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Interactive comment on "Fully probabilistic seismic source inversion – Part 2: Modelling errors and station covariances" *by* Simon C. Stähler and Karin Sigloch

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Summary

This is a nice paper that (to me) offers two important parts: (1) the traditional cross-correlation (CC) provides a more stable measurement of waveform misfit than either the L1 or L2 norms (2) a complete data covariance matrix can be estimated (prior to the inversion) that takes into account the station spacing and statistical properties of noise in the data. The source is described as in Stahler and Sigloch (2014): hypocenter, magnitude, moment tensor, and coefficient for a source time function. The target is on P and SH teleseismic waveforms, and it is unclear how extensible this is to, say, surface waves. The paper is very well written and well presented, with the exception of

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a few points (below). Data covariances tend to be messy (and ignored), but I think this paper brings a certain amount of elegance to the problem. Using a full data covariance seems tractable (if CC is the misfit function), and I suspect there are cases where it will really impact the estimated parameters of the source.

I recommend the paper be published after minor revisions.

General points

+ I think there needs to be more emphasis on the point that this study applies to teleseismic P wave source inversion. It is true that the main concepts are general, but some of these main concepts (or choices) could be overwhelmed by other factors for an inversion based on surface waves. Moment tensor inversion codes "standards" for global (GCMT, USGS) and regional (Dreger) scales are all based on surface waves, where cross-correlation measurements may be inappropriate in the presence of frequency-dependent dispersion. It might be helpful to have something in the discussion about what the authors expect might be needed if one were to consider surface waves in addition to body waves. Cycle skipping can be a nightmare with surface waves – even an excellent CC value can doom an inversion, for example. What will the noise characteristics be for surface wave measurements – do we expect them to follow a log-normal distribution?

+ I had some challenges determining exactly what was done. Search for the label 900, for example, to see the different descriptions. Are these 900 different earthquakes or could they be 900 different solutions for the same earthquake? (I'm assuming it's 900 different earthquakes, but please try to make this more clear, if so.)

+ On a related point, is ns really the number of seismograms or is it the number of time windows used? If you have a P and S measured on two different components (Z and R), would that be ns = 4 or ns = 2?

+ In essence, the authors are proposing a misfit function based on the cross-correlation. The implication is that such a misfit function could be used within adjoint-based source or structure inversions. If so, perhaps make a statement that one could start with the misfit function and derive an adjoint source (e.g., Tromp et al. 2005).

+ P15, L23. Somewhere in Step 5 you should at least mention that you generate synthetic waveforms and subject them to (some of) the same processing steps as the data. For example, D never appears in the description (though it is there).

Add this clause: "... equation 20, which contains N decorrelations between observed and synthetic waveforms, and combine..."

+ P17, L32. "where n is the number of stations used to estimate the source parameters of one earthquake" Would it be easier to generalize this to the number of time windows used for one earthquake? You have up to 3 components and up to X windows per time series.

+ P3, L8. "Depth is one parameter and a normalized description of the moment tensor requires five more (a more rigorous and uniform parameterisation of the moment tensor has been derived by Tape and Tape, 2015, 2016)."

Thanks for the nod. Stahler and Sigloch (2014) is distinguished by their use of a uniform parameterizaion for moment tensors, something that is seldom done in grid searches. (They also used an ad hoc constraint on the prior toward double couples.) You might want to replace the word "focal mechanism" (which people may interpret as double couple moment tensors, by which I mean eigenvalues -lam, 0, lam) with "moment tensor" (which includes "full" moment tensors). Your approach can probably handle full moment tensors even more easily than double couple moment tensors, since no constraint is needed in the case of full moment tensors.

+ A fraction of your audience will invariably wonder, "So does it matter whether we use a sophisticated data covariance?" You did this for the Virginia earthquake. Do you want to comment on how the use of SD might impact the determination of the mean model or the associated uncertainties (the "Bayesian beachball" in the authors' parlance).

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Miscellaneous points

+ Figure 3 is an excellent demonstration. A few comments:

The text (P9, L24) says alpha=0.9, beta=0.5 for Figure 3. The text about the figure says alpha=0.4, beta=0.8.

"in 40deg distance" to "at an epicentral distance of 40deg"

How many stations were used for this synthetic test? I don't have a sense for the distribution of stations by distance or azimuth (or even how many).

It says "The normalization coefficients are plotted in the top right corner." Are they? (Or do they need to be?)

separate –> separately

+ Eq. 28. Why log10? Using ln, you would have a number that is equivalent to percent difference in the limit of small values. Traditional amplitude measurements have been delta ln A (e.g., Baig and Dahlen, 2002).

+ There are several occurrences of words separated by /: uncorrelated/correlated 95%/2 sigma Gaussian/l^2 "l^1/l^2" Please find a way to eliminate the usage of /, since it is ambiguous (and, or, division?).

+ P1, L10. "of the broadband fits" add": between observed and modeled waveforms.

+ Table 1. Might want alpha and beta here. They seem important.

+ Eq. 3. Describe k' (presumably normalization factor).

+ P5, L28. "of how to construct" what?

+ I've come across some studies that weight stations by voronoi cells, so a big voronoi

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cell would have a big weight. Not sure if this is worth mentioning.

+ Figure 4. I think it'd be better to just have six labels in the legend. Or delete the legend and extend the labels at right to "D - weak pert," D - strong pert.," etc. Add label to ""the decorrelation D has a higher...".

+ Figure 8. I think the dotted lon-lat lines are more harmful than helpful in the small globe plots.

Please state if this is a subset of stations used in the inversion or whether this includes all stations in the inversion (how many for P and SH?). Please explain the two epicentral small circles plotted (32 and 85?).

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