Towards Assessing the Quality of Surface Waves in the Reviewed Event Bulletin

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- The International Data Centre (IDC) produce a Reviewed Event Bulletin (REB) of global seismological events.
- The association of surface waves in the REB is handled automatically with an expected dispersion predictive model and a list of logic rules to handle signals associated with multiple events.
- Three scenarios where this automatic processing can fail have been identified:

1. Signals from $\Delta > 100°$ distance can be misassociated with closer events.

2. As a *P* arrival is required for an event to be formed, arrivals from surface wave only events can be misassociated into other events with a *P* detection.

3. At close distances, impulsive signals from further away can pass the dispersion test.

The inclusion of these misassociated arrivals in an event can reduce the accuracy of the network M_s and hence reduce reliability of the characterisation criterion.

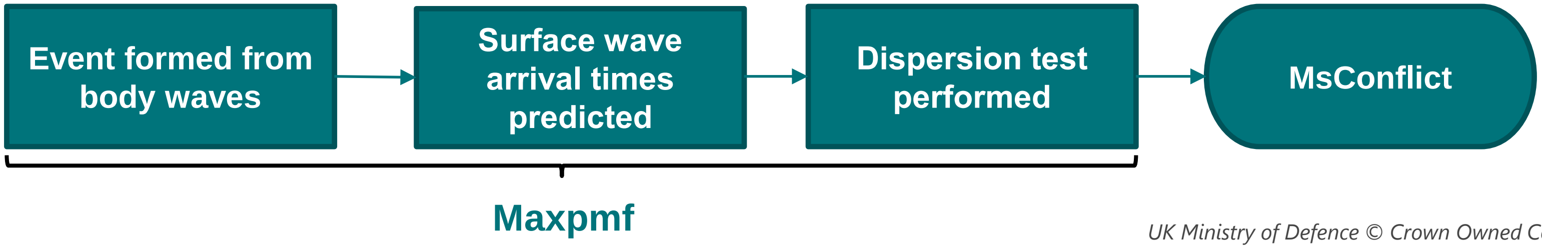
1. IDC Surface Wave Processing

- Current IDC surface wave processing consists of a number of steps:
  - Event is formed from body waves.
  - Predicted arrival times are generated from the regionalized group velocity model.
  - Check to see if signal passes the dispersion test.
  - “MsConflict” handles arrivals associated with multiple events.

- The failure rate assumptions are that the measurements are independent and noise is random. This corresponds to ‘approximately one false detection per day from random noise’ (Stevens *et al*., 2007).

- At $\Delta > 100°$, surface waves are not associated. As the group velocity window increases with distance, the chances of a false positive increases with distance.

- The algorithm “Maxpmf” includes phase matched filtering and a 1° resolution global dispersion model. This reduced the number of impulsive signals passing dispersion test.

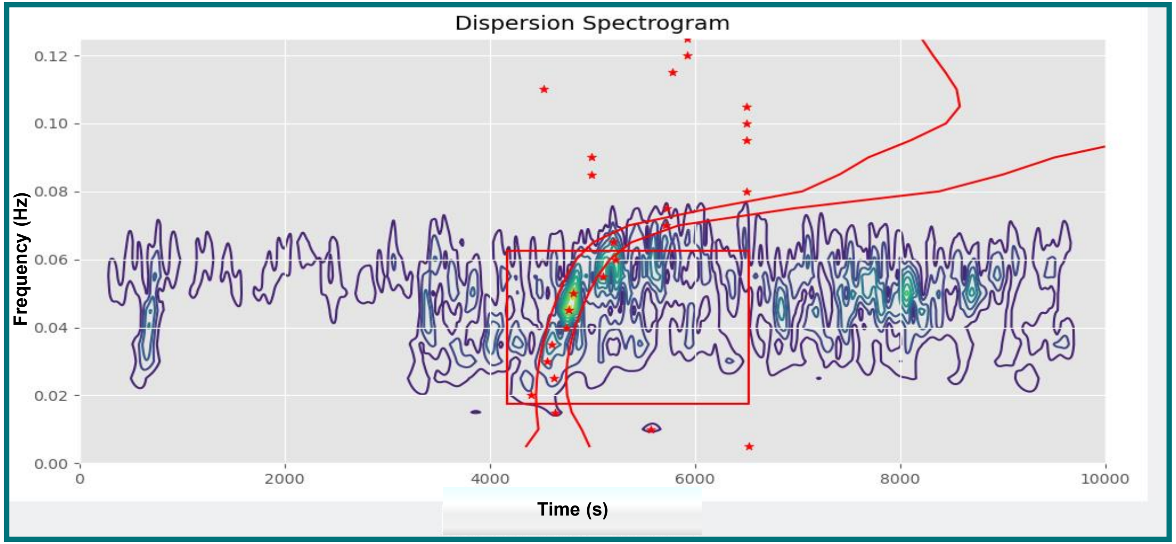


2. Dispersion Test Used by the IDC

- Dispersion means that for a given signal, the wave speed is frequency dependent. Therefore the wave packet arrives over an extended interval rather than impulsively.

- As the group speed of a signal at a particular frequency is dependent on the path travelled, the peak envelope arrival time of the signal, bandpass filtered to each specific frequency band, can be indicative of a specific surface wave travelling along a known path. This assumes that the event hypocentre and dispersive characteristics of the path between the event and station are known.

- By taking a swath of bandpass filters and looking for the time at which the envelope of the signal is maximised (shown as red star), we can compare this to the expected dispersion produced by the same path from a global 1° resolution group velocity model (shown as red curves).



Right: Predicted dispersion within error limits (red curves), contours show envelope energy at each frequency band, with maximum energy shown as red star for a swath of narrow band filters. The red box indicates the bounds in which the test is performed.

4. Misassociation Type One: *Signals from $\Delta > 100°$*

- Surface wave analysis at the IDC is only carried out to $\Delta = 100°$. This is due to the group velocity window increasing as the event-to-station distance increases.

- The number of false detections due to noise is proportional to the distance from source.

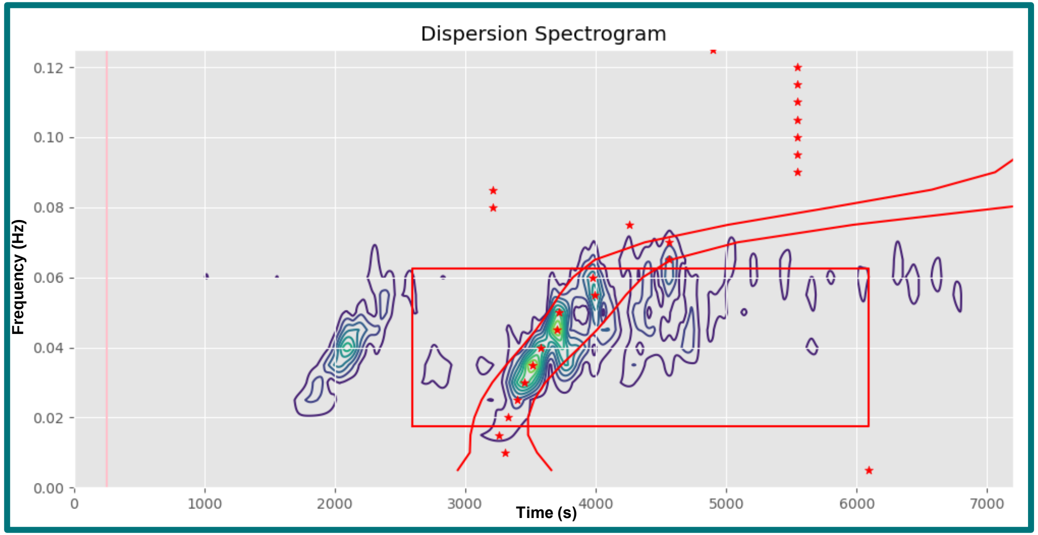
- However, “real” detections from $\Delta > 100°$ do exist, can pass the dispersion test, and may sit in the expected group velocity window of a closer event.

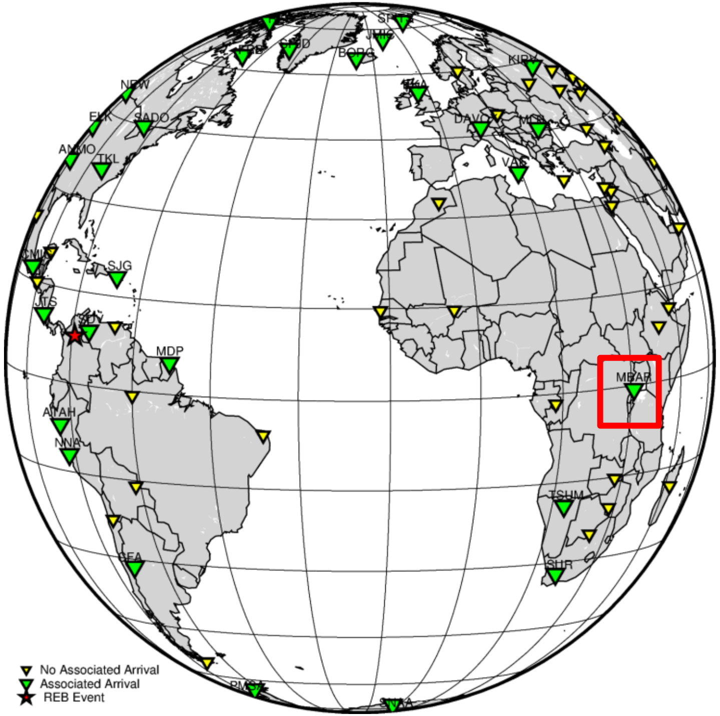
- This leads to events with surface waves associations that are inhomogeneous with distance, such as two detections at $\Delta < 10°$ and a single detection at $\Delta = 90°$, with no arrivals associated in the REB at stations in-between.

- Such events can be seen in the REB and this discrepancy in distance ranges can be used as an indicator that a misassociation has occurred.

5. Signals from Δ > 100°: Colombia Example

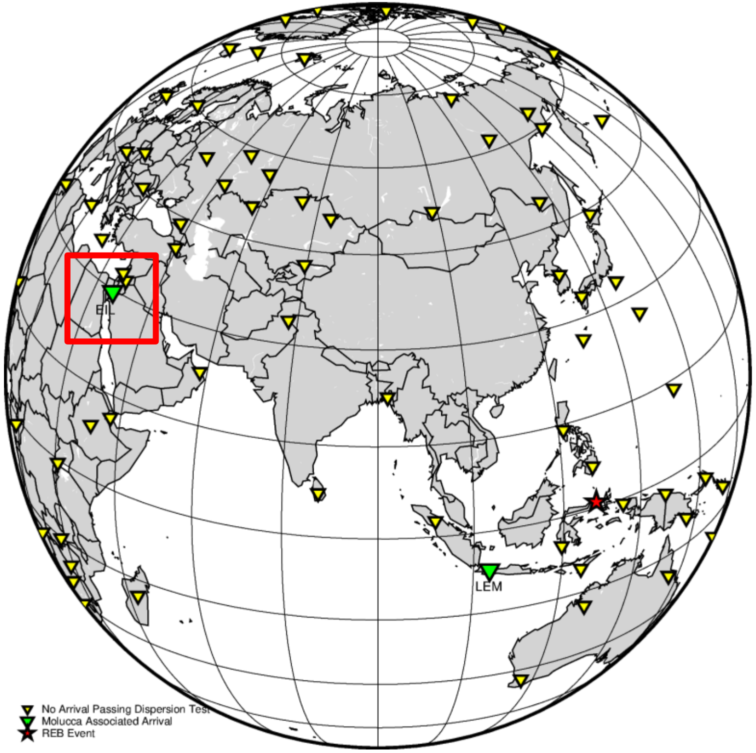
- An M_s 4.6 event occurred in Colombia on the 23rd of February 2022 at 12:49:31 with a depth of 60km.
- 53 associated arrivals in the REB. The closest surface wave association is at SDV (Δ = 3.75°) and the furthest association is at SUR (Δ = 98°).
- MBAR (Δ = 105°) has a clear surface wave but is not reported in the REB as it's Δ > 100° from the event location.



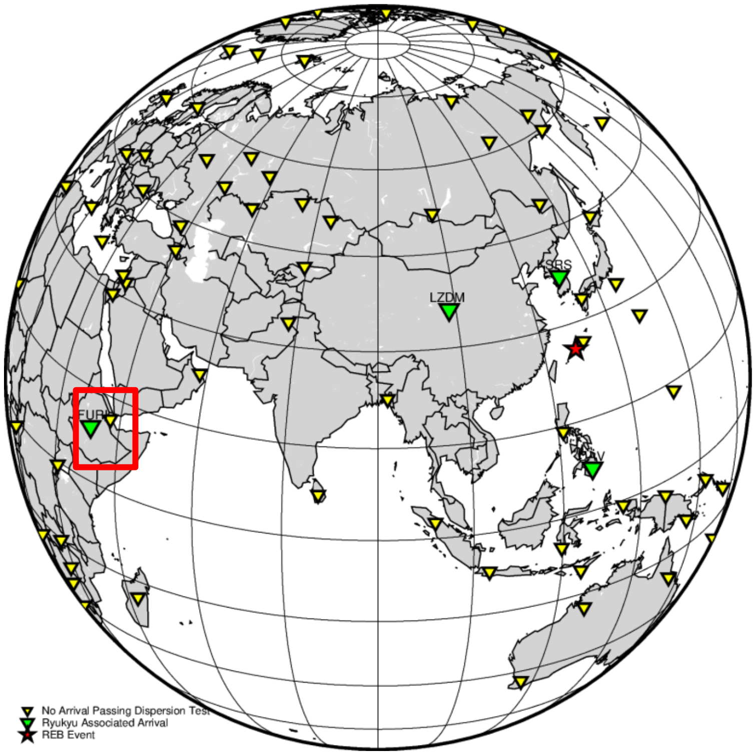


Above: Global plot showing distributions of detections for Colombia event.
Left: Dispersion test for MBAR station using event parameters of Colombia event, showing clear detection of surface wave within expected dispersion limits.

6. Signals from Δ > 100°: Colombia Example



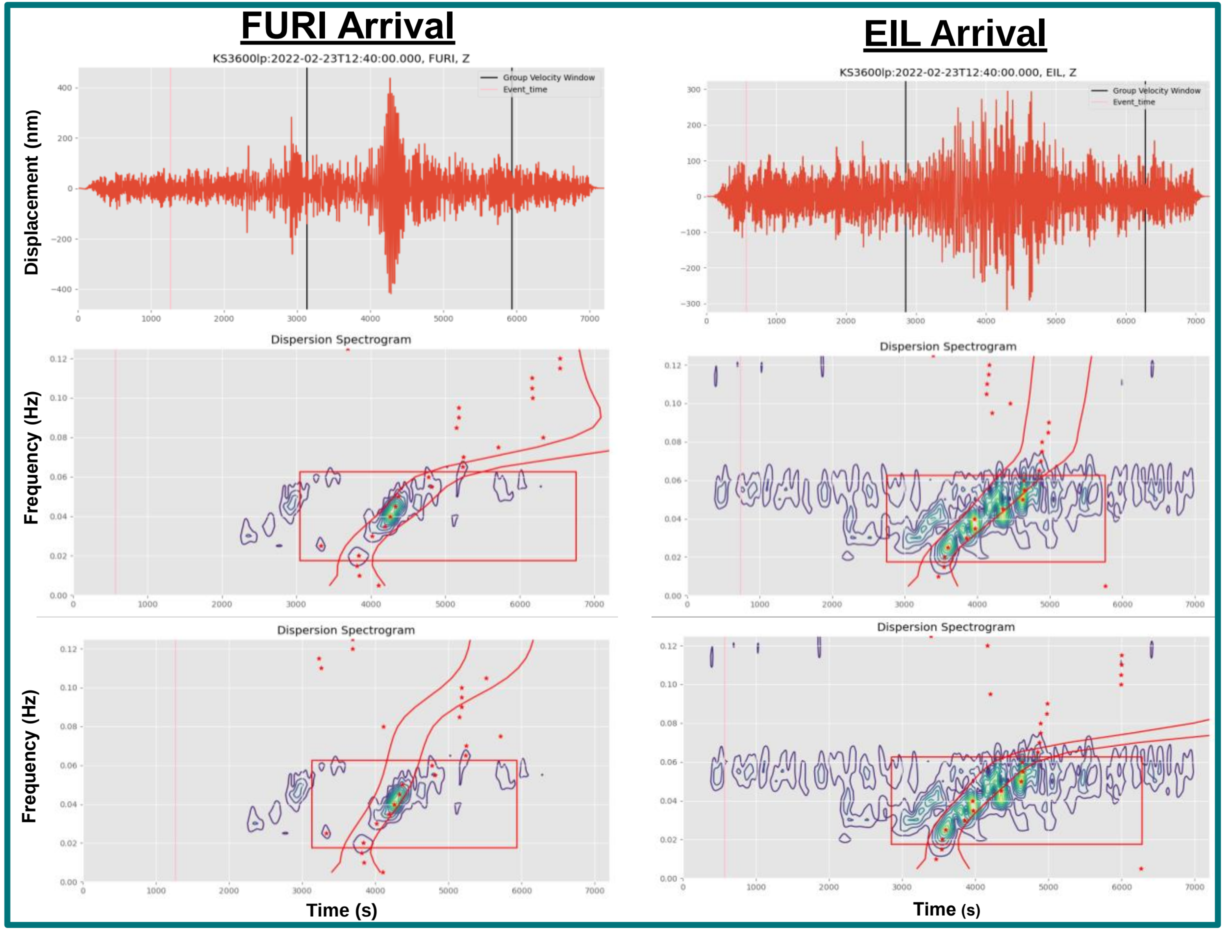
Event in Molucca Sea with an M_s of 4.0 has two surface waves associated at LEM and EIL. Event occurred three minutes after Colombia event.



Event in Ryukyu Island with M_s of 3.8 has four surface wave associations. Event occurred five minutes after Colombia event.

Detections at EIL and FURI seem very unlikely as no stations have detected the signals out this far. Both EIL and FURI lie Δ > 100° from the Colombia event and fit the pattern of association for the Colombia event much better.

7. Signals from Δ > 100°: Colombia Example



Long period response data:
Long period response shows a clear surface wave arrival for both FURI and EIL. The EIL data are much noisier than the FURI data.

Dispersion test using the Colombia event location: Both surface waves pass the dispersion test with the envelope energies fitting the expected dispersion curves more precisely than the original event locations.

Dispersion test using the original event information: When using an assumed event location of the Molucca Sea (right) or Ryuku Island (left) the dispersion test is passed. However less of the test frequencies sit between the dispersion bands than for the Colombia path.

8. Misassociation Type Two: *Signals with no P-wave detections.*

- The process of searching for a surface wave relies on an initial known event location to construct the group velocity window and the dispersion limits.

- If no body waves are detected to construct an event in the REB, the surface waves generated from this event with no *P*-wave detection can be misassociated if they sit within the expected group velocity window of another event.

- Using the Centroid-Moment-Tensor (CMT) catalogue, which contains some events constructed using only surface waves, it can be seen that arrivals from these events are being misassociated with other events in the REB.

9. Signals with no *P*-wave Detections: CMT Catalogue

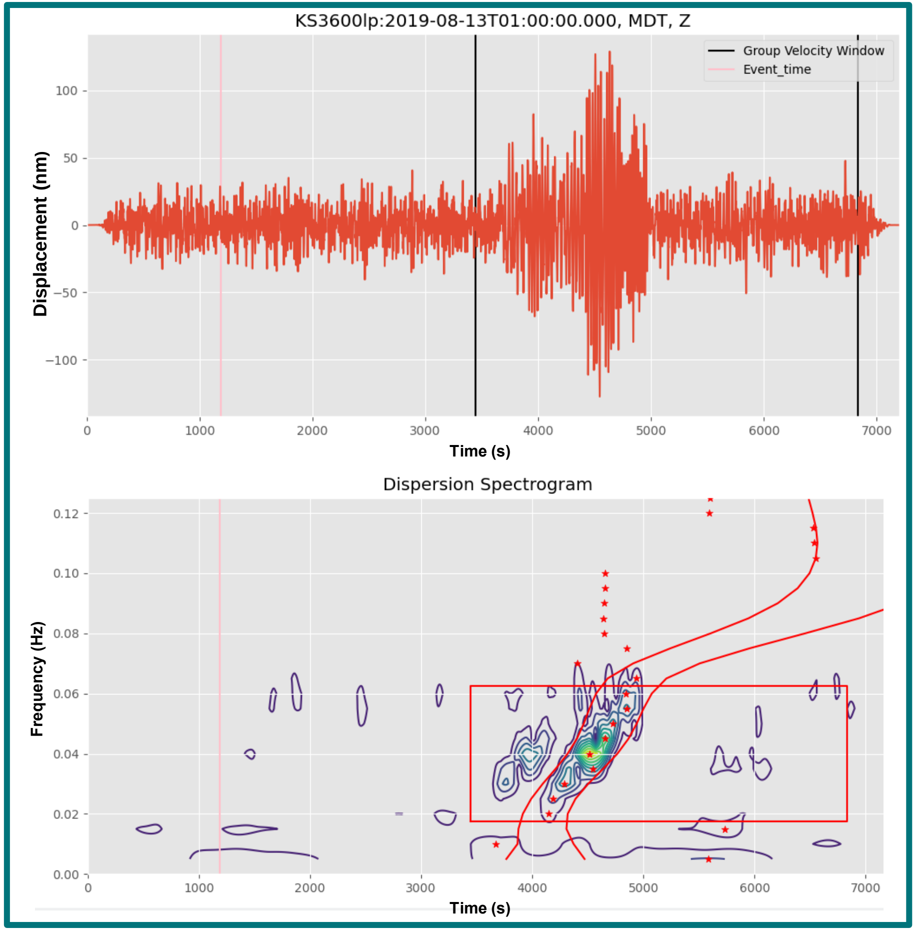
- Earthquakes in regions of sparse network coverage with certain source mechanisms can have small *P*-wave amplitudes that sit below the noise thresholds for detection (Ekström, 2006).

- The REB was searched in the period of 2019-2020 for surface wave only events from the CMT catalogue.

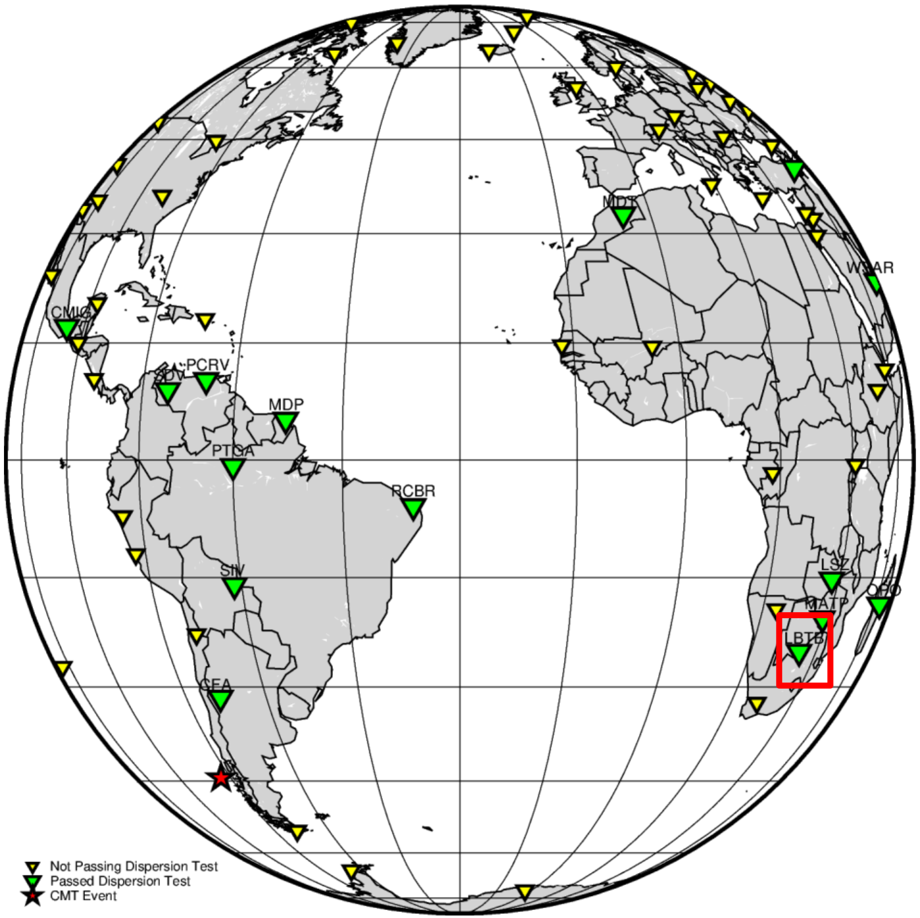
- If the event did not appear in the REB, events around the reported CMT event time were searched for arrivals that passed the dispersion test for both CMT and REB locations in the same group velocity window.

- Surface waves from the CMT events can still be detected if they occur within the expected group velocity window of another event in the REB and can be of significant magnitude.

- Example on the right shows a surface wave arrival at MDT that does not appear in the REB but passes the dispersion test for the CMT catalogue event location.

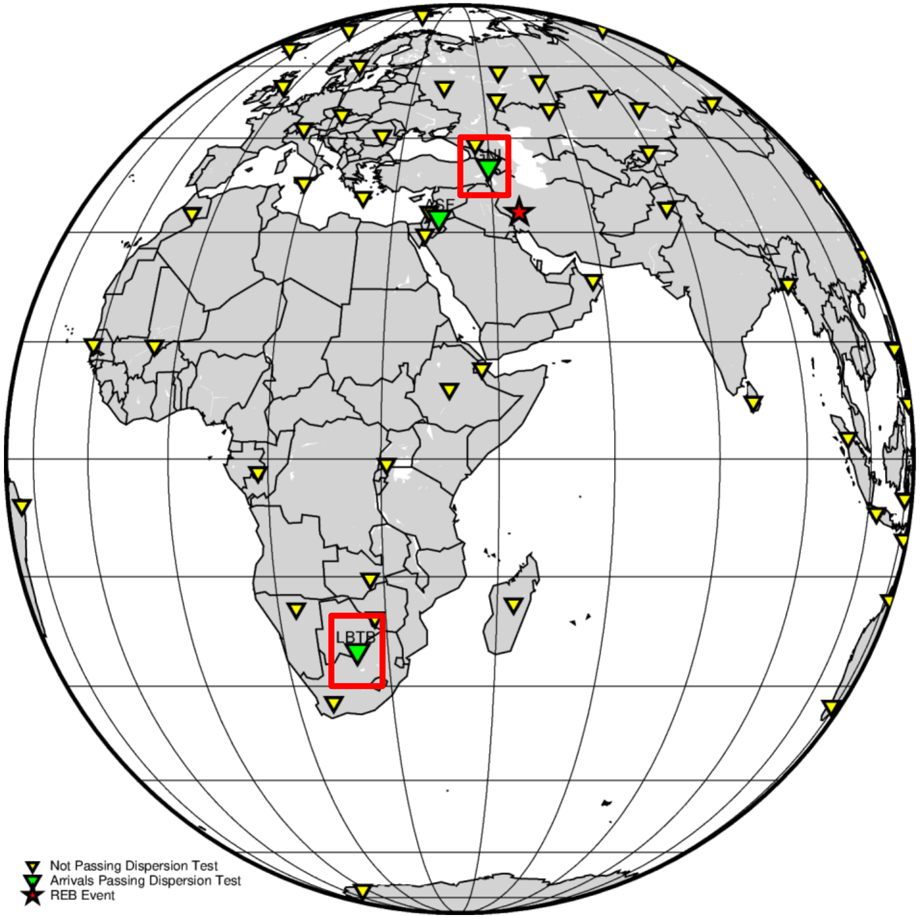


10. Signals with no *P*-wave Detections: Chile-Iran Example



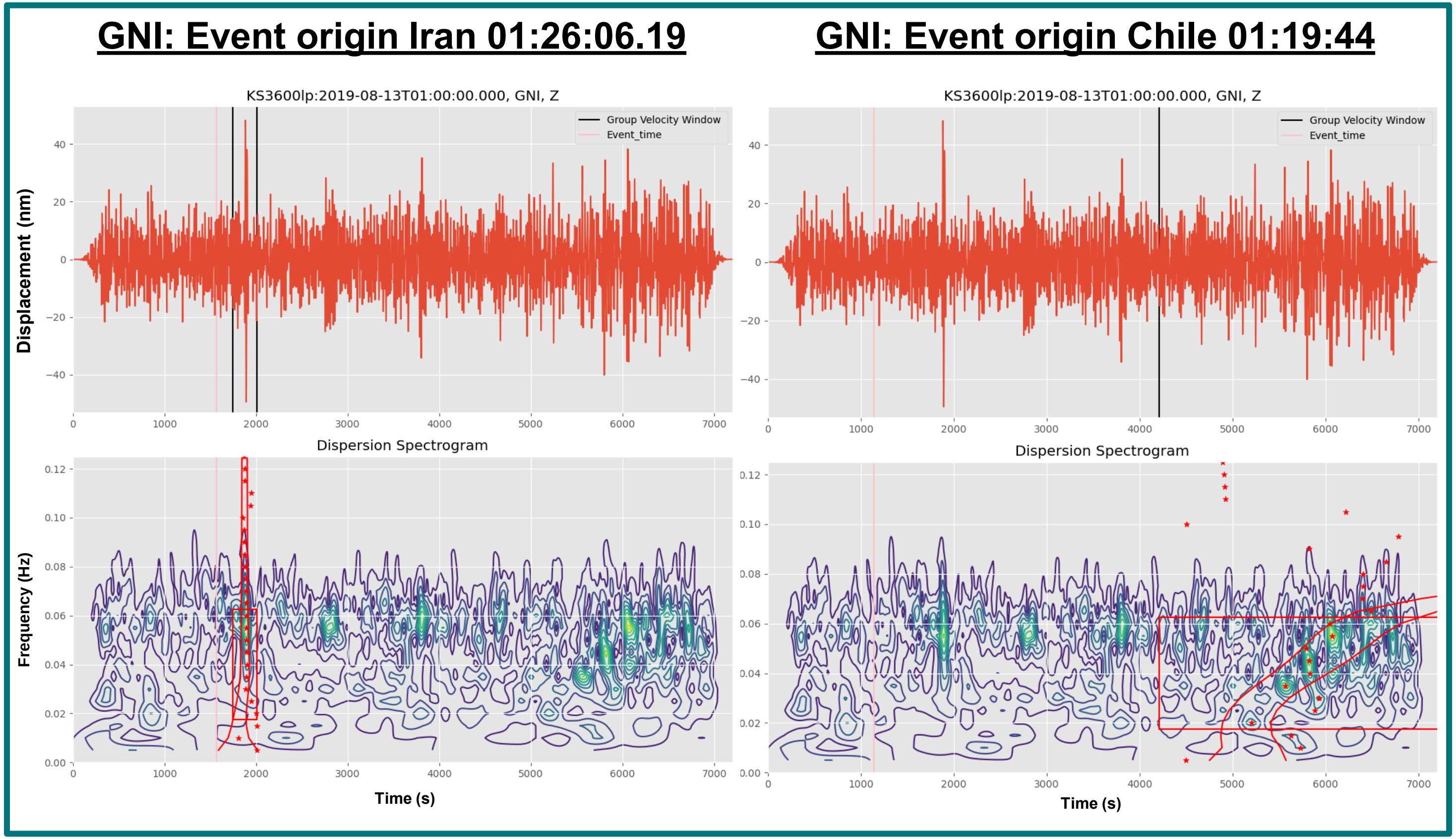
- An M_s 4.8 CMT event in Chile occurred at 01:19:44 on the 13th of August 2019 with a depth of 10km.
- The event in the CMT catalogue is a surface wave only event. In the CMT catalogue only the event information is published, not the individual arrivals.
- 12 arrivals pass the dispersion test for the Chile event location only one of which is in the REB, associated with an event in Iran.
- Predicted arrival times at LBTB are the same for the Chile CMT event and the Iran REB event.

11. Signals with no *P*-wave Detections: Chile-Iran Example



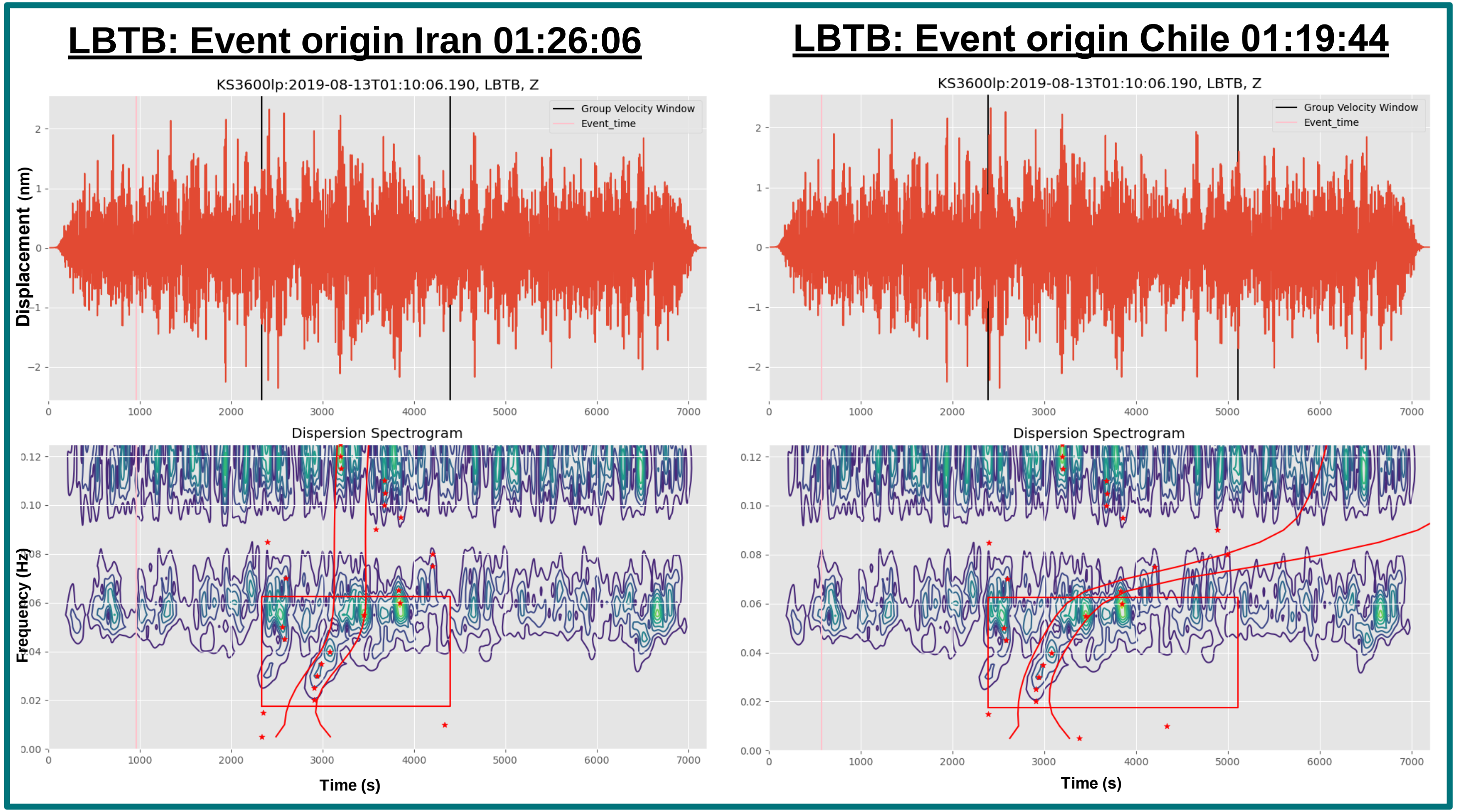
- REB event in Iran occurs seven minutes after CMT event in southern Chile, M_s of 3.2 with three surface wave detections.
- Two of the associated arrivals recorded in the REB are at ASF and GNI ($\Delta < 10°$).
- GNI has surface wave arrivals from both the Chile and Iran event, that can be seen in the data, separated in time.
- LBTB has surface wave arrivals within the same group velocity window that pass the dispersion test for both the CMT and the REB event information.

12. Signals with no *P*-wave Detections: Chile-Iran Example



- Two distinct arrivals in time, one from Iran at Δ = 8° (left) and the other from Chile at Δ = 138°(right).
- Arrival from Chile much more dispersed and sits within a large amount of noise.
- Arrival from Iran almost impulsive as the shorter path means less dispersion.

13. Signals with no *P*-wave Detections: Chile-Iran Example



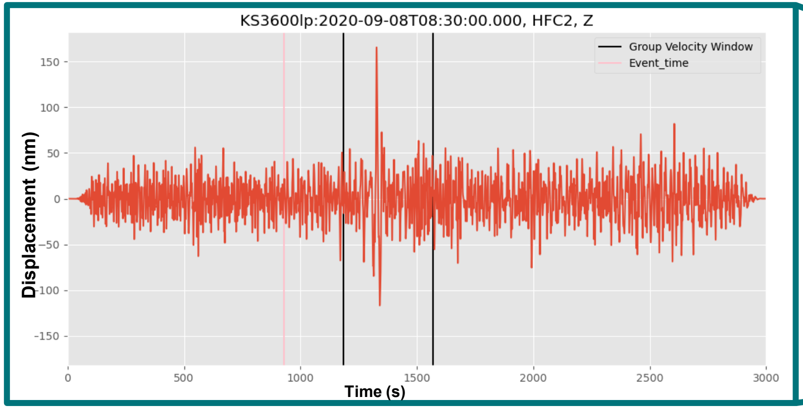
- Arrival at the same time for both the Iran (left) and Chile (right) event.
- Distances Δ = 62° from Iran and Δ = 82° from Chile.
- Noisy at 0.12Hz however does not effect dispersion test.
- Data seems to follow dispersion curve generated with Chilean event information.
- Difficult to make magnitude measurement on overlapping surface waves.

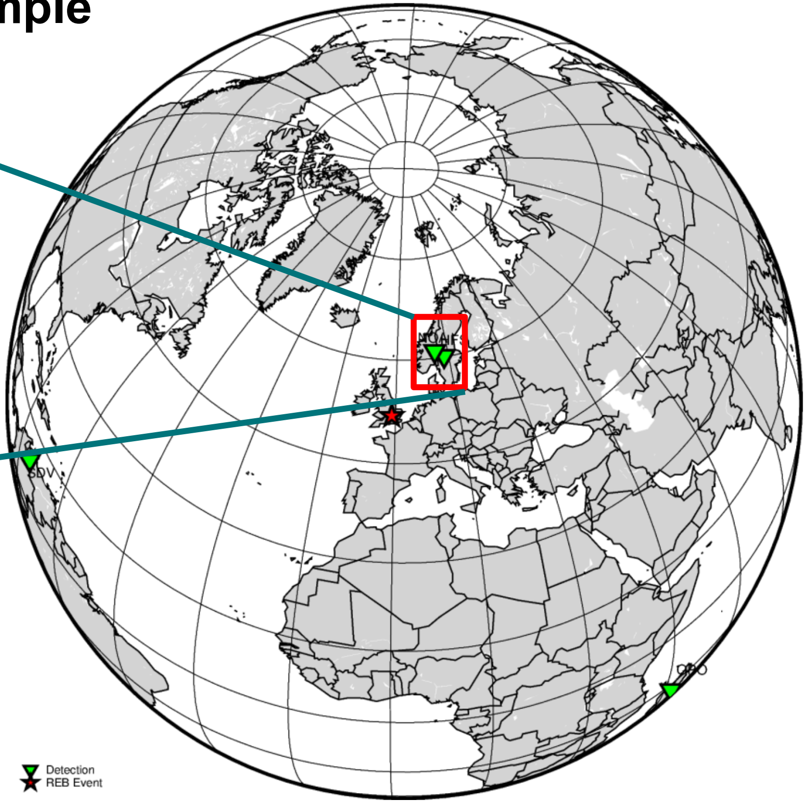
14. Misassociation Type Three: Impulsive Signals from Distant Events

- Surface waves generated very close to a station;
    - Experience little dispersion along their travel path.
    - Produce extremely impulsive looking dispersion curves.

- If an impulsive signal from further away sits within the group velocity window of this impulse-like dispersion test, this can be misassociated as a surface wave.

15. Impulsive signals: Leighton-Tonga Example





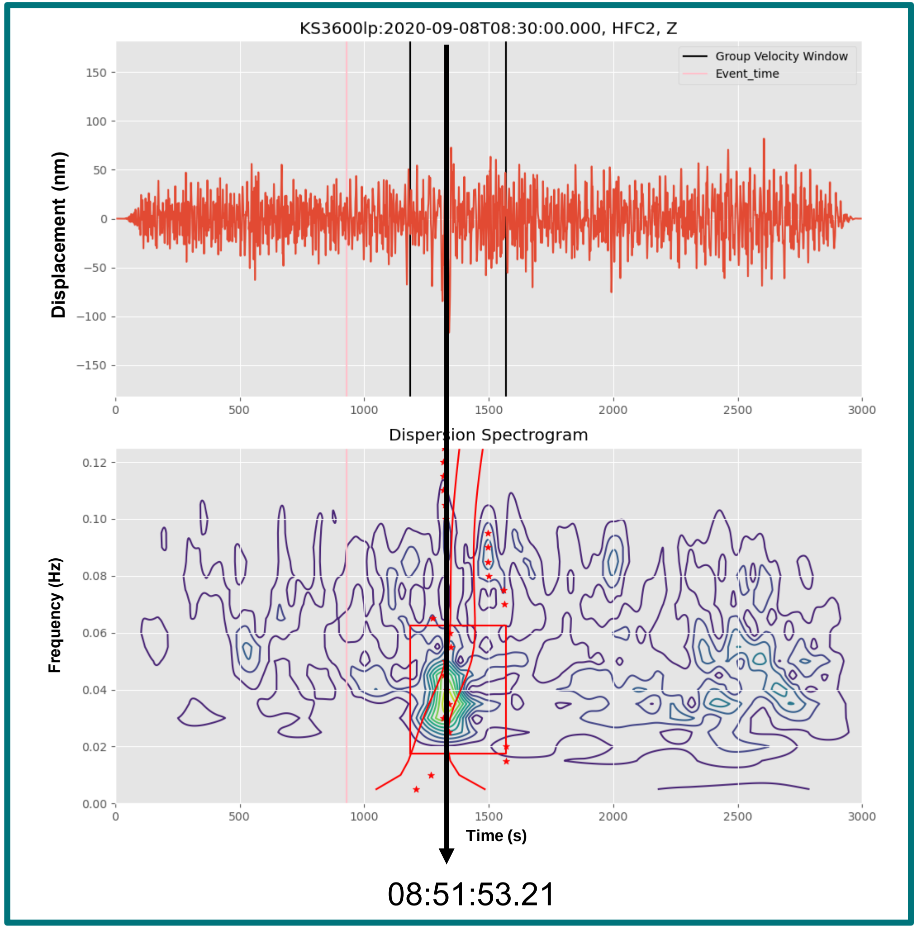
- Leighton Buzzard event on the 8th of September 2020 in the REB with an M_s of 4.2, two surface wave associations at stations $\Delta < 10°$. Two associations at SDV ($\Delta = 70°$) and OPO ($\Delta = 80°$).

- There is an REB event in Tonga 15 minutes prior to the Leighton Buzzard event that explains the two further detections.

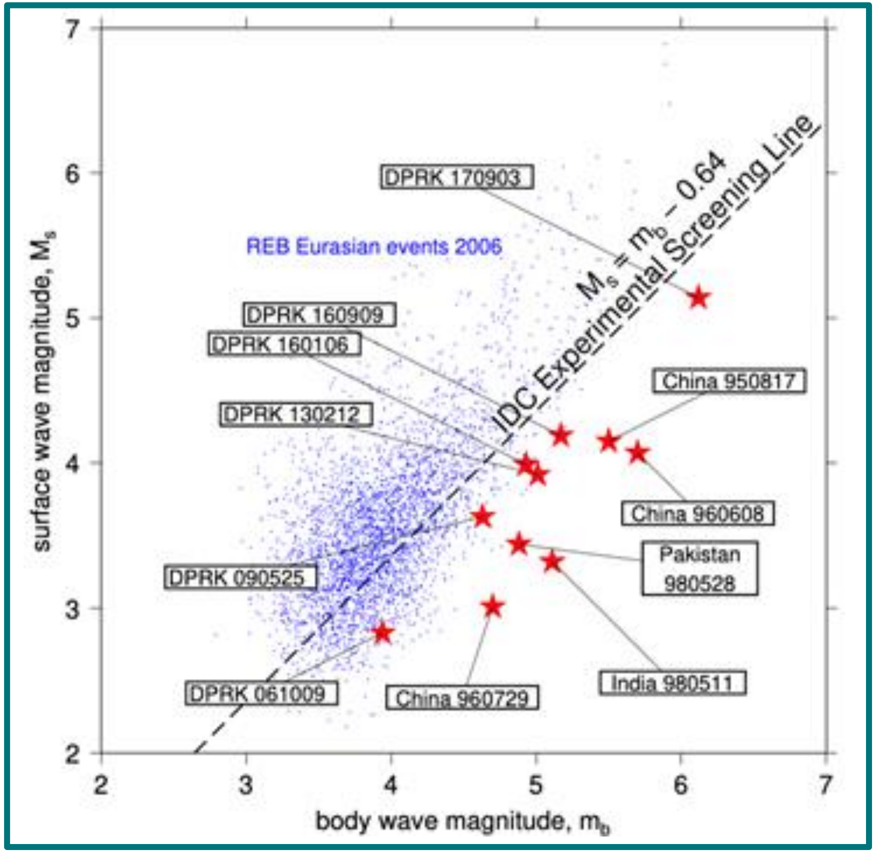
- Detections at NOA and HFS look impulsive as very little dispersion is seen at distances $\Delta < 10°$.

16. Impulsive signals: Leighton-Tonga Example

- Using IASPEI91 travel time predictions for HFS from the Tonga event location, an *SKP* phase is seen coming in at 08:51:45.74.
- The arrival time in the REB for the surface wave at HFS is 08:53:01.32 but the clearest arrival is at 08:51:53.21.
- The observed impulsive signal arriving at the same time as a short path surface wave, can be difficult to differentiate from the predicted *SKP* phase from the Tonga event and may be responsible for the signal seen at HFS.



17. m_b:M_s Event Screening Criteria: Why Surface Waves Matter



Above: Comparison of m_b and M_s for earthquake and selected test explosions. From Selby et al., 2012.

- One of the main event screening criteria used by the IDC is the ratio m_b:M_s or the body wave magnitude compared against the surface wave magnitude.
- Explosions usually generate weaker surface waves than earthquakes of a similar magnitude.
- *LR* phases in the period 18-22s are used to calculate station M_s. A network average is taken and reported in the REB.

18. Effects of misassociation on M_s

Molucca Event: REB M_s = 4.0. This study M_s = 3.8

- LEM station M_s: 3.4
- KBZ station M_s : 4.2
- EIL station M_s : 4.4 (from wrong event)

Ryukyu: REB M_s = 3.8. This study M_s = 3.6

- KSRS station M_s : 3.1
- DAV station M_s : 3.3
- LZDM station M_s : 3.5
- FURI station M_s : 4.5 (from wrong event)
- KMBO station M_s : 4.5

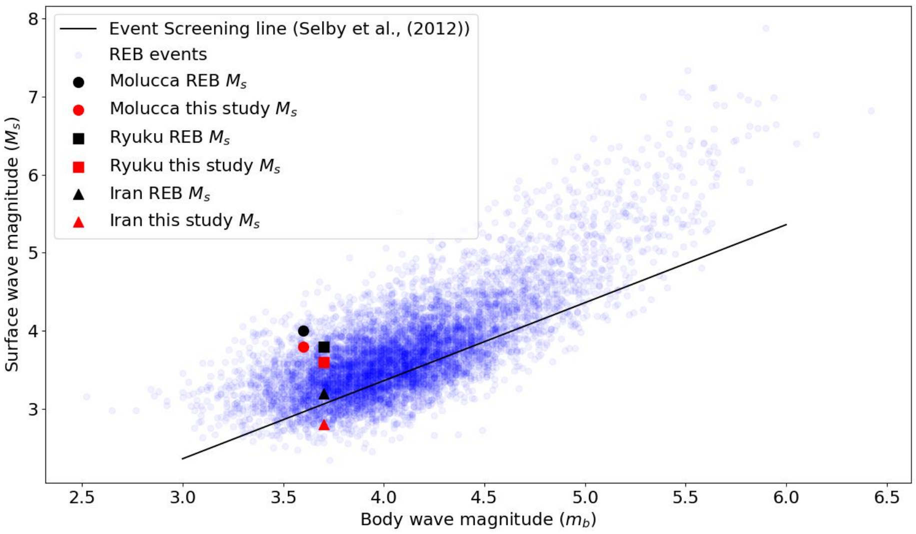
Iran: REB M_s = 3.2. This study M_s = 2.8

- GNI station M_s : 2.7
- ASF station M_s : 2.9
- LBTB station M_s : 4.1 (from surface wave only event)

Leighton: REB M_s = 4.2. This study M_s = ?

- NOA station M_s : 3.2(impulse from wrong event)
- HFS station M_s : 3.0 (impulse from wrong event)
- SDV station M_s :4.0 (from distant event)
- OPO station M_s : 4.4 (from distant event)

Corrected m_b:M_s Ratios



Misassociations tend to come from larger events directly preceding smaller events and hence increase the M_s of the network average.

19. Conclusions and Future Work

- The REB produced by the IDC contains events in which surface waves detections, handled by Maxpmf, have been misassociated.
- Three specific cases for when and why this might happen have been identified and examples for each presented.
- The impact of these misassociations on the $m_b : M_s$ criteria has been demonstrated for these example events, resulting in a reduced network M_s for each event.
- An investigation into the prevalence of these misassociations is required and further research into potential updates to the MsConflict rule set or the underlying Maxpmf detection technique should be conducted.

References

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