

EXTENDING REGIONAL WAVE FORM MODELING TO SHORTER PERIODS TO IMPROVE THE LOCATION AND IDENTIFICATION OF SMALL SEISMIC SOURCES

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ABSTRACT

In an effort to improve the location of small seismic events near known test sites, we are determining source-station specific corrections (SSSC's) for regional P, S and Lg phases recorded at IMS stations within 20° of these locals, in particular the central Asian test sites of Lop Nor and Semipalantinsk. To this end, we are calculating travel-time residuals between phase arrival information from various sources -- CEB and ISC values as well as direct waveform picks -- and IASP91 predictions using available ground-truth data for events in and near these test sites. These residuals are then averaged for each station to determine the empirical SSSC's. Ground-truth data for these events vary in accuracy; in particular, the level of ground truth for more recent Lop Nor explosions, which are the only ones recorded by many of the newer IMS stations, is not well constrained, being GT25 locations from the Reviewed and Calibration Event Bulletins (REB and CEB). As accurate hypocentral information is crucial to obtaining well-calibrated travel-time corrections, we re-evaluated these more poorly constrained ground-truth data. We found that the ISC locations were quite similar to those of GT5 Lop Nor events which were determined from joint epicenter determinations (JED). For $m_b \geq 5$ explosions the average difference in epicentral locations is 2.9 km, with the maximum being 5.5 km; and differences in origin time being 0.1 sec on average, with the maximum being 0.3 sec. Epicentral errors for these ISC locations are small, being less than 5 km. Discrepancies and errors are significantly larger for the smaller ($m_b \leq 4.7$) explosions, and are assumed to be due to SNR phase picking problems and fewer observations used to determine locations. Consequently the ISC teleseismic locations for $m_b \geq 5$ explosions can be considered to be of GT5 quality. We compared the ISC and GT25 (CEB) locations of the four available 1995+ Lop Nor explosions -- those occurring in the operating period of most of the present IMS stations in the region -- to ascertain how accurate the CEB locations actually are. The difference in epicentral location, on average, is 11.3 km with the maximum being 18.4 km; the average differential origin time is 1.4 s, with the maximum being 1.7 s. These differences are larger than those between the GT-5 and ISC locations. As the ISC locations are fairly consistently determined over time and use a large number of observations (200+), their values are considered robust and more accurate than the CEB values, which are determined from far fewer observations. Furthermore, travel-time corrections were determined for ISC reporting stations which observed both the 1995+ and earlier (1980-1994) GT5 events. Three sets of corrections were calculated: one using the GT5 locations for the earlier (1994-) events and the other two using the ISC or CEB locations for the more recent (1995+) events. The 1994- GT5 and 1995+ ISC location-based corrections are quite similar in value, whereas the 1994- GT5 and 1995+ CEB location-based corrections are significantly different. Therefore we used the ISC locations for these 1995+ events to establish SSSC's for regional P phases. The 1995+ explosions were then relocated using IMS phase information both with and without SSSC's, and compared these hypocenters to the ISC, or assumed GT, values. The average difference in location is 6.6 km and 17.4 km respectively for the corrected and uncorrected locations, with error-ellipse axes being only marginally smaller (5%) for the corrected locations.

Key Words:

Regional Location, Travel-time Calibration, SSSC's

OBJECTIVE

We are developing techniques to better locate and characterize small ($m_b < 4.5$) seismic events, particularly for regions surrounding known nuclear test sites. Such events are of particular interest to the CTBT monitoring community, and reliably locating and identifying them is of paramount concern. Events of this size are usually only observed regionally ($\Delta < 20^\circ$) as was the case of the August 16, 1997 Kara Sea event (Israelson *et al.*, 1997). Consequently we are concentrating on improving location capabilities for stations within 20° of test sites in central Asia. Attempts at developing improved 1-D models for these purposes has proven difficult, in part, no doubt, due to the laterally varying nature of the crustal structure in the region. Therefore we have more recently concentrated on determining source-specific station corrections (SSSC's) for IMS stations relative to specific test sites; this scheme is particularly well suited to the problem at hand, that is to determine empirical travel-time corrections for a relatively small geographic region centered about a point with several master events. To determine SSSC's it is important to have accurate ground truth (GT) information regarding the location of master events used in determining the travel-time calibrations, or residuals; therefore the accuracy of GT hypocenters must be verified as well. These SSSC's, which are determined for the IASP91 global travel-time model using the location code LocSAT, used by the IDC, can be directly applied to future operational location determinations for events in this area.

RESEARCH ACCOMPLISHED

We are determining SSSC's for IMS stations within 20° of nuclear test sites in central Asia; the work described here pertains specifically to the Lop Nor test site. Unfortunately, for this region there are no GT-10, or better, events in the PIDC GT Event Database (Yang and Romney, 1999) for the period in which most of the IMS stations, or their surrogates, have been operating. Therefore it was first necessary to develop a set of alternative "quasi-GT" events for calibration purposes; in particular we wished to make use of the 1995 and 1996 Lop Nor explosions as they were well recorded by the IMS stations in the region. We first compared ISC and CEB (The PIDC's Calibration Event Bulletin) locations for these events and found significant differences in the epicenters and origin times; Table 1 provides these comparisons. The average difference between the ISC and CEB locations is 11.4 km, and the ISC origin times (OT) are, on average, 1.43 seconds earlier than the CEB OT's. Thus further analysis was needed to determine which set of locations were more accurate and should be used to determine travel-time calibrations; although the error ellipses for the ISC locations are a factor of 2-3 smaller, suggesting they are better constrained.

To this end we compared ISC locations for Nor explosions from the early 1990's and the 1980's with their GT-5 locations and OT's, which were taken from a joint epicentral determination study by Gupta (1995) using master events with locations determined by satellite imagery. Table 2 compares these two sets of locations as well as providing other relevant information; the last column, the number of observations, refers to the number of picks used to determine the ISC location for each event. For the larger ($m_b \geq 5.0$) events the locations and OT's are quite similar, being, on average, less than 2.9 km and 0.1 s apart, respectively. The differences are significantly larger for the smaller ($m_b \leq 4.7$) events. These relationships are shown graphically in Figure 1 in which the difference in epicentral location are plotted vs. m_b , and the number of observations. From these results it seems appropriate to take ISC locations of the larger explosions, particularly those determined with more than 100 observations, as comparable to GT-5 events.

The next step was to establish the effectiveness of SSSC's for known GT-5 events before determining corrections for the later (1995+) ersatz GT-5 events. For this we used the 9 events given in Table 2 and their ISC P-wave picks from stations within 25° ; this distance range was chosen so as to provide more adequate station coverage, particularly for the less well recorded, older events. As these events vary in number of observations as well as azimuthal coverage (see Figure 2), the location results for them should give an indication of the limitations of this method. Locations were determined using the LocSAT code (Nagy and Bratt, 1991) and the IASP91 model (Kennett and Engdahl, 1991). P-wave residuals were calculated relative to the GT-5 hypocenters and OT's, and averaged for each station; individual residuals which were over 1.5 standard deviations from the average station value were determined to be spurious and removed, and the average station residual, or correction, was recalculated.

These events were then relocated separately using the corrected and uncorrected arrival times; the results are given in figure 2. The corrected locations are significantly closer in distance to the GT-5 locations —usually by a factor of two or more —and on par with the ISC locations; the poorest corrected relocations, as would be expected, correspond to events with the fewest observations and poorer azimuthal coverage. Thus the travel-time correction procedure applied here provides more accurate locations and, consequently, justifies applying the same methodology to the IMS stations in this region.

Corrections were then determined in the same fashion for the IMS alpha and beta stations within 25° of the Lop Nor test site using the ISC hypocenters; for this no distinction was made between alpha and beta station, and, in a few cases, surrogate ISC stations and their arrival picks were used to make up for non-reporting IMS stations. The mislocations relative to the ISC hypocenters are plotted in Figure 3. The corrected relocations are 2-4 times closer to the ISC epicenters, taken to be GT, than the uncorrected relocations, and are on par with, or better than the CEB locations assuming that the ISC locations are more accurate. Clearly if the CEB locations were used as GT, the corrected relocated events would be closer to these locations as well. For the case of using observations out to 25° degrees, the mislocations are less than 5km relative to the ISC epicenters, whereas the the mislocations are between 5 to 10 km using observations out to 20°. The former use between 9 to 13 observations while the latter only use between 4-8 observations, with a corresponding degradation in azimuthal coverage. Figure 4 provides map-view comparisons of the locations for these events. None of the uncorrected location error ellipses overlap with the ISC location, whereas the ISC locations all lie within the corrected location 90% error ellipse for that event.

CONCLUSIONS AND RECOMMENDATIONS

P-wave SSSC's were determined for IMS and ISC stations within 25° of the Lop Nor test site, an area in which GT-5 events are available, thus making this method viable. Regional relocations using these corrections provided significantly improved epicenters, relative to the GT epicenters, compared to uncorrected relocations using the same set of stations; the GT locations lie within the 90% confidence intervals for the corrected relocations, which is not the case for the uncorrected relocations. These SSSC's for IMS stations can be directly incorporated into IDC location routines for this particular geographic region, *i.e.* within several hundred kilometers of the GT-5 epicenters used as master events. This same methodology can be applied to other regions with such GT information, particularly known nuclear test sites. Further, it was found for the set of explosions examined here that ISC locations based on 100+ observations were very close to GT-5 locations. This suggests that in some cases ISC events can be used as GT events for travel-time calibrations. This possibility needs to be examined for the case of earthquakes.

REFERENCES

- Gupta, V., 1995. Locating nuclear explosions at the Chinese test site near Lop Nor, *Science and Global Sec.*, **5**, pp. 205-244.
- Israelsson, H., M. D. Fisk, X. Yang, and R. G. North, 1997. The August 16, 1997 event in the Kara Sea, *CMR Technical Report*, CMR-97/38, Alexandria, VA.
- Kennett, B. L. N., and E. R. Engdahl, 1991. Traveltimes for global earthquake location and phase identification, *Geophys. J. Int.*, **105**, pp. 429-465.
- Yang, X. and C. Romney, 1999. PIDC Ground Truth Database, *CMR Technical Report*, CMR-99/15, Alexandria, VA.

Table 1

Comparison of GT (CEB) and ISC Locations and Origin Times					
Event Julian Date	m_b (ISC)	ΔR (km)	$\Delta O.T.$ [†] (sec)	Smaj, Smin CEB (km)	Smaj, Smin ISC (km)
95135	6.0	18.4	1.6	8.7, 8.0	2.4, 2.3
95229	5.9	9.6	1.2	9.3, 7.8	2.4, 2.3
96160	5.7	9.1	1.2	7.4, 6.6	2.8, 2.4
96211	4.7	8.2	1.7	9.4, 7.8	4.5, 3.2

[†]: $\Delta O.T. > 0$: ISC earlier

Table 2

Comparison of GT(JED) and ISC Locations and Origin Times				
Event Julian Date	m_b (ISC)	ΔR (km)	$\Delta O.T.$ [†] (sec)	Num. Obs.
92269	5.0	2.2	0.3	110
92142	6.5	3.5	0.1	710
90228	6.2	1.1	0.0	598
90146	5.5	3.4	0.0	276
88273	4.6	33.6	-4.0	25
87156	6.2	3.6	-0.2	491
84354	4.7	21.4	-4.5	43
84277	5.4	5.5	0.1	76
83279	5.5	1.0	0.1	54

[†]: $\Delta O.T. > 0$: ISC earlier

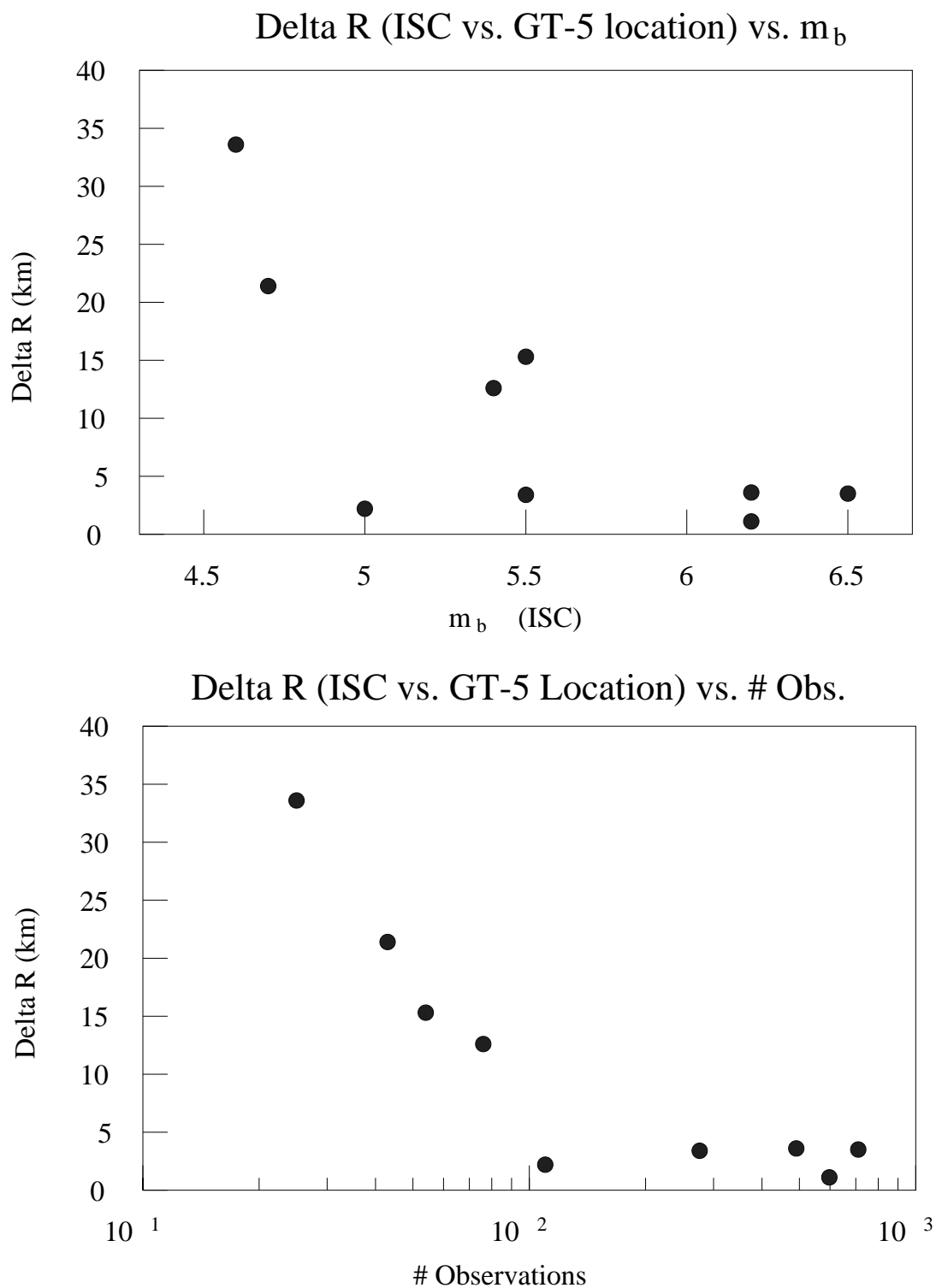


Figure 1. Relative location of ISC epicenters with respect to GT-5 locations for Lop Nor explosions: (top) vs. m_b (ISC); (bottom) vs. number of observations used to determine the ISC location.

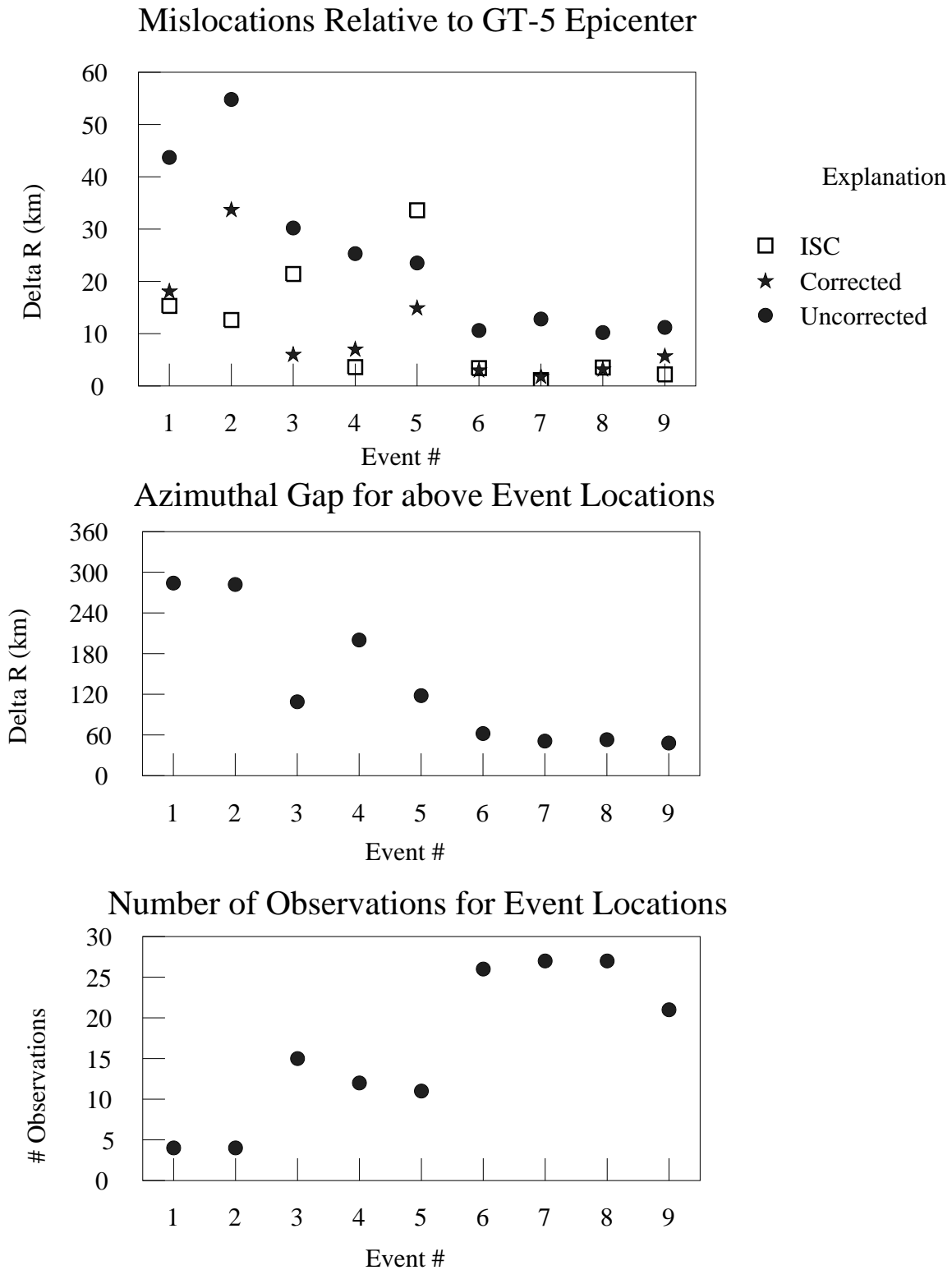


Figure 2. (top) Comparison of locations relative to GT-5 epicenters for regional corrected (star), uncorrected (circle), and ISC (open square) values; (middle) maximum azimuthal gap for the above regional locations; (bottom) number of observations used for the above regional locations

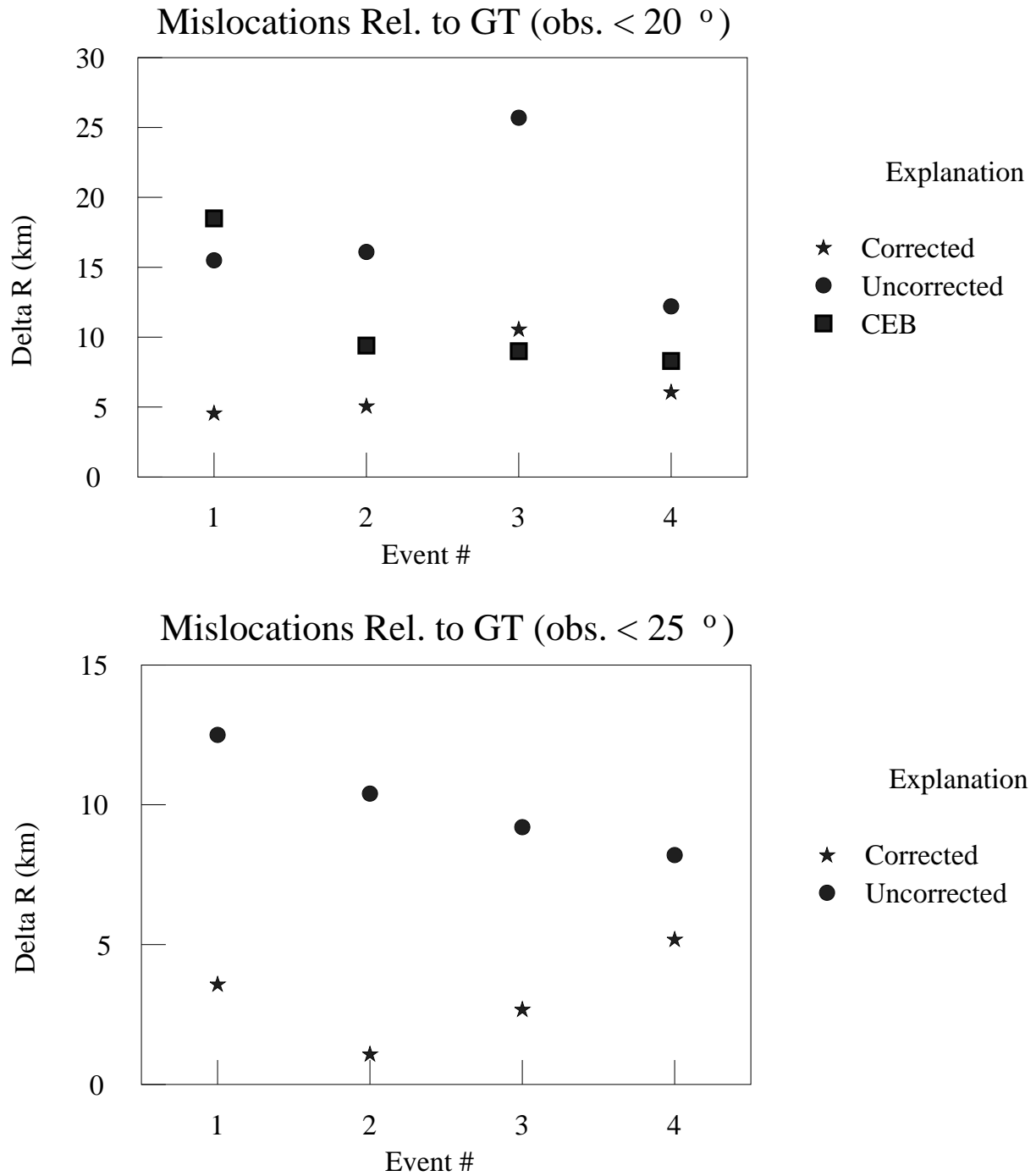


Figure 3. Comparison of locations relative to GT-5 (ISC) epicenters for regional corrected (star), uncorrected (circle), and CEB (square) values; the top figure is for locations using observations within 20°, while the bottom figure is for locations using observations within 25°.

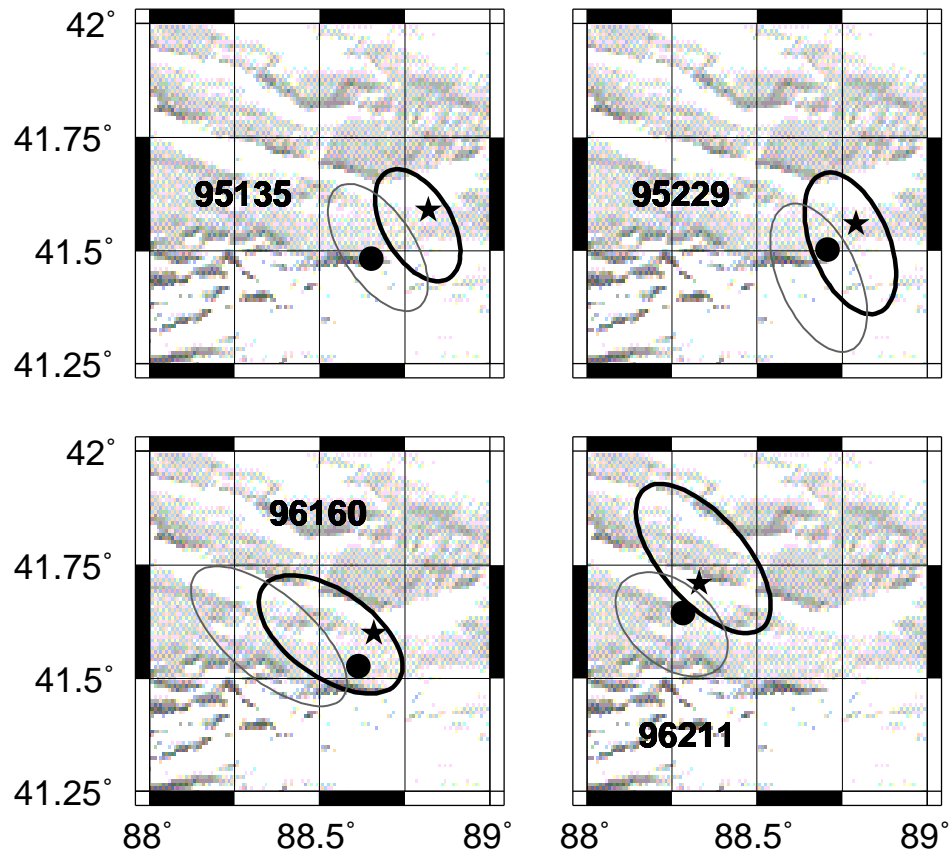


Figure 4. Map projections of ISC (star) and CEB (circle) locations, along with the corrected (thicker, darker line) and uncorrected (thinner, lighter line) regional ($\Delta < 20^\circ$) location 90% confidence-level error ellipses, for 4 Lop Nor explosions (Julian date is given in each panel). The ISC locations were taken as GT for the purpose of determining the SSSC's used in the corrected regional locations.