Station Corrections for the Katmai Region Seismic Network

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Introduction

Most procedures for routinely locating earthquake hypocenters within a local network are constrained to using laterally homogeneous velocity models to represent the Earth's crustal velocity structure. As a result, earthquake location errors may arise due to actual lateral variations in the Earth's velocity structure. Station corrections can be used to compensate for heterogeneous velocity structure near individual stations (Douglas, 1967; Pujol, 1988). The HYPOELLIPSE program (Lahr, 1999) used by the Alaska Volcano Observatory (AVO) to locate earthquakes in Cook Inlet and the Aleutian Islands is a robust and efficient program that uses one-dimensional velocity models to determine hypocenters of local and regional earthquakes. This program does have the capability of utilizing station corrections within it's earthquake location proceedure. The velocity structures of Cook Inlet and Aleutian volcanoes very likely contain laterally varying heterogeneities. For this reason, the accuracy of earthquake locations in these areas will benefit from the determination and addition of station corrections.

In this study, I determine corrections for each station in the Katmai region. The Katmai region is defined to lie between latitudes 57.5 degrees North and 59.00 degrees north and longitudes –154.00 and –156.00 (Figure 1) and includes Mount Katmai, Novarupta, Mount Martin, Mount Mageik, Snowy Mountain, Mount Trident, and Mount Griggs volcanoes. Station corrections were determined using the computer program VELEST (Kissling, 1994). VELEST inverts arrival time data for one-dimensional velocity models and station corrections using a joint hypocenter determination technique. VELEST can also be used to locate single events.

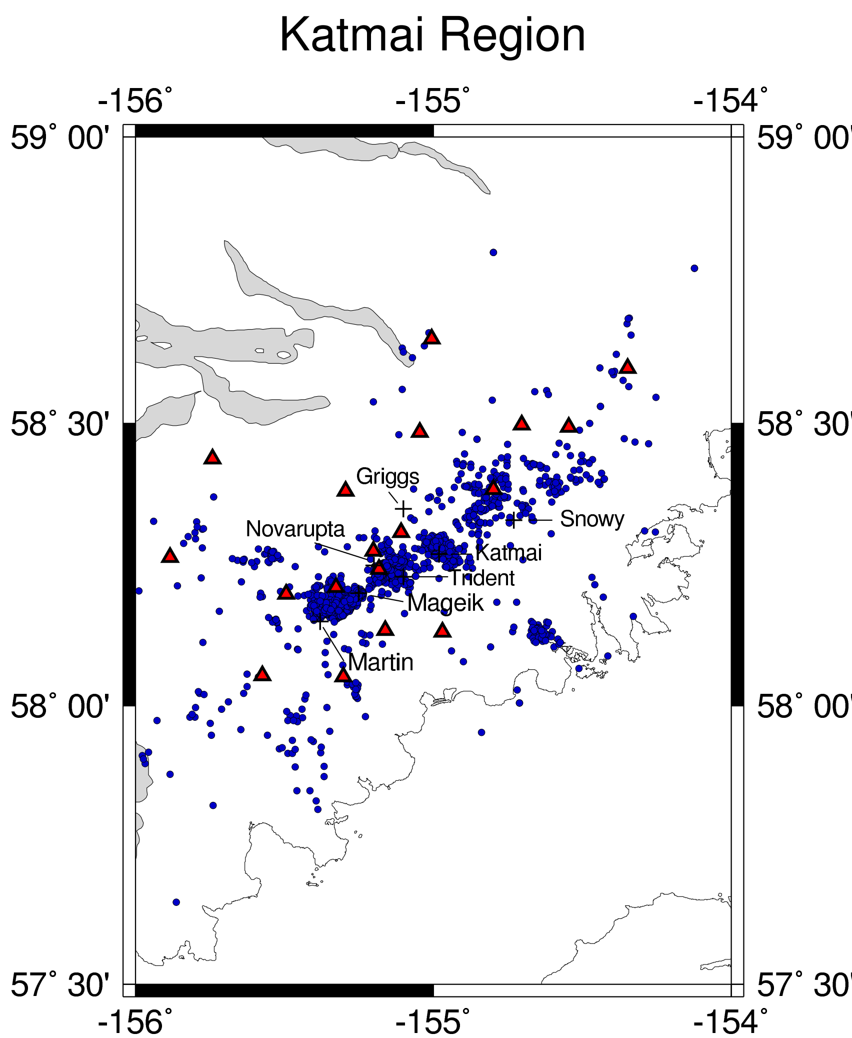


Figure 1: Map of the Katmai Region. Blue dots represent earthquakes used in the study. Red triangles represent seismic stations. Green crosses represent volcano summits.

Methods

Data Collection and Criteria

Data was collected from the AVO seismicity catalog for the period between August 1995 and April 2001. Earthquakes that occurred outside of the study region were rejected, as were earthquakes that were not recorded at six or more stations on the Katmai network. The total number of earthquakes used in this study is 2958. A series of inversions on nine independent subsets of the data were completed and the results of these inversions were then averaged. By utilizing this averaging procedure, random noise in the model velocity perturbations and station locations is somewhat suppressed. In addition, this procedure gives some indication of the robustness of the final model and station corrections by the variation of the final values between data sets. To avoid clusters of events influencing the results, the subset placement of each event was based on the outcome of a random number generator. The number of earthquakes in each subset ranged between 313 and 344. For all inversions, station KBM was chosen as the reference station because of its central location within the network and the abundance of events recorded at this station.

Inversion Methods

Inversions for velocity models and hypocenter locations were first run on each of the nine data subsets using the generic Alaskan model as the starting velocity model. This is the model that is currently used by AVO to locate earthquakes in areas of Alaska where specific velocity information is not available. This starting model is referred to as "akgeneric". The velocity models resulting from each of the nine individual inversions were then averaged to obtain a final velocity model called "akgeneric_ave".

Inversions for velocity models and hypocenter locations were also run using the model developed by Jolly (2000) for the Katmai area as the starting velocity model. This is a one-dimensional velocity model developed by forward modeling and is currently being used by AVO to locate events in the Katmai area. This starting model is referred to as "katvbest". The velocity models resulting from each of these nine inversions were also averaged to obtain a final velocity model called "katvbest_ave".

The velocity models "akgeneric_ave" and "katvbest_ave" are very similar. Exceptions are at very shallow depths (< 2 km) and depths greater than about 22 km. (Figure 2). At greater depths the two velocity models approach the velocity profiles of the starting models used in each case. This result is expected since most of the hypocenters are at a depth above 20 km. "Katvbest_ave" and "akgeneric_ave" were averaged, with the resulting velocity model referred to as "katfin".

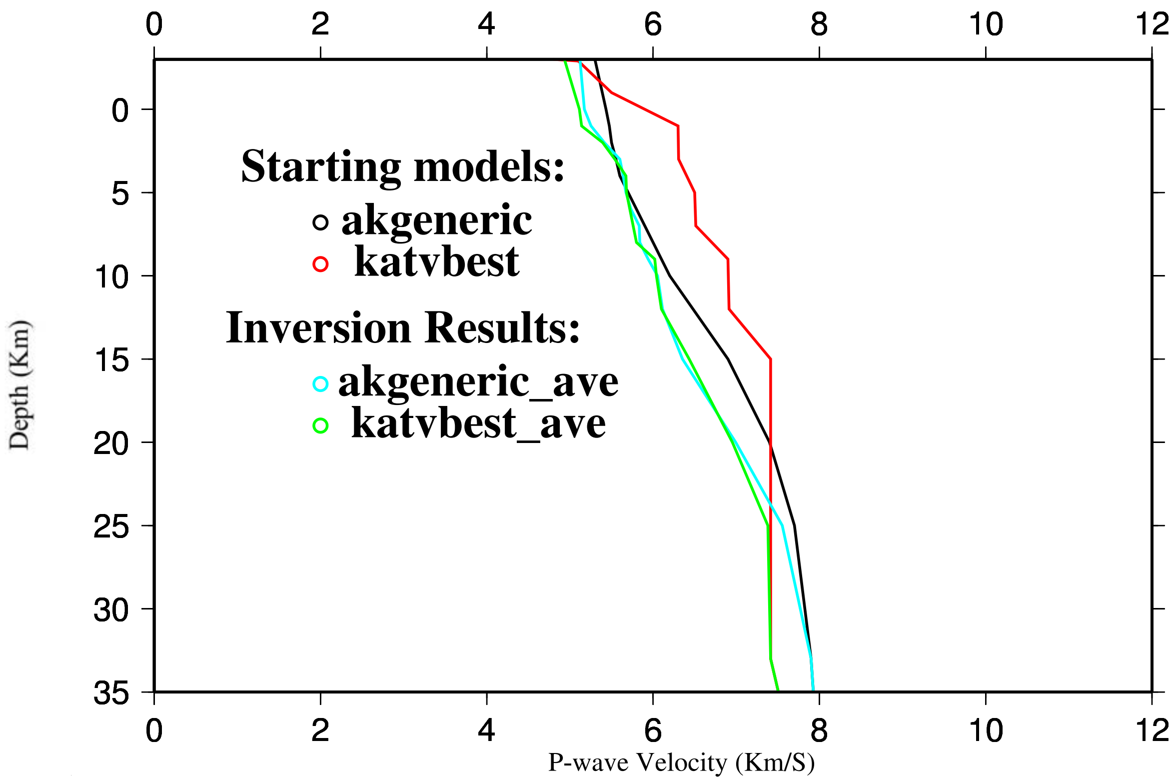


Figure 2: Starting velocity models and the velocity models resulting from the inversions. The black line represents the "akgeneric" model currently used in HYPOELLIPSE to locate earthquakes in areas where more detailed velocity information is not available. "Katvbest" is the velocity model currently used in HYPOELLIPSE to locate earthquakes beneath Katmai Volcano.

VELEST was then run in single event mode using “katfin” as the starting velocity model to relocate all 2958 Katmai events. Starting locations of the earthquakes and the new locations are shown in Figure 3.

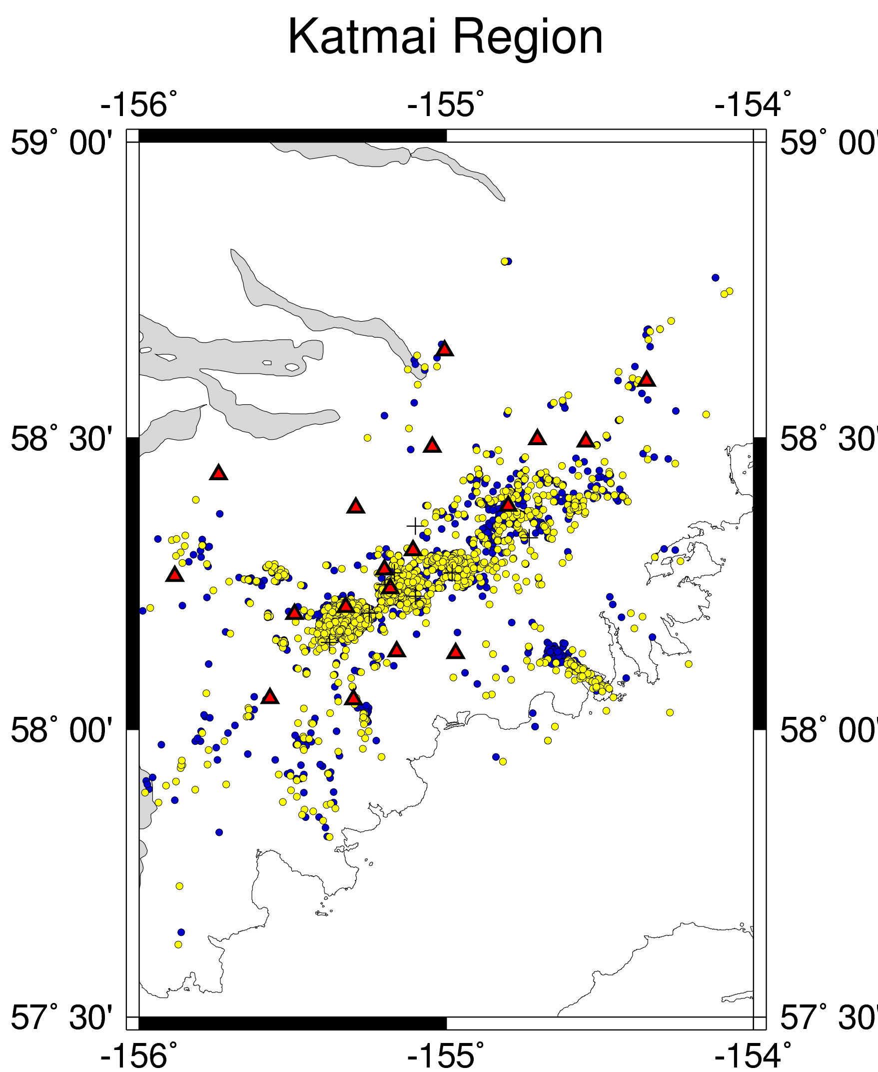


Figure 3: Relocated earthquakes. Blue dots represent original hypocenter locations. Yellow dots represent the location of hypocenters relocated using the velocity model katfin. Triangles represent seismic stations and green crosses represent volcano summits.

In the final step, full VELEST inversions were run on all nine subsets using the relocated events and the starting velocity model katfin. Station corrections determined in these inversions were averaged to compute the final values.

Results

Velocity models from the final inversions did not change much from the starting model (Figure 4; Table 1). Figure 5 shows the station locations and the travel time corrections. There is no station correction for KBM since this station was the reference station. Stations shown in red recorded greater than 100 earthquakes per inversion and had small variations in the computed station correction for each of the nine runs. The variation in the travel time corrections is represented by the spread, defined as the difference between the highest station correction and the lowest station correction for each station. Stations that recorded fewer events tended to have higher spreads in computed station corrections. Stations shown in pink and purple had spreads that were greater than 0.1. Stations shown in pink recorded fewer than 100 events per inversion whereas the three stations shown in purple recorded greater than 100 earthquakes per inversion. Station corrections (Corr) from each of the nine runs, their averages, spread, and the number of events used for each station in each run are shown in Table 2.

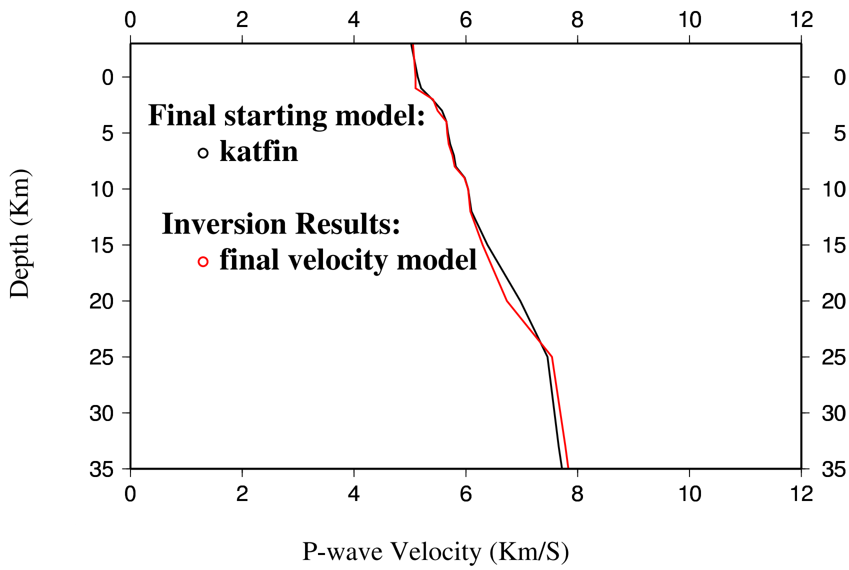


Figure 4: Starting model used to relocate hypocenters in the Katmai region and used in the final inversions is shown in black. The velocity model averaged from the results of nine inversions from which station corrections are computed. There is little variation between the beginning and final models.

Table 1: Final Velocity Model

Depth (Km)	P-wave Velocity (Km/S)
-3	5.05
1	5.10
2	5.41
3	5.49
4	5.65
5	5.67
6	5.69
7	5.76
8	5.80
9	6.00
10	6.04
12	6.08
15	6.30
20	6.73
25	7.54
33	7.78

Station corrections are mostly consistent with the results of a P-wave velocity inversion study conducted by Jolly (2000). In particular, station KCE has a high average station correction (0.253) (Table 2 and figure 5). KCE is located in the vicinity of the Katmai Pass between Mount Mageik and Mount Trident. Jolly (2000) reported a region of low P-wave velocities and high attenuation between Mount Mageik, Mount Martin, and Novarupta at depths between 0 and 4 km. Saltus et al. (1992) found a low Bouger gravity anomaly in this same region. The high correction at KCE is consistent with these previous studies. Jolly's (2000) study also found Mount Griggs and Snowy Mountain to have higher shallow velocities relative to Mount Mageik, Mount Trident and Novarupta. This is consistent with lower station corrections determined for KCG (0.019), KVT (-0.082), and KAWH (-0.098).

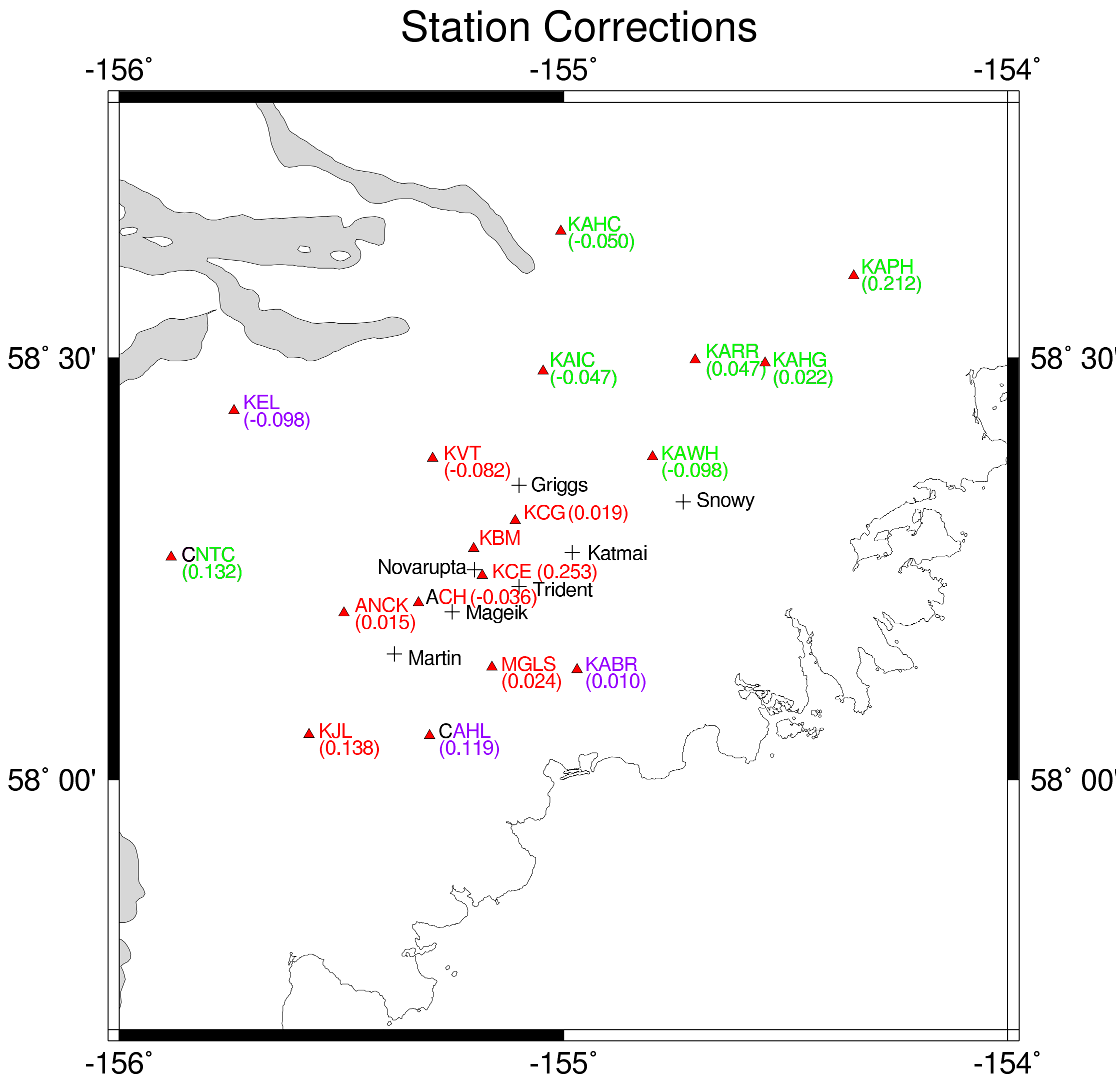


Figure 5: Station names and travel time corrections for the Katmai Network. Stations shown in red are considered to have well determined travel time corrections with greater than 100 events recorded per inversion and correction spreads less than 0.1. Stations shown in pink recorded fewer than 100 earthquakes per individual inversion and had correction spreads greater than 0.1. Stations shown in purple recorded greater than 100 earthquakes per inversion but still had an average spread greater than 0.1. Blue crosses represent volcano peaks.

Table 2: Station Corrections

RUN	ACH		ANCK		CAHL		CNTC		KABR		KAHC	
	N	Corr.	N	Corr.	N	Corr.	N	Corr.	N	Corr.	N	Corr.
1	304	-0.019	199	0.012	187	0.072	76	0.139	133	-0.019	65	-0.066
2	297	-0.026	209	0.025	197	0.126	85	0.134	143	-0.014	69	0.016
3	295	-0.041	195	0.008	196	0.120	84	0.096	138	-0.009	58	-0.103
4	288	-0.048	204	0.009	191	0.133	73	0.148	152	0.048	63	-0.052
5	302	-0.013	206	0.059	194	0.199	79	0.245	141	0.069	63	0.019
6	278	-0.025	183	0.048	177	0.173	77	0.214	145	0.089	62	0.006
7	289	-0.049	208	0.001	185	0.118	81	0.073	147	0.032	67	-0.008
8	291	-0.063	195	-0.022	191	0.057	68	0.047	138	-0.064	60	-0.203
9	312	-0.043	201	0.002	192	0.071	86	0.090	139	-0.040	69	-0.062
Ave.	-0.036		0.015		0.119		0.132		0.010		-0.050	
Spread	0.050		0.081		0.142		0.198		0.153		0.222	

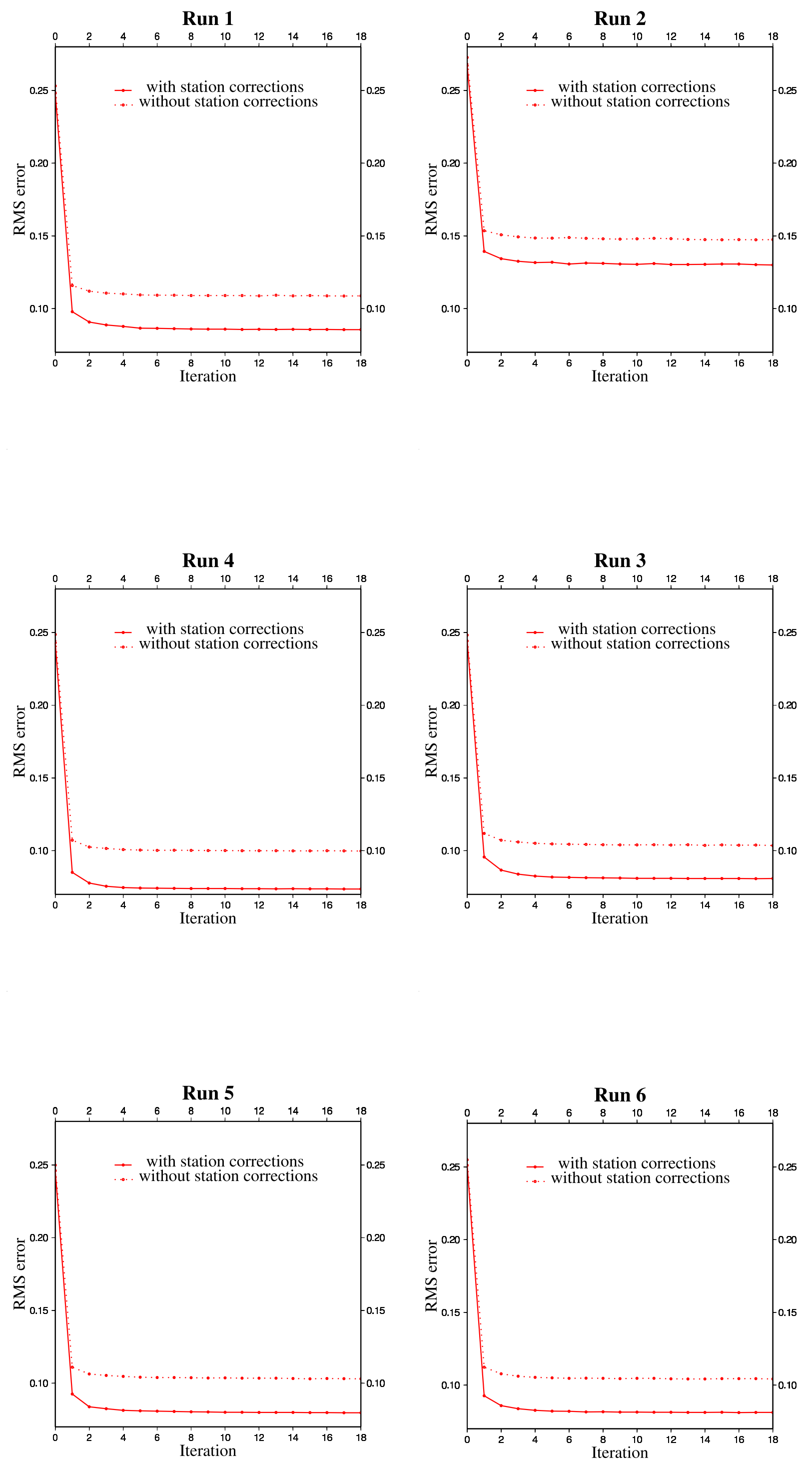
Table 2, Cont.

	KAHG		KAIC		KAPH		KARR		KAWH		KBM (ref.)	
RUN	N	Corr.	N	Corr.	N	Corr.	N	Corr.	N	Corr.	N	Corr.
1	43	-0.031	52	-0.054	32	0.113	66	0.013	64	-0.138	299	0.000
2	50	-0.041	53	0.003	31	0.122	78	-0.058	69	-0.137	298	0.000
3	41	-0.021	49	-0.092	25	0.214	67	0.016	63	-0.138	298	0.000
4	46	0.085	51	-0.042	33	0.274	63	0.124	64	-0.047	288	0.000
5	38	0.120	48	-0.049	24	0.321	52	0.118	58	-0.080	295	0.000
6	40	0.035	49	-0.015	32	0.273	64	0.089	66	-0.103	282	0.000
7	43	0.105	43	0.002	34	0.336	61	0.145	65	-0.010	291	0.000
8	42	-0.023	44	-0.141	27	0.090	59	-0.053	63	-0.138	285	0.000
9	42	-0.034	50	-0.052	31	0.171	62	0.029	63	-0.093	309	0.000
Ave.	0.022		-0.047		0.212		0.047		-0.098		0.000	
Spread	0.161		0.156		0.256		0.203		0.128		0.000	

Table 2, Cont.

	KCE		KCG		KEL		KJL		KVT		MGLS	
RUN	N	Corr.	N	Corr.	N	Corr.	N	Corr.	N	Corr.	N	Corr.
1	268	0.265	273	0.021	152	-0.098	146	0.114	276	-0.078	259	-0.005
2	261	0.274	274	0.024	138	-0.075	161	0.132	279	-0.067	263	0.023
3	265	0.232	267	0.012	140	-0.121	142	0.098	279	-0.093	249	0.030
4	253	0.259	263	0.005	132	-0.078	144	0.157	276	-0.092	255	0.042
5	265	0.257	277	0.029	128	-0.089	145	0.242	284	-0.072	263	0.057
6	248	0.249	262	0.021	137	-0.034	133	0.184	259	-0.061	246	0.073
7	262	0.251	267	0.018	142	-0.115	157	0.137	281	-0.092	246	0.018
8	256	0.257	265	0.012	140	-0.170	133	0.059	276	-0.121	253	-0.019
9	272	0.237	280	0.031	139	-0.100	151	0.116	290	-0.059	263	-0.007
Ave.	0.253		0.019		-0.098		0.138		-0.082		0.024	
Spread	0.042		0.026		0.136		0.183		0.062		0.092	

To demonstrate the improvement in earthquake locations by using the station corrections, events from the original data sets were relocated using the model "katfin" both with station corrections and without. Figure 6 shows the average root mean squared (RMS) errors for earthquake locations both with and without corrections. For all data sets the errors were greatly reduced in the inversions using the station correction.


Run 1
Run 2
Run 4
Run 3
Run 5
Run 6
with station corrections
without station corrections
RMS error
Iteration
0.10
0.15
0.20
0.25
0 2 4 6 8 10 12 14 16 18

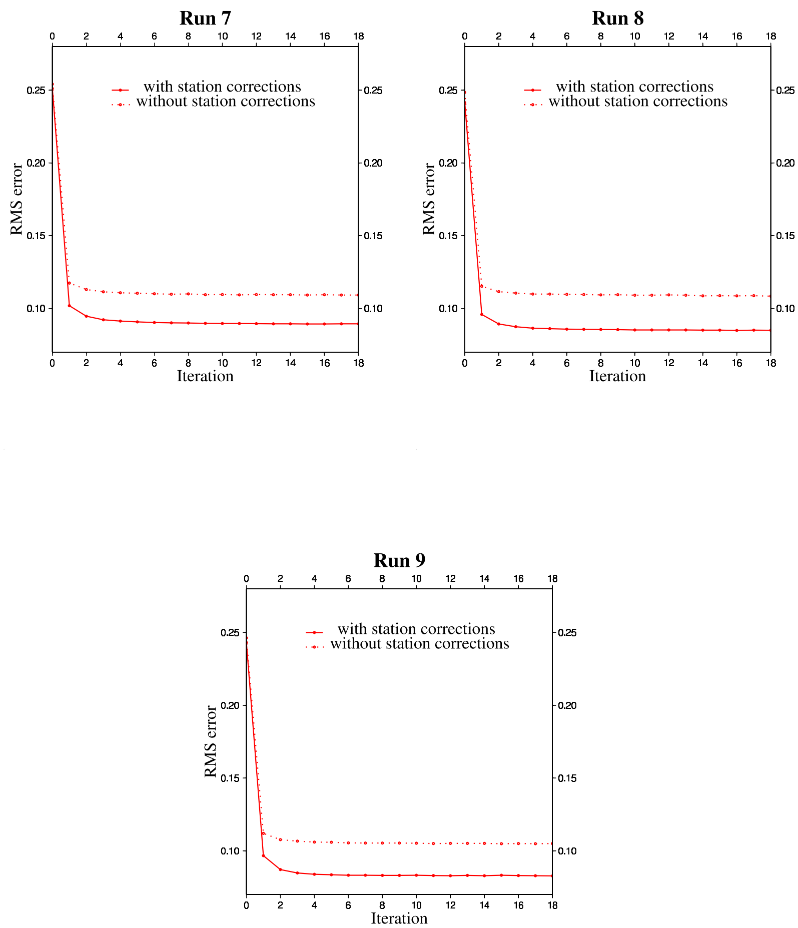


Figure 6: RMS errors for earthquake locations in each of the nine runs. Dotted line represents the RMS errors without station corrections. Solid lines represent RMS errors with station corrections.

References

Douglas, A., (1967), Joint epicenter determination, *Nature,* **215**, 47-48.

Jolly, A.D. (2000), Subsurface structure of the volcanoes in Katmai National Park, Alaska, *Ph. D. Thesis*, University of Alaska, Fairbanks.

Kissling, E., Ellsworth, W. L., Eberhart-Phillips, D. and U. Kadolfer,(1994), Initial reference models in local earthquake tomography, *J. Geophys. Res*.,**99**, 19,635-19,646.

Lahr, J.C., (1999), Hypoellipse: a computer program for determining local earthquake hypocentral parameters, magnitude, and first-motion pattern, U. S. Geological Survey Open-File Report 99-23, 115p.

Pujol, J., (1988). Comments on the joint determination of hypocenters and station corrections, *Bull. Seism. Soc. Am*., **78**, 1179-1189.

Saltus, R. W., Stone, D., Kienle, J., and Goodliffe, A. D., (1991), New gravity data at Katmai National Park, Alaska, suggest a magma body analogous to that at the Geysers-Clear Lake Region, California (abstract), *EOS*, **72**, 429.

Ward, P. L., Pitt, A. M., and Endo, E.,(1991), Seismic evidence for magma in the vicinity of Mt. Katmai, Alaska, *Geophys. Res. Let*., **18**, 1537-1540.