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Integration of a Generalized-F Detector at the IDC and US NDC

Jeffrey Given (Leidos, Inc), Thomas VanDeMark (US NDC), Douglas Brumbaugh (Leidos, Inc)

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ABSTRACT

Selby (2008, 2011) developed a Generalized-F method (Gen-F), to enable application of an F-statistic detector to small-aperture arrays where correlated background noise, non-white signal, and noise power would otherwise degrade performance. In 2013, Selby introduced an innovative time-frequency approach that further enabled application of Gen-F to arrays independent of aperture, specifically where the transit time across the array is longer than the signal duration. Tests of the method on the IMS arrays have shown that the Gen-F detector outperforms the current detector in use at the IDC for many of the arrays: increasing valid detections, while decreasing the overall number of detections.

The UK NDC contributed software based on Selby's 2013 method, and the US NDC integrated it into the DFX detection framework in use at the IDC and US NDC. The Gen-F detector is implemented as a module fully compatible with the input and output of the existing DFX framework, allowing either, or both, to be used for a given array. The current DFX post-detection feature analysis continues to be used and the output is fully compatible with the subsequent down-stream station and network processing, (StaPro, GA, NetVISA).

The US NDC is tuning the Gen-F parameters that frame an isotropic noise model to suppress correlated noise at regional, small-aperture arrays. Using a multi-month set of waveforms, historic noise picks, and the observed intrastation correlation, the US NDC will demonstrate the impact of tuning these Gen-F parameters at one (1) regional array.

The Gen-F detector introduces additional options for improving the station detection performance, and the time-frequency approach suggests new ways to exploit the data from the IMS network.

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INTRODUCTION

A stand-alone implementation of the Gen-F algorithm (Selby, 2008, 2011, 2013) was contributed to the CTBTO PrepCom by the UK AWE for evaluation as a new detector capability for the IMS seismic arrays.

In subsequent work, the IDC and US NDC integrated the contributed software into their respective detector frameworks (the Detection and Feature eXtraction (DFX) framework), which share a development history and software architecture.

The earlier IDC effort appears to have stopped short of being able to fully replace the current “DFX Classic” detector with Gen-F. Several practical areas remaining to be addressed:

- Onset time, analysis filters, fk analysis, pipeline integration

The USNDC development project addresses these issues.

DFX-Gen-F output is compatible with DFX Classic for SEL input.

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OBJECTIVES

Integrate the AWE software into the IDC's DFX detection framework to provide a 'drop-in' replacement for the current DFX seismic array detector.

- Robust, fault tolerant
- Resilient to acquisition peculiarities (*e.g.*, data gaps, backfilling)
- Reliable feature estimates (azimuth/slowness, onset times)
- Straightforward configuration; defaults to DFX Classic for those stations not suited to Gen-F

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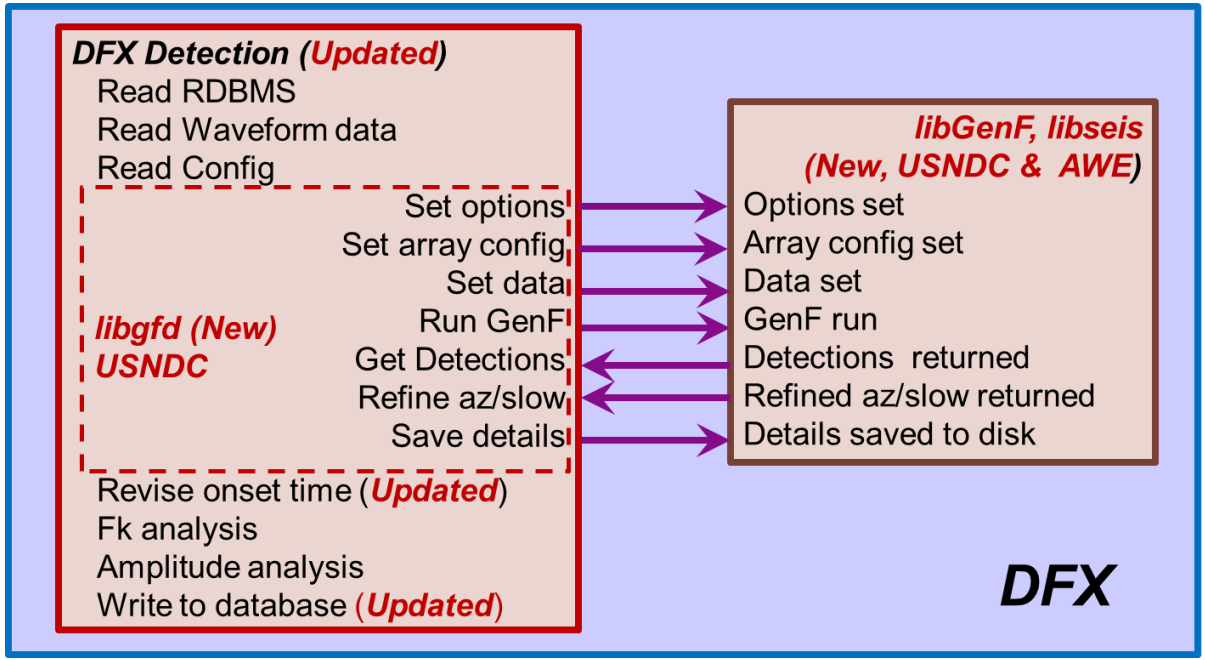
METHODS

Gen-F Processing and DFX



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Gen-F Software

The Gen-F software comprises the following new and updated software:

1. *New DFX library* to bind DFX to Gen-F functionality
2. *Updated DFX library* to support additional RDBMS table (IDCX.DETECTION_GENF)
3. *Modified Fortran module/library from US NDC & AWE* to implement the Gen-F detector
4. *Contributed AWE Fortran library*
5. *Modified DFX configuration to enable Gen-F detector for selected stations*

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Integrating the Gen-F Detector

Several practical issues needed to be addressed to use the Gen-F detector in an operational setting:

1. A new RDBMS database table, DETECTION_GENF, to store Gen-F results
2. Map Gen-F zero-phase (non-causal) filters to DFX (causal) analysis filters for feature measurements
3. Determine a reliable onset time
4. Determine a reliable, accurate az/slow (fk analysis)
5. Run reliably in IDC's near-real-time operational pipeline
   - Account for data acquisition delays, and implement warm-up period for noise long-term average

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Integrating the Gen-F Detector: Measurement Filters

METHODS

- Assign causal filters equivalent to Gen-F zero-phase (non-causal) filters for DFX feature measurements
  - Gen-F applies zero-phase filters, band-limited in the frequency domain, which are inappropriate for estimating onset time
  - Each of Gen-F's freq-domain filters are associated with a similar butterworth filter to be used by DFX for further feature measurements
  - The detecting Gen-F beam and its associated butterworth filter describe a detection's so-called "best beam" used in DFX feature measurement

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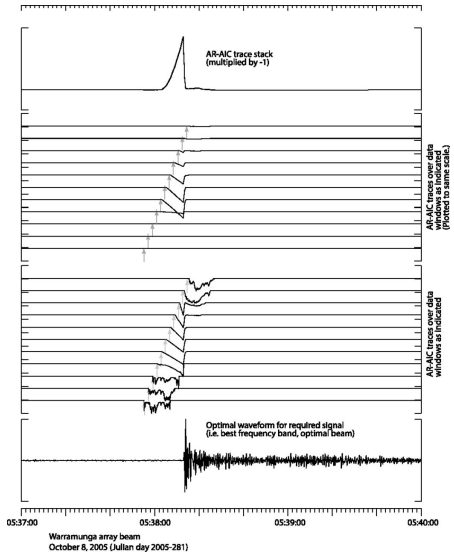
Integrating the Gen-F Detector: Onset Time Estimates

Similar to onset-time estimator described in Gibbons, *et al.*, 2016 (as a detector).
Bottom is the best beam; lower trace group is AR-AIC traces scaled to max on each trace; upper trace group is AR-AIC traces at same scale; top is rectified stack of AR-AIC traces.



From: **Iterative Strategies for Aftershock Classification in Automatic Seismic Processing Pipelines**

Generates a trace for arrival detection, formed by continuous stacking of autoregressive Akaike information criterion (AR-AIC) functions calculated in overlapping data segments. The beam uses back azimuth 322˚, apparent velocity 22 km/s, and the frequency band 1–5 Hz. For each time window used for calculating an AR-AIC trace, the window length has total duration of 15 s, and the autoregressive (AR) noise model is calculated using the data from only the first 5 s of the current window. The AR linear prediction filter uses eight (8) coefficients.

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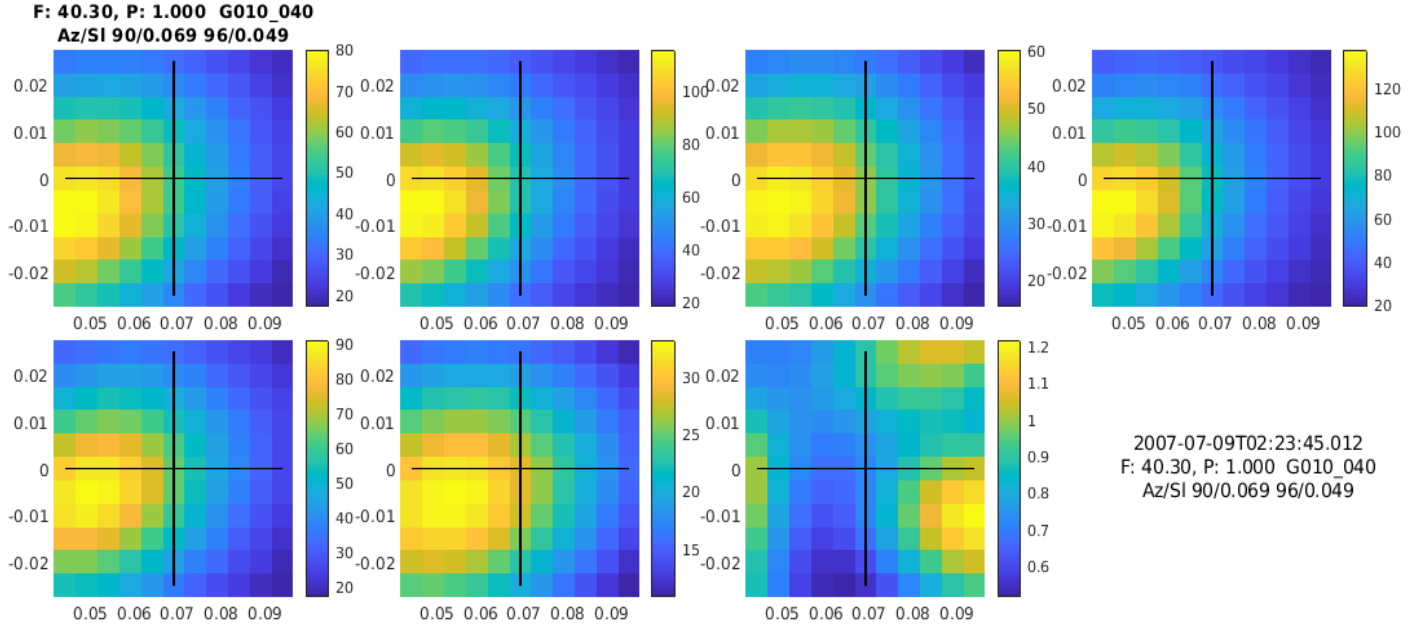
Integrating the Gen-F Detector: fk Analysis

METHODS



Azimuth/slowness refinement in Gen-F. The images are the F-statistic in slowness space around a detecting beam. Using Gen-F's analytic time-frequency representation of the channels, the detecting beam is calculated by explicitly shifting the narrow-band-filtered analytic channels in time and applying the beam weights. The beam refinement is calculated by applying phase shifts to the beam weights calculated for the detecting beam.

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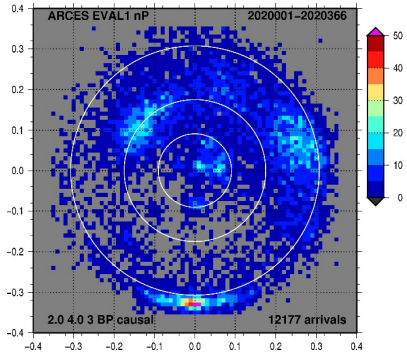
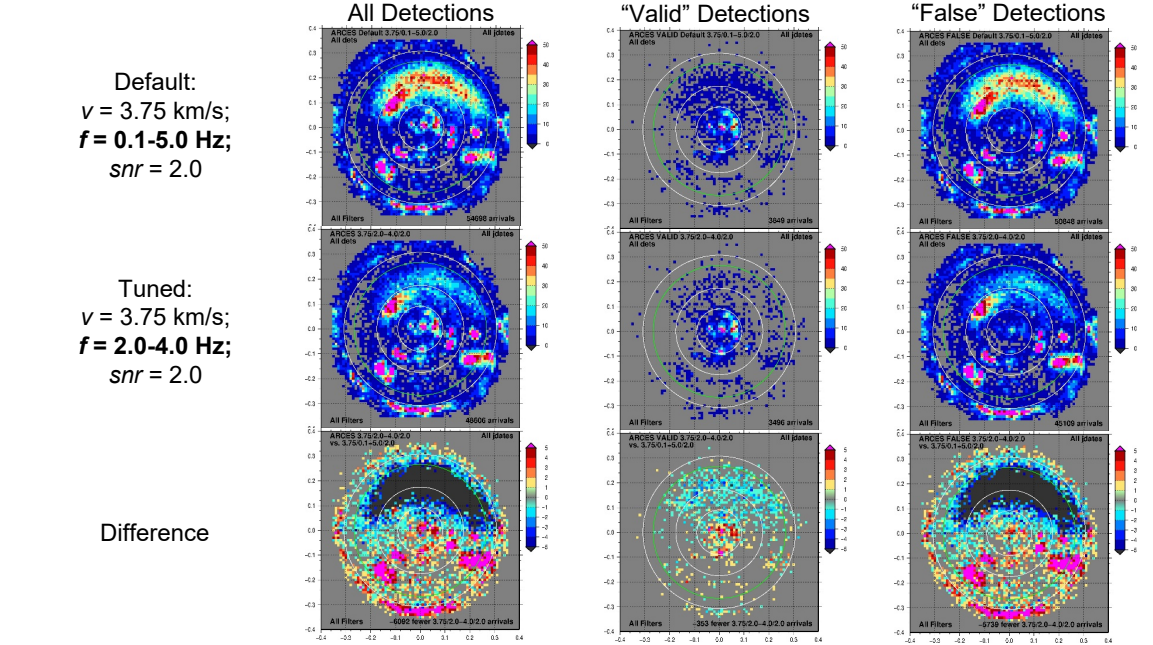
RESULTS

Gen-F Detector Tuning



2.0-4.0 Hz EVAL1 noise picks in fk space at small-aperture seismic array ARCES for 2020. Velocity rings are at 11.0, 6.0, and 3.0 km/s. Trial isotropic noise model configurations were selected for tuning by evaluating the US NDC analyst-reviewed EVAL1 bulletin's noise picks, "false" (*i.e.*, not in EVAL1) detection features, and observed intrastation correlation.



Detection comparison in fk space of Selby's "out-of-the-box" default noise model configuration and a tuned noise model configuration at ARCES for four (4) months (Jan, May, Aug, Nov 2020). Gen-F-DFX was used to process the raw waveforms. Green velocity ring is at 3.75 km/s. "Valid" and "false" detections are relative to the EVAL1 bulletin. Limiting the filter band to 2.0-4.0 Hz reduces the number of "false" detections by 11.3%, and improves the "valid"/"false" detection ratio by 2.4%.

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CONCLUSIONS

- The Gen-F Detector, contributed to the CTBTO by AWE Blacknest and the US NDC, has been successfully integrated into the CTBTO DFX detector framework.
- The new software capability provides a new option for IDC detection processing of the IMS seismic arrays.
- The new software is intended to be fully compatible with the current DFX processing for use in automatic station and network processing pipelines for those arrays where it is shown to be beneficial.
- Tuned Gen-F detectors can notably improve Gen-F detection performance at small-aperture seismic arrays.