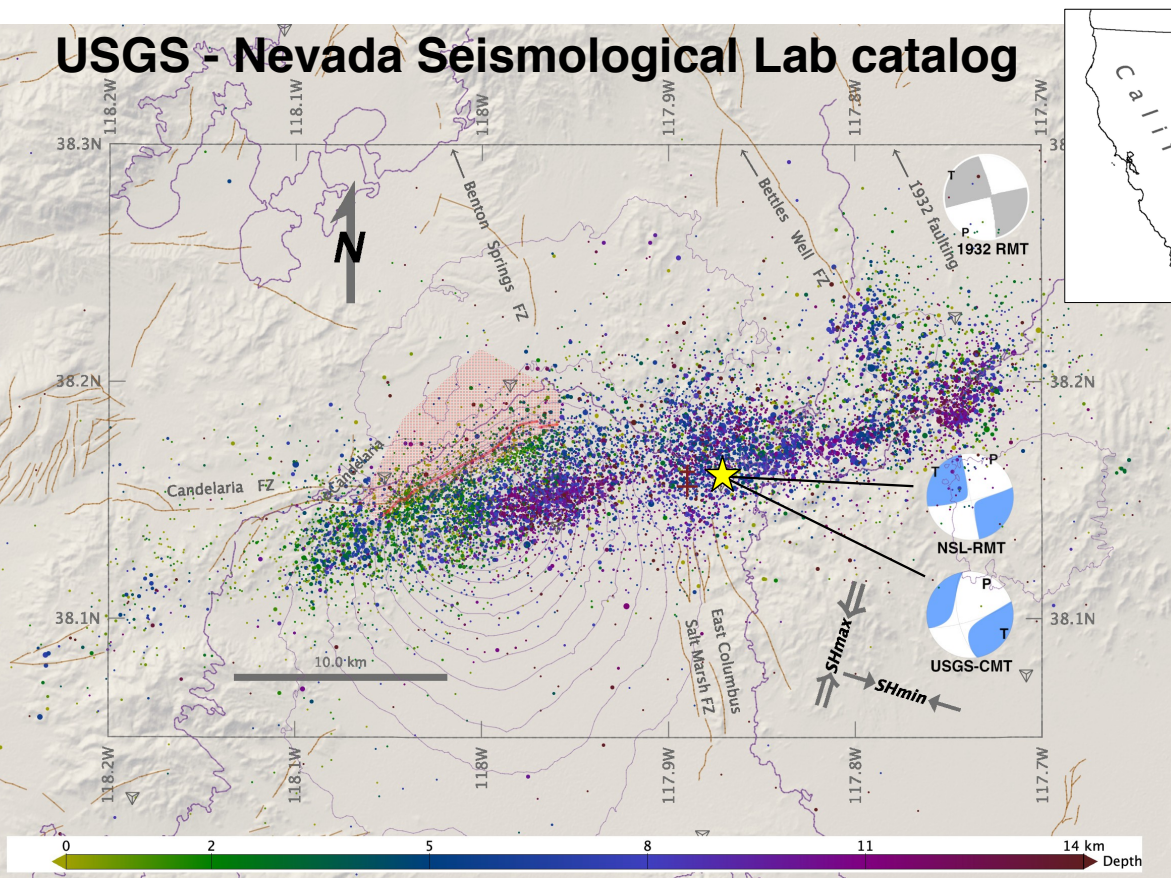
NLL-SSST-coherence (2570 events)



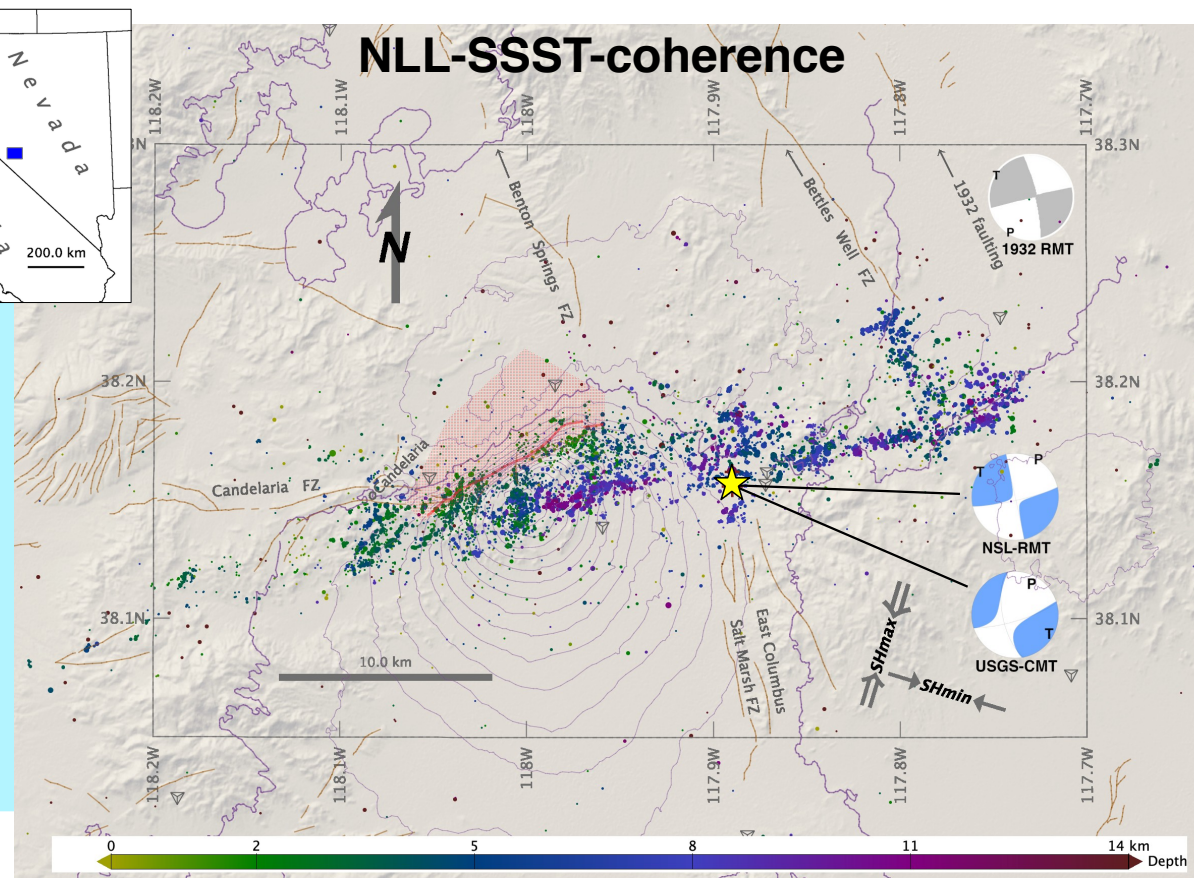
Mw 6.4 2020 Monte Cristo, Nevada sequence

NLL-SSST-coherence relocations greatly sharpens clustering and features in the seismicity relative to routine catalog locations.

USGS - Nevada Seismological Lab catalog

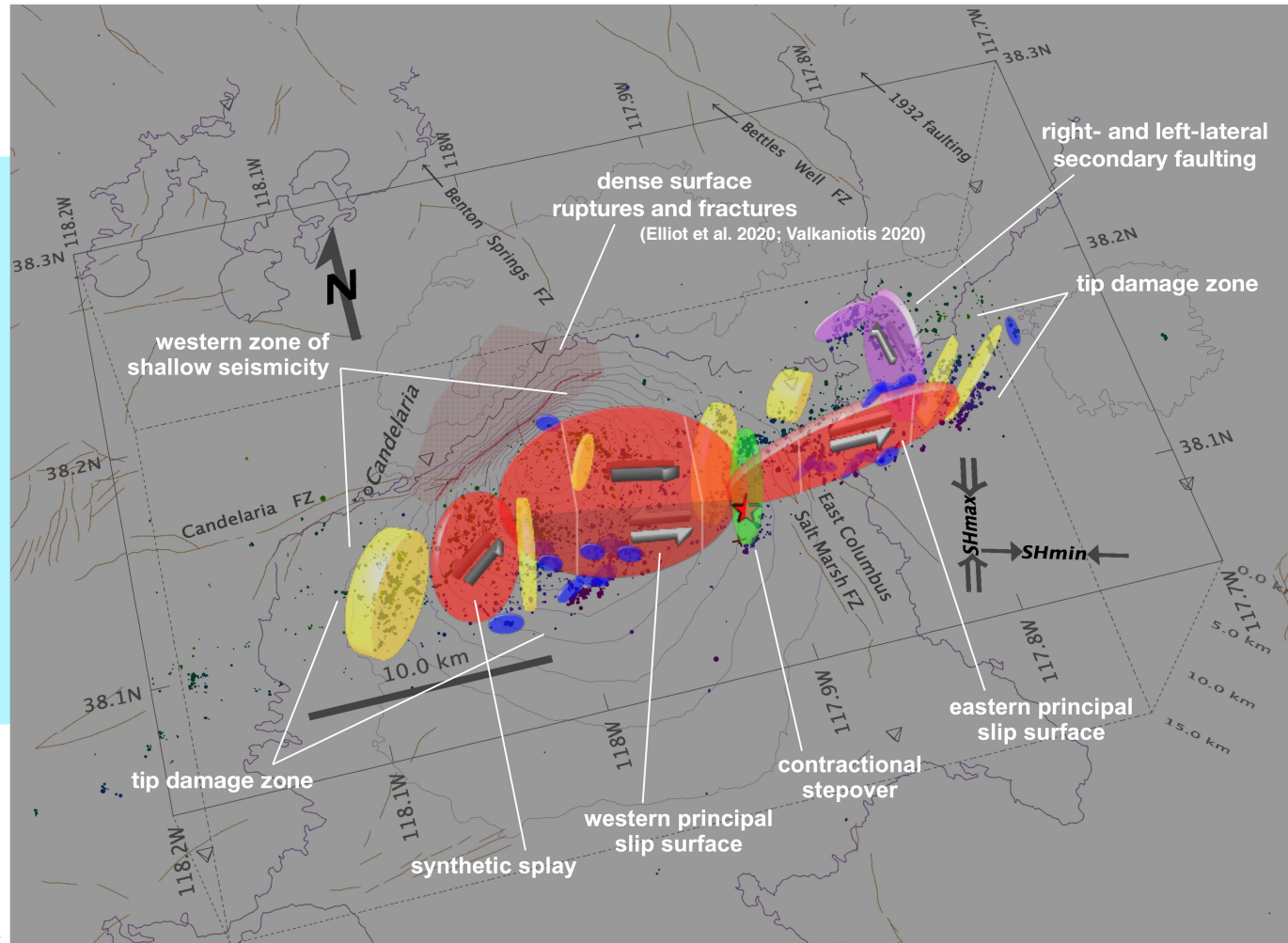


NLL-SSST-coherence

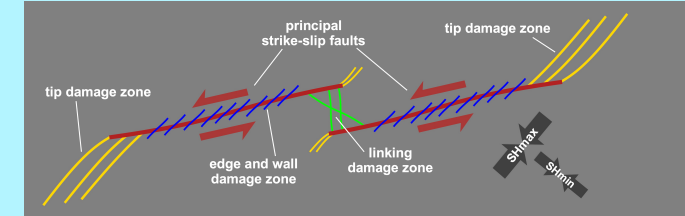


Lomax 2020

NLL-SSST-coherence absolute relocations show rupture of a complete shear-crack system. Schematic shows simplified interpretation of primary fault planes, main fault damage zones and surface fracturing.



A complete shear crack system is composed of principal faulting cores surrounded by tip and linking damage zones.



Lomax 2020

Conclusions and Discussion

- We have introduced a new procedure (NLL-SSST-coherence) for high-precision, probabilistic, absolute earthquake location which uses source-specific station corrections (NLL-SSST) and inter-event waveform similarity measured by cross-correlation coherence (NLL-coherence).
- NLL-SSST and NLL-coherence together greatly increase location precision over initial seismicity catalogs.
- NLL-SSST-coherence approaches the precision of cross-correlation based, relative location. For sequences with few or no nearby stations, NLL-SSST-coherence may produce more stable and meaningful hypocenter locations, especially in depth.
- NLL-SSST-coherence can be used to get an optimal set of absolute, starting locations before application of a relative location procedure.
- NLL-SSST-coherence requires less computing resources than cross-correlation based, relative location, and can be applied with events in a sequence before temporary station deployments and to older sequences with few waveform data.

See also: EGU21-13447 Imaging damage zones and fault growth processes with high-precision relocations of earthquake sequences.

<https://meetingorganizer.copernicus.org/EGU21/EGU21-13447.html>

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Richards-Dinger, K. B., and P. M. Shearer, 2000, Earthquake locations in southern California obtained using source-specific station terms, J. Geophys. Res., 105, no. B5, 10939–10960, <https://doi.org/10.1029/2000JB900014>