NORSAR

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7.4   NORSAR Large Array Processing at the IDC Testbed

Introduction

Beginning September 1, 1996, large array NORSAR (NOA) data have been continuously trans-
mitted to the IDC. Already in April 1996, a new function, *"compute-beamform-fk"* (Fyen
1996), to be used for large array slowness vector estimation was implemented into the DFX in
cooperation with SAIC staff. IDC testbed operation of this version for NOA data was initiated
on October 9, 1996 and initial results from DFX processing of NOA was reported in NORSAR
Sci. rep. No 2-96/97.

NOA processing at the testbed

It has earlier been found that DFX processing of the large primary array station NOA is func-
tioning satisfactorily (see NORSAR Sci. rep. No 2-96/97). During the current reporting period,
efforts have been made to find useful setup for the analysts to use ARS and XfkDisplay. ARS is
used at the IDC for waveform analysis and phase picking. XfkDisplay is used to perform F/K
analysis on array data, and prepare new beams for analysis.

The standard way of IDC processing is that for each origin, an array *origin beam* is prepared
using the predicted slowness vector. Additionally, a beam using the DFX estimated slowness
vector is prepared, called *fk beam*. After refinement of the location, the analyst may prepare
either a new origin beam using ARS and with slowness vector predicted from the new location,
or a new fk beam, using results from supplementary F/K analysis. The latter option is exten-
sively used by the analyst.

During a visit to SAIC, La Jolla, we used ARS to find whether large array NOA analysis
demanded changes to ARS or XfkDisplay. It was found that station NOA can be implemented
and used for analysis just like any other array in IMS. Origin beams are prepared that make use
of time delay corrections. XfkDisplay was able to perform standard F/K analysis on NOA data,
and suprisingly good results were obtained.

In addition, the NOA array has features that make it possible to introduce subarray processing,
but these features have not yet been tested extensively.

We have continued additional review and analysis of NOA detection processing at the testbed.
In particular, we have analyzed in detail detection statistics for the period 21 August-3 Septem-
ber 1997, and compared them to results obtained for the earlier period 11 January-19 February
1997 (see NORSAR Sci. rep. No 2-96/97). In general, the results were similar, but some prob-
lems from the earlier period were found to have been corrected. This concerns in particular the
reliability and stability of the automatic testbed processing. Details from both of these analysis
periods have been reported in the CCB memo discussed below.

Operational implementation of NOA at the IDC

In cooperation with SAIC staff, we have submitted to the IDC Configuration Control Board
(CCB) a memorandum proposing the inclusion of NOA as a primary station in the GSETT-3
network. This memorandum consists of a main text with general discussion of the objective,

expected benefits, possible risks and dependencies, suggested procedures and testing results. It is supplemented by three appendices, describing in detail an evaluation of the testbed processing, the overall structure of the configuration files and the detailed contents of these files.

A summary of the CCB memorandum is included as an appendix to this chapter.

Recommendations for the IDC

There are two features with the NOA array that impose demands on the software developers to do signal processing correctly. The array is large and thus sensitive to correct use of slowness and azimuth in beamforming. All seismometers have large DC offset which requires that filter processes include mean removal ("demean") and tapering. We will here list some points that we think are important for all IMS station processing.

Demean, taper, filter

For any process involving a filter operation, the data segment should be demeaned and tapered before filtering. The demean function must be based on the average value of all samples in the data segment. Sample masking from the QC operation should be included. After demean, the data should be tapered. Tapering must be applied to the start of the segment and after all known data gaps. NORSAR has submitted a code for smooth tapering to the SAIC staff. The effect of ignoring tapering is particularly exposed when using ARS. However, it is recommended that any filter operation should use tapering.

ARS

For the analyst to be able to view data with large offset, it is essential that demeaning be applied to the data. For almost all data, it is also essential that tapering be applied before filtering.

Origin beams

During the testing of ARS, it was noted that NOA origin beams had significantly smaller SNR as compared to beams formed at NORSAR. The reason for this was found to be that a fixed slowness parameter is used in the origin beam recipes. All origin beam recipes for all arrays have parameters that tell the DFX-beamer to use predicted azimuth and a fixed slowness of 0.125 sec/km (8.0 km/sec velocity). The fixed slowness is used instead of predicted slowness. For large arrays, the effect of using fixed slowness rather than predicted is a clear degradation of the beam. For a small-aperture array like Spitsbergen, the effect is not so dramatic. However, even for arrays like ARCES, the degradation of the beam is significant. When origin beams are formed for ARCES, the D-ring is excluded. This makes the array smaller, and the effect of a fixed slowness is therefore reduced. At the same time, the exclusion of the D-ring means a degradation of the noise suppression.

The reason for using fixed slowness has been that the origin may be wrong. However, in addition to origin beams, the analyst may use "fkb" beams, i.e., beams formed by using the DFX estimated slowness and azimuth. If the origin is incorrect, then this detection beam would be a better choice than forming beams with fixed slowness and azimuth predicted from the origin.

For NOA it is absolutely necessary to use predicted slowness rather than fixed slowness for origin beams, and we strongly recommend that predicted slownesses be use also for other arrays.

XfkDisplay

For NOA, the "beamform-fk" option may be used to perform time domain f/k analysis. The first implementation of this option works very well, but the possibility to switch between the time domain and frequency domain analysis is limited. We have noted that experienced analysts at CMR use XfkDisplay very often, and also use the options for change of filter bands, etc., quite extensively. We propose that this analyst tool be further enhanced to include interactive switching between standard and other types of f/k-type processing. The "beamform-fk" can be developed further by including an option to do incoherent in addition to conventional beamforming. This may be useful for all arrays, if the analyst has an easy way to switch between these methods. If such options are included, it will be necessary to extend the text on the contour plots to include a list of parameters describing the method used.

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References

Fyen, J. (1996): Improvement and Modifications, NORSAR Sci.Rep. No. 2-95/96.

Appendix A

Summary of a memorandum to the CCB on including NOA as a primary station in the GSETT-3 network

Statement of Objective

To include the large array NOA as a primary station in the PIDC operations pipeline. The station will replace NORES.

Summary of Proposed Change

The large NORSAR array (NOA) is designated as one of the IMS primary seismic stations. So far during GSETT-3, the small NORES array, which is located within the NOA aperture, has been used as a substitute, awaiting finalization of NOA refurbishment. NOA processing has now been extensively tested on the testbed and is ready for operational implementation. It is therefore proposed to remove station NORES from operations and install NOA.

At the moment, both NOA and NORES data are transmitted continuously to the PIDC. Subject to funding, we propose to continue transmitting NORES data to the PIDC to permit continued use of both NOA and NORES data at the testbed. Depending on testbed and operational experience, and funding, the NORES array may be included as an additional NOA subarray.

Although NOA consists of 7 (and possibly 8) subarrays, the NOA station processing with DFX will result in one arrival and one station for a detected seismic phase arrival. For analyst review, one array beam representing NOA will be used for teleseismic events.

Expected Benefits

The large NOA array has a superior capability in providing very accurate azimuth/slowness estimates as compared to the small NORES array (see Appendix A of the CCB memo).

Furthermore, NOA, which is comprised of 7 subarrays, will provide the possibility for subarray-based processing, which could take advantage of the significant signal focusing effects in improving detectability. In a longer term, it may be decided to use NORES as an additional NOA subarray to retain the regional capability. An evaluation of possible improvement in detection capability using subarray detection (by defining subarray groups using same reference as NOA), can be performed when both operations and testbed detection results are available for comparison.

A summary of testbed experience with NOA processing is presented in Appendix A of the CCB memo.

The NOA array has 7 three-component broadband instruments over an aperture of 60 km. The use of array processing techniques (F/K analysis) using broadband data is has been very useful for determining slowness vectors of surface waves.

Possible Risks and Dependencies

The use of NOA instead of NORES will mean a possible risk of reduced capability for processing of regional events in Fennoscandia. However, an update of the detection recipes to include regional phases may to some extent compensate for this. Moreover, we propose to continue transmitting NORES data to the PIDC, such that continued testbed operations using NORES and/or NOA data may be continued.

For GA processing we propose to use the same slowness/azimuth association parameters as are used for NORES. Although NOA array will show smaller azimuth residuals as compared to NORES, we do not at this stage propose to use smaller azimuth limits for NOA. Note also that the estimated slowness vector for NOA is compensated for azimuth residuals through the use of time delay corrections in the DFX "*beamform-fk*" process.

It has been demonstrated that DFX detections obtained at the PIDC testbed are in very good correspondence with detections obtained at Norway NDC. Moreover, Appendix A show that the slowness vector estimation is by far better than the one used at the NDC.

Since testbed DFX processing of NOA data started in October 1996, there has been periods where detections have been missing and false detections have been reported. This has been identified as problems with data transfer from operations to testbed, and wrong use of parameters. Since November 97, the operations data availability for NOA has been 97-99%, and the detection processing at the testbed has shown no such failures.

Summary of Testing Results

It has been demonstrated that DFX processing results for NOA are comparable to the results obtained at the NDC, and that the azimuth residuals using "*beamform-fk*" process are significantly better than those obtained by traditional beampacking (NDC process). Moreover, it has been shown that ARS analysis of NOA data can be performed just like for any other array.

Analyst Review

One NOA\cb origin beam and one NOA\fkb detection beam is formed by DFX using time delay corrections, which should give the analyst nearly optimal beams for NOA arrivals. This has been verified by experienced analysts at CMR. NOA data may be sent to XfkDisplay for further analysis using standard F/K analysis, and create new NOA\fkb beams. This has also been verified using ARS and XfkDisplay. New NOA\cbtmp origin beams can also be formed by ARS, and this has been verified.

For the operation of NOA as one array station, all standard analysis procedures like forming new origin beams, sending data to XfkDisplay, calcuate FK and form new beams have been verified to function correctly.

Optional Analyst Review using Time-Domain F/K

XfkDisplay patch release PIDC_5.0.44 has the ability to use the *"beamform-fk"* process. This process is initiated if the /nmrd/ops/net/idc/static/XfkDisplay/recipe/NOA.par includes the following parameter settings:

- fk_timedelay_file= /nmrd/ops/net/idc/static/DFX/fk/fkgrid/NOA.BMFK.maxslow0.1
- max_slow=0.1
- nslow=51
- beam_timedelay_file=/nmrd/ops/net/idc/static/DFX/beam/tdcorr/NOA.tdcorr

By default, these parameters will be set in the NOA.par file, but these parameters may be set interactively by the analyst using the edit parameter option of XfkDisplay. The use of this option for many cases gives a better estimate of the slowness vector when compared to the standard F/K. Also, an SMR has been submitted to extend the capabilities of this option to include interactive switching between standard and other types of F/K processing.

Optional Analyst Review using Subarrays

The large array NOA has large amplitude variations across the array. In some areas, 2-3 subarrays have clear signals, whereas the rest of the array has no signal. In some of these cases, the full array beam will not detect the signal, and it can be useful to inspect a single subarray for a signal. Each one of the 7 subarrays has at least one region where it is clearly best.

If there are missed detections, or detections with bad slowness vector estimate, the analyst may use ARS to form subarray origin beams for inspection. In this way, if the origin is correct, the subarrays can be inspected for possible signals.

Another approach is to inspect individual sensors for signals, and then use XfkDisplay to calculate F/K and prepare subarray beam(s). For weak signals, an estimate of slowness from one good subarray may be better than full array F/K.

The basic operational concept for NOA is to use full array beams just like any other array. The use of readings from subarrays is optional as help for the analyst. If the analyst include readings from e.g. subarray NC6, the parameter files are specified such that postprocessing can be performed for station NC6. Station code NC6 will then appear in the REB, and the quality control should make sure that for the same phase, only one station from affiliation NOA should be represented in the REB. It is the authors experience that analysts have very good understanding of the use of subarrays, and problems with both subarray (e.g. NC6) and full array (NOA) station readings for same phase may not occur. Moreover, the use of a subarray rather than full array will be used only in cases where readings from the full array beam is impossible.

Configuration Files

The configuration files from the testbed necessary to implement NOA processing in operations are all listed in Section 4. They should be installed in the corresponding subdirectories in the OPS tree.

Database Tables

In order to process NOA and its subarrays, new entries need to be made in the affiliation, sensor, site, instrument and sitechan relations of the operational databases. In Appendix C to the CCB memo a list of the necessary values for the new tuples can be found.

Plan and Schedule for Implementation

We recommend implementation as soon as possible.

The following steps are necessary to implement the installation:

1. Enter necessary tuples into **site, sitechan, affiliation, sensor,** and **instrument** relations to allow automated and interactive processing to utilize NOA and its subarrays.
2. Install all listed configuration files from the testbed into the OPS tree.
3. Install new DFXdefault.scm file and DFX executable into operations.
4. Initiate new station NOA as a part of the automated operational pipeline.

Costs and Resources Required for Implementation

Installation of the configuration files and the Scheme and executable file should not take more than a few hours. It should be implemented by PIDC operations staff.