Memo

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From:	D. Salzberg and H. Israelsson
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Subject:	Overview of Magnitude Computation at CMR
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This memo describes the automatic procedures used to compute the network average m_b which are reported in the Reviewed Event Bulletin published during the Prototype International Data Center (PIDC) experiment at the Center for Monitoring Research (CMR). In addition, this memo describes manual steps that simulate the automatic procedures. Following these steps allows one to reproduce the network average m_b that are automatically produced both at CMR and at the International Data Centre (IDC).

Table 2 summarizes the steps in the magnitude computation process, while Tables 3, 4, and 5 provide details of some of the steps listed in Table 2. The steps in the example of manual computation, shown in the shaded columns, were based on the origin from the PIDC REB listed in Table 1. The example first validates the FK analysis, then the computation of the 1/2 peak-to-trough amplitude (A5/2), and finally the station and network magnitude. All data used in the example are from the primary seismic array CMAR and are analyzed using the analysis tool *geotool*.

Table 1: Origin used in the example

Origin Time	Lat	Lon	Depth	m_b
1999/11/08 14:19:29.29	54.6605	168.3210	0.0000	4.21

Table 2: Steps to determine magnitudes from waveforms

Step	Action	System element	Input	Output	Descriptions
Form Beam (see Table 3)	Generate a beam for arrays	*DFX*	components of an array	beam	Combine the channels of an array into a beam
Measure Amplitude and Period (see Table 4)	Compute the 1/2 peak-to-trough amplitude (A5/2)	*DFX/libamp*	beam, instrument response	amplitude, period values	Compute the peak-to-trough amplitude, and the peak-to-peak duration (for the period). Also, correct for instrument response at measured period (versus calibration period) (IDC521, P 27, 28).
Form Event	Associate the arrivals to form events	*GA*	**arrival** rows	**origin, origerr, assoc** rows	Associate the arrivals together using the location software to determine the origin location.
Compute Station Magnitude (see Table 5)	Compute the station specific magnitude	*GA/libmagnitude*	**amplitude**, **assoc** rows, Veith-Clawson tables	**stamag** rows	Compute the station magnitudes using the procedures from the PIDC, as outlined in IDC521, P 234-235.
Compute Network Magnitude (see Table 6)	Compute the network magnitude from the station magnitude	*GA/libmagnitude*	**stamag** rows	**stamag** rows**,** **netmag** rows	Compute the network (averaged) magnitude

Table 3: Form Beam

Action	System element	Input	Output	Descriptions	Example	SQL for example
Remove bad channels	*DFX/libbeam*	components of an array	flags indicating bad channels	Inspect the channel data to identify any channels that fail QC	In our example (shown in Figure 1), CM18 has spikes, CM15 has anomalous noise problems, and CM31 is BB while the other CMAR channels are SZ.	N/A
Filter waveforms	*DFX/libfilter*	components of an array	components of an array	Improve the S/N ratio of the waveforms (before beam forming) by filtering. Several filter windows are used, as described in (IDC5.2.1, P17).	In our example, a causal three pole Butterworth filter with a band-pass of 1-3 hz produces the best SNR.	N/A
Perform FK analysis	*DFX/libfk*	components of an array	FK plot	Calculate the FK spectrum using the proper lead and lag time from the arrival. The lead and lag time are specified as station specific parameters for beaming. At CMR, these are stored at, for example /cmss/config/app_config/DFX/fk/CMAR-fk.par.	Set a window 1.8 seconds before probable P wave arrival, to 3.15 seconds after P (This is specific for CMAR; each station is individually tuned).	Note: The values of the FK window are extracted from the parameter file for CMAR. The parameters are: `fk-lead=1.8` `fk-lag=3.15`
Find the optimal slowness and azimuth	*DFX/libfk*	FK Plot	slowness, azimuth	Read the FK plot, determine the peak of the FK plot, calculate the azimuth and slowness.	The peak is (2.81sec/degree, 6.44sec/degree), which corresponds to an slowness of 7.026 sec/degree, and azimuth of 23.6 degrees.	`select slow, azimuth from reb.arrival where arid=26313053:` `7.16 sec/degree, 21.691796 degrees`

Table 3: Form Beam

Action	System element	Input	Output	Descriptions	Example	SQL for example
Form the beam	*DFX/libbeam*	components of an array, slowness, azimuth	beam	Apply the channel specific delays and sum the unfiltered waveforms. Then, scale the beamed waveform by dividing by the number of channels to ensure that the beam is normalized to the same scale as the original waveforms. Note that this approach assumes that all channels have the same instrument response and calibration; The CMR processing software makes this assumption. (IDC5.2.1, P11-16).	Using the beam form function in *geotool*, generate a beam for the slowness 7.026 sec/degree, 23.6 degrees.	N/A
Apply instrument calibration	*DFX*	waveforms, calibration	beam (in units of nm)	Apply the correction factor from counts to nm, using the value from **wfdisc**.*calib*.	*geotool* performs this action. Otherwise the calibration factor would be 0.005 nm/count (from the calibration value in the wfdisc flat file).	N/A

Table 4: Measuring the Amplitudes and Periods

Action	System element	Input	Output	Descriptions	Example	SQL for example
Filter the beam	*DFX/libfilter*	beam	filtered beam	Apply a non-causal 3 pole Butterworth filter with corners at 0.8 and 4.5 Hz (IDC5.2.1, P28).	Use the edit/filter/butterworth pop-up, enter 0.8 Hz for the low frequency, 4.5 Hz for the high, set the order to 3, and ensure that it is causal	N/A
Measure the peak-to-trough amplitudes	*DFX/libamp*	filtered beam	peak-to-trough amplitudes	Find the maximum peak to trough (or trough-to-peak) amplitude in a 5.5 second window starting 0.5 seconds before the P arrival (IDC5.2.1, P28).[a]	Minimum amplitude is observed to be -3.97 nm; maximum amplitude is 2.38 nm	N/A
Measure period (PER)	*DFX/libamp*	filtered beam	period of the measured peak-to-trough amplitude	Determine the period of measured amplitude. Simplistically, the period can be obtained by measuring the duration between the observed peak and trough. The CMR automatic processing software, however, uses a Cosine or Lagrangian interpolation scheme to obtain the optimal period.[b]	As a practical matter, measuring the half-period of the peak-to-trough gives results very close to the polynomial fit. The peak-to-trough duration was measured to be 0.4 seconds, giving a period of 0.8 seconds.	`select per from reb.amplitude where arid=26313053 and amptype='A5/2'`: `0.821 seconds.`

Table 4: Measuring the Amplitudes and Periods

Normalize amplitudes for response, filter band	*DFX/libamp, libfilter, libresponse*	peak and trough amplitudes, instrument response	corrected amplitude	removes the Butterworth filter response from the observed amplitude for the computed period by determining the filter response and applying that to the observed amplitude. The instrument response is similarly normalized from the observed period to the nominal calibration period.	In this case, since the observed period was far from the filter cutoff frequencies (cutoff of 0.8 hz vs 1.25 hz observed), the filter factor is 1.0. Examining the response curves (from the CMR web page, www.cmr.gov) indicate that the ratio of calib at 0.8 sec to the calib value at the calibration frequency is 0.8. Thus, the peak and trough amplitudes adjust to: 1.90 nm and -3.18 nm.	N/A
Compute the amplitude (AMP)	*DFX/libamp*	corrected amplitudes	1/2 peak-to-trough amplitude	Compute the peak amplitude minus the trough amplitude divided by 2.	(1.90 nm - (-3.18nm))/2= 2.54 nm	`select amp from reb.amplitude where arid=26313053 and amptype='A5/2': 2.5294 nm/`

a. The automatic processing software at CMR performs some QC checking. First, it ensures that there are multiple peaks in the time window, that is, the dominant period is less than the duration of the time window. It then removes peak-to-trough values that are below a threshold (percent of maximum value) which removes inflection points from the curve. It then finds the maximum difference in amplitude between the remaining adjacent peaks and troughs.

b. Identify extrema to either side of the minimum and maximum amplitudes. Then, use Lagrangian or Cosine fit to three points centered on the extrema (and previous and post extrema if they exist). Use extrema positions to compute up to three half-period values. Check half-periods for validity against Nyquist frequency, processing window length, band-pass corner frequencies, filter response correction. Average the acceptable half periods to obtain the period.

Table 5: Compute Station Magnitude

Action	System element	Input	Output	Descriptions	Example	SQL for example
Compute the value of the amplitude divided by the period	*GA/libmagnitude*	AMP (Table 4, step 5), PER (Table4 step 3)	AMP/PER	compute AMP/PER	2.54/.8=3.175	`select amp/per from reb.amplitude where arid=26313053 and amptype='A5/2';` `3.0808`
Determine attenuation correction	*GA/libmagnitude*	adjusted attenuation correction tables event-sta distance, event depth	attenuation Correction, B	Use the bi-cubic spline[Press et al. (natural, i.e., 2nd derivative on boundaries is 0), as described in IDC5.2.1, P234. Note that the Veith-Clawson (1972) corrections are computed for peak-to-peak amplitudes whereas the CMR uses a 0-to-peak amplitude. As such, the CMR attenuation corrections are adjusted by adding log(2) relative to the Veith-Clawson curves.	CMAR distance is 63.233, depth is 0; atten. value for 63 deg at 0 km depth is 3.751, and 64 deg, 3.751. Thus, the result is 3.751 (this example does not use the cubic spline)	Note: the corrected 0-to-peak Veith-Clawson curves are stored at CMR in parameter files (/cmss/config/earth_specs/MAG/atten/atten.p)
Compute station magnitude	*GA/libmagnitude*	AMP/PER, attenuation correction (B)	**stamag** row	execute the formula, mb=log(AMP/PER)+B	log(3.175)+3.751= 4.2527	`select magnitude from reb.stamag where arid=26313053 and magtype='mb_ave";` `4.2404`

Table 6: Compute Network Magnitude

Action	System element	Input	Output	Descriptions	Example	SQL For example

Ensure that all stations are in the allowable distance range	*GA/libmagnitude*	**stamag** row	updated **stamag**. *magdef*	When locating (or relocating) an event, it is possible that the distance to a station is changed and thus falls out of the allowed distance range.	station JKA reports a distance of 19.675, and thus should be excluded (by setting the *magdef* to 'n').	`update stamag set magdef='n' where delta > 20;`
						
						`update stamag set magdef='n' where delta < 100;`

Compute network magnitude	*GA/libmagnitude*	**stamag** rows	**netmag** row	Average the station magnitude values, excluding removed values (either outliers or distance not correct, as determined in the next step).	Average the station magnitude values.	`select avg(magnitude)from reb.stamag where magtype='mb_ave' and magdef='d' and orid=20609877:` `4.20669133`
Identify and remove outliers (then repeat previous step)	*GA/libmagnitude*	**stamag** row	updated **stamag**. *magdef*	Remove the station magnitude values for stations where the reported magnitude differs from the average magnitude by more than 1.0 (IDC5.2.1, P285). Once outliers are removed, recompute the magnitude and apply the outlier correction again. (Step two in this table)	In our example, there are no outliers. However, the process is to first compute an average magnitude. The compare the station magnitude values; if any differ by more than 1.0 magnitude units, it should be classified as an outlier.	`update stamag set magdef='n' where abs(magnitude - (select avg(magnitude) from reb.stamag where orid=20609877 and magtype='mb_ave' and magdef='d' )) > 1 and orid=20609877 and magtype='mb_ave' and magdef='d';`

Table 6: Compute Network Magnitude

Compute error	*GA/libmagnitude*	**stamag** rows**, netmag** row	**netmag** row	Compute the uncertainty of the network magnitude values, excluding removed values (either outliers or distance not correct) (IDC5.2.1, P285).	N/A	`select 1/(count(*)-1) * sqrt(sum(power((magnitude-4.20669133),2))) from reb.stamag where magtype='mb_ave' and magdef='d' and orid=20609877: .080419929`

Figure 1: Unfiltered Waveforms at CMAR