Seismicity Parameters for Seismic Hazard Assessment in Alaska

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Investigations Undertaken:

1. We investigated the homogeneity of the earthquake catalog in interior Alaska (Zuniga and Wiemer, 1999) and mapped the minimum magnitude of completeness.
2. We extracted additional felt reports for seismic shaking from Alaskan news papers and combined this information with previously known intensities to map the maximum intensity reported throughout Alaska (Lu and Wyss, 1999).
3. We examined the details of the history of assessment of seismic hazard in the Adak segment of the Aleutian Islands because, to some, the 1986 M8 Andreanof island earthquake seemed a violation of the seismic gap hypothesis. We show that on the contrary the earthquake was expected on the basis of the elastic rebound theory and the hypothesis that seismic quiescence precedes some main shocks (Wyss and Wiemer, 1999).
4. We investigated aftershock sequences in Alaska, California, and Japan (Wiemer and Katsumata, 1999), with emphasize on the spatial and temporal homogeneity of the b- and p-values. We implemented the capability to evaluate the probabilistic hazard posed by large aftershocks of main shocks in Alaska.
5. We developed a system to take near-real time information on the occurrence of seismic events and provide rapid notification to government and private agencies responsible for seismic hazard mitigation (Lindquist, 1998).

Results:

The results of the research supported by this grant are detailed in one Ph. D. thesis (Lindquist, 1998), one article in press (Zuniga and Wiemer, 1999), two articles submitted for publication (Wyss and Wiemer, 1999; Wiemer and Katsumata, 1999) and one article in preparation (Lu and Wyss, 1999).

Minimum Magnitude of Complete Reporting: Figure 1 shows the minimum magnitude of complete reporting for the years 1988-1998 in Alaska. This map was compiled by selecting the 100 nearest earthquakes to each node in a grid of 10 km spacing and then finding the point of departure from a straight line fit to the frequency-magnitude relation ($\log N = a - bM$). Visual checks of the results thus obtained by algorithm confirmed that they are correct.

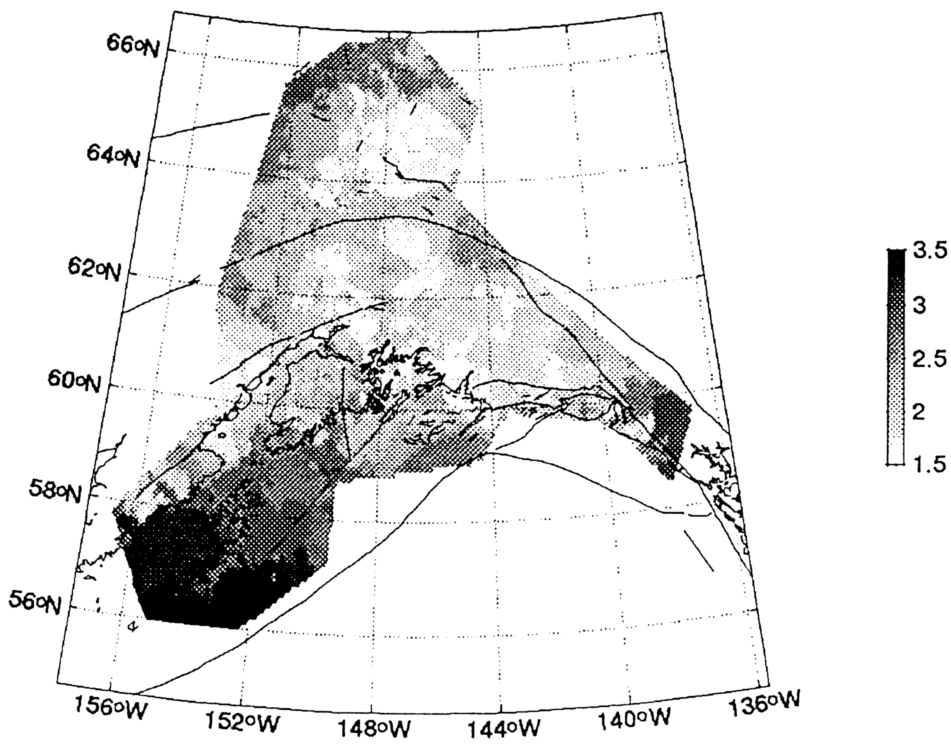

Figure 1: Map of minimum magnitude of complete reporting for the years 1988-98 in Alaska. Parts outside the shaded area do not have enough earthquakes for analysis, except for the Aleutians.

From Figure 1 we conclude that, for the years 1988-98, the minimum magnitude of completeness was Mc=1.5 in those parts of Alaska with the best coverage (for example near Anchorage and near Fairbanks). In most parts of Alaska Mc<2.4. In the panhandle Mc increases to above 2.5 near latitude 60° and further south it becomes Mc=3. In the far NE of the state Mc=2.8, and on Kodiak island Mc is typically 3.5 with higher values off shore. The history of seismic coverage in the Aleutians is checkered, with local networks being established and then dismantled again. Currently the Mc pattern is rapidly changing since new seismograph stations are being installed for volcano monitoring.

The period used for estimating the Mc in Figure 1 was 1988 through 1998 because the reporting of earthquakes above M=1.5 was relatively homogeneous in this period, as suggested by the approximately constant slope in the cumulative number curve of Figure 2. The data in Figure 2 are the same as those used in Figure 1, that is Mmin=1.5. Thus, the reporting in areas with strongly incomplete recording at that level are mixed with areas of complete reporting. In spite of this mixture, the rate of earthquakes recorded is constant (Figure 2), because always about the same per cent of events are reported.

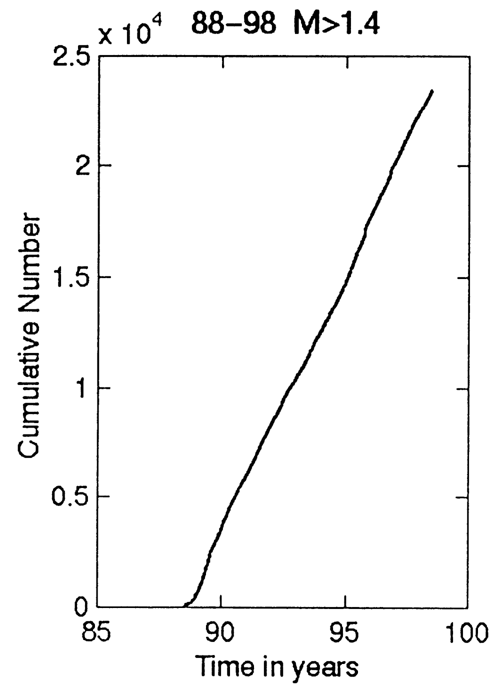

Figure 2: Cumulative number of earthquakes as a function of time for Alaska, M>1.4. The constant slope suggests that above this magnitude cutoff the reporting in Alaska was relative homogeneous with time.

Homogeneity of Reporting of Earthquakes: We investigated the homogeneity of reporting in seismicity catalogs because the reliability of various methods to estimate the seismic hazard depends on the catalog quality. Since this is a general problem, we included the catalogs of Guerrero, Mexico, in addition to the Alaskan catalog in this investigation.

For Interior Alaska we computed the standard deviate Z as a function of time by comparing the overall seismicity rate with the rate in a 3-year window. The maps of Z-values were inspected for all times. The most outstanding rate change is found around 1992.5, seen as a lowering of the slope in the cumulative number curve of Figure 3a. This decrease of reporting of small events is clearly illustrated in the normalized non-cumulative frequency-magnitude distribution in Figure 3c, where the larger events occur at the same rate in the two periods, whereas the smaller ones diminish in numbers for magnitudes below 1.5 during the second period compared to the first. Therefore, and because the *b*-value remained unchanged (Figure 3b), the most reasonable explanation for the observed rate change around mid-1992 is a decrease in the detection ability of the network in Inte-

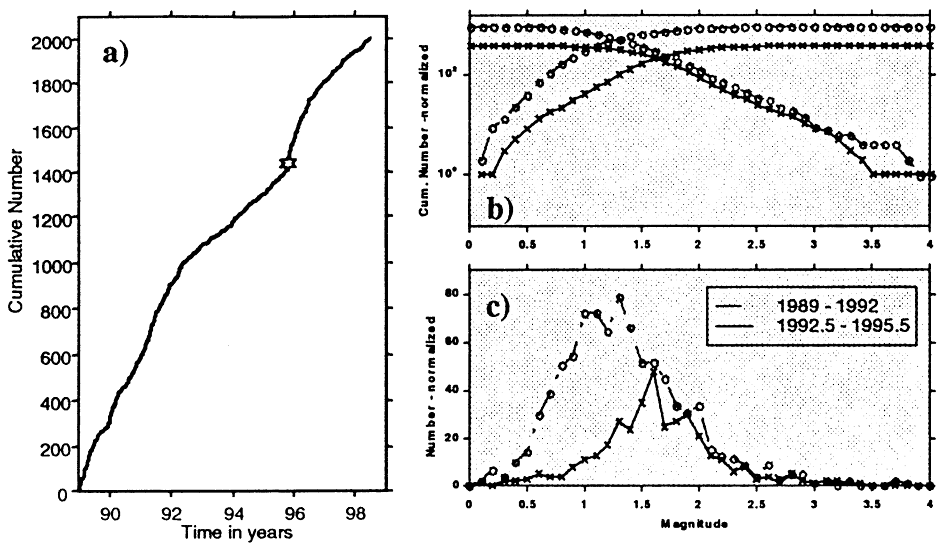

Figure 3: (Left) Cumulative number of events as a function of time for the seismicity in Interior Alaska. The 1995 M6.2 Tatalina river earthquake is marked by a star. Note the rate decrease that started in 1992.5. (Right) Cumulative (top) and non-cumulative (bottom) number of events as a function of magnitude. Two periods are compared in each frame: 1989 – 1992 (o) and 1992.5 – 1995.5 (x). The numbers have been normalized by the duration of each period.

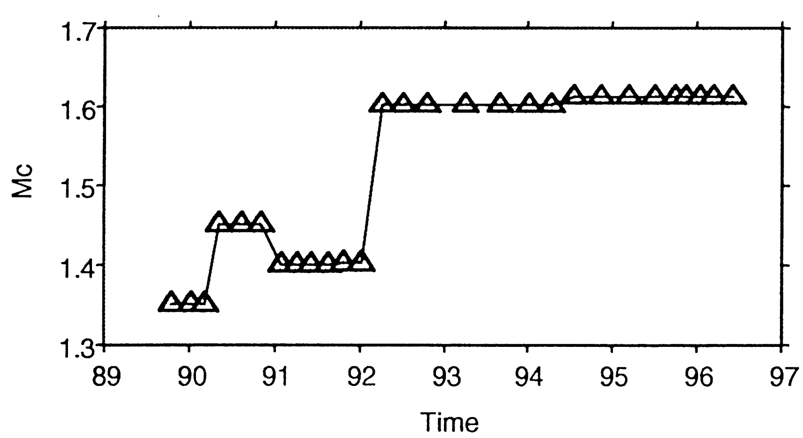

Figure 4: Magnitude of completeness as a function of time for the seismicity in Interior Alaska. The completeness is computed based on the frequency-magnitude distribution and using overlapping windows containing 500 earthquakes each.

rior Alaska and not a possible precursory change before the Tatalina earthquake. This case study demonstrate the usefulness of systematic comparisons of the cumulative and non-cumulative frequency-magnitude distribution and of spatial and temporal mapping of the seismicity rates as a tool to investigate the homogeneity of earthquake reporting (Zuniga and Wiemer, 1999).

Maximum intensity: We mapped the maximum intensities reported for all parts of Alaska because this value is to some degree a test of validity for estimates of the seismic hazard. Methods of seismic hazard estimates, which do not predict high hazards in areas that have experienced relatively strong shaking in the past, are not likely to be reliable. The converse is not true: Low historical shaking cannot necessarily be interpreted as an indication of low hazard. Given the short recorded history and the sparse population density of Alaska, it is likely that some areas have not been subjected to shaking by the maximum credible earthquake.

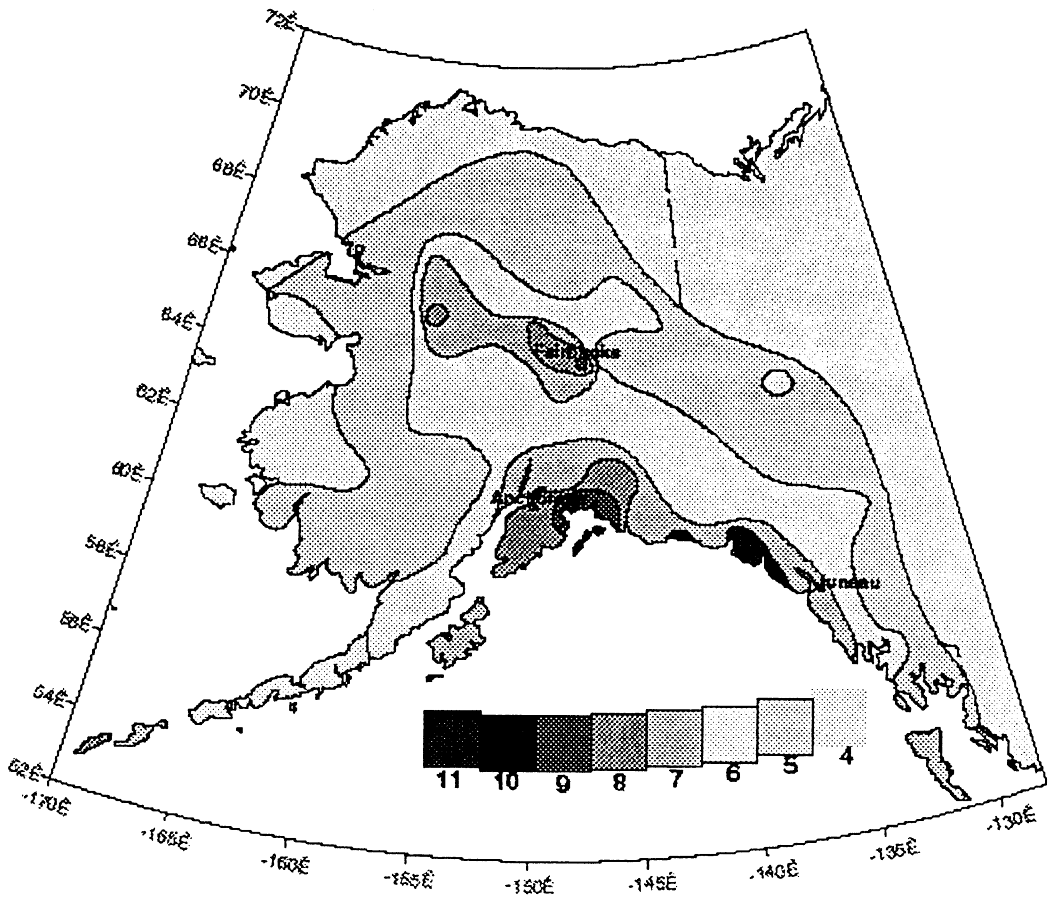

Figure 5: Maximum intensities (Modified Mercalli Scale) experienced due to earthquake shaking in Alaska. This is a composite map, using all published and some newspaper reports on damage.

Using the existing data banks and summary volumes on intensity reports in the United States and Alaska, as well as additional newspaper records, we constructed new isoseismal maps for all large earthquakes in Alaska. From these maps we then compiled a composite map of the strongest shaking reported for each location in the Sate (Figure 5; Lu and Wyss, 1999). This map of maximum intensity (Figure 5) resembles strongly the seismic zoning map proposed by J. Davies (personal communication, 1991). Thus, one can say that this seismic zoning map is reasonable, but changes may become necessary as strong earthquakes may occur in the future, where none have in the past.

Seismic Hazard Estimates near Adak: The seismic hazard in the Aleutian-Alaskan subduction zone is of course of major interest because three of the seven historically largest earthquakes occurred there. Various methods have been used to estimate the probability for large earthquakes there (e.g. Nishenko and Jacob, 1990). If enough information is available, one can even attempt to estimate the change of seismic hazard as a function of time. In the Aleutians one could formulate this question as follows: Which segments of this plate boundary are mature seismic gaps?

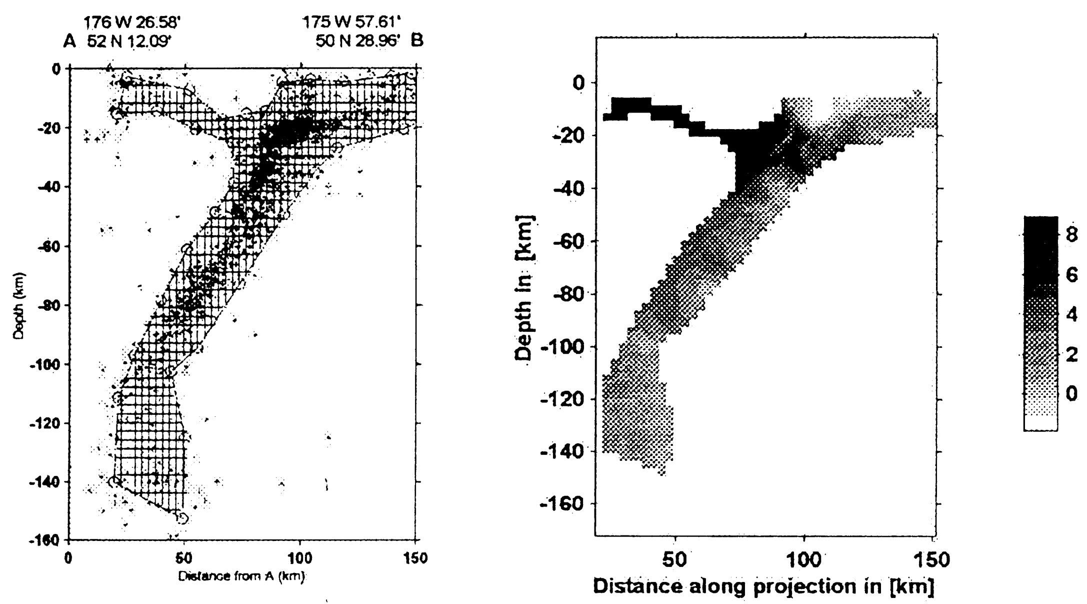

Figure 6: Cross section of the hypocenters beneath Adak on the left side and on the right side an image of the degree of seismic quiescence in a four year time window before the 1986, M8.0 Andreanof Islands earthquake in a cross section perpendicular to the Aleutian plate boundary. Dark gray marks locations of statistically highly significant seismicity rate decreases, in light gray areas the rates increased. The anomalous quiescent volume is located above the megathrust and to the north of it, where it is expected, if it results from precursory a-seismic slip on the deep extension of the megathrust.

The seismic gap hypothesis has recently been criticized heavily and termed incorrect (Kagan and Jackson, 1995). Because the great earthquakes of the Aleutian-Alaskan subduction zone are important pieces of evidence in this debate, we investigated the case of the supposed failure of the gap hypothesis in the repeated rupture of part of the 1957 great earthquake by the 1986 Andreanof island M8 earthquake. We show that two lines of evidence investigated by two sets of authors indicated in 1980 and 1985, before this great earthquake, that a main shock was likely. First, Wahr and Wyss (1981) estimated the amount of slip that occurred in the M8.7, 1957 earthquake as only 2 m. Their estimate was based on a dislocation model in an elastic half space that had to fit the 15 cm subsidence recorded by a tide gauge at Adak. They found that varying other parameters, such as the dip and width of the rupture plane could not substantially increase this estimate. Thus, they concluded that the recurrence time of ruptures in the Adak region may be very much shorter than expected for M9 class earthquakes. Second, Kisslinger (1985) predicted a large earthquake in the Adak segment of the Aleutians for the end of 1985 or the beginning of 1986. The earthquake that followed occurred a little too late and was larger than expected by Kisslinger. Nevertheless, the interpretation by Kisslinger that the seismic quiescence observed for the years 1982 through 1985 was a precursor, was correct. We mapped this precursory quiescence with modern tools in map view and cross section again (Figures 5a, b). The anomaly was highly significant and correlates with the 1986 rupture of the M8.0 Andreanof earthquake. Therefore, we conclude that the evidence analyzed by Wahr and Wyss (1981) and by Kisslinger et al. (1985) clearly pointed to an approaching large earthquake, and thus the Adak segment was recognized as a mature seismic gap before the earthquake occurred. Therefore, this event did not violate the seismic rebound theory, nor the seismic gap hypothesis.

Characteristics of Aftershock Sequences: We investigated the spatial and temporal variability of seismicity in aftershock sequences. This was the first detailed investigation of parameters in aftershock sequences conducted by anyone. To our surprise, we discovered very pronounced differences in both the *b*- and *p*-value (of the modified Omori law) within all aftershock sequences investigated (Wiemer and Katsumata, 1999). The 1995 M6.2 Tatalina River (Interior Alaska) earthquake was followed by aftershocks with b-values ranging from 0.6 to 1.5 (Figure 7). The contrast in the frequency magnitude distribution between different volumes is not a subtle feature (Figure 8).

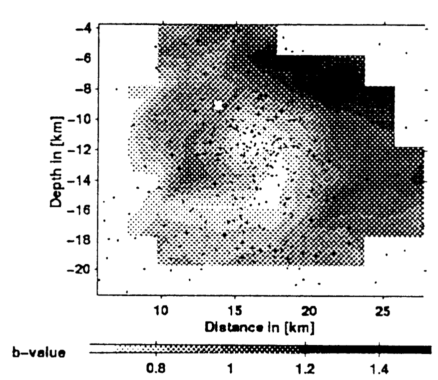

Figure 7: Map of b-values for the Tatlina 1995 aftershock sequence. The star marks the epicenter of the main shock, dots show the aftershocks. The b-values ranged from 0.6 to 1.5, indicating the heterogeneity of the crust in this area. Figure 8 contrasts two samples of events with contrasting b-values.

Because the recent earthquake catalogs for California contain larger and well documented aftershock sequences, we tested the hypothesis that in general the heterogeneity of the crust generates pronounced spatial differences in the parameters of a single aftershock sequence in three cases: the Landers, Northridge and Morgan Hill main shocks (Wiemer and Katsumata, 1999). In all of these the parameters varied widely; p-values ranged from 0.7 to 1.6 and b-values ranged from 0.5 to 2.0.

Along with the a-value that describes the productivity of an earthquake sequence, p- and b- can be used to assess the probability of a large and potentially hazardous aftershock. Because we discovered that all of these parameters vary strongly within an aftershock sequence, the calculated probability of large aftershocks also varies as a function of space. Probabilistic aftershock hazard assessment has been used in near-real time in California for a number of years and we have now implemented the capability to assess aftershock hazard in Alaska in near real time, and as a function of space in the aftershock sequence.

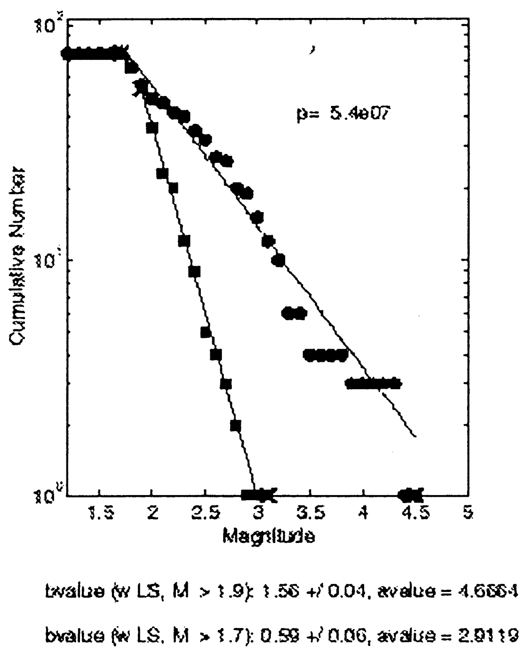

Figure 8: Two examples of the frequency magnitude distribution from the same aftershock sequence but volumes separated by a few kilometers. The probability that these two samples cannot be differentiated is $5x10^{-7}$. This illustrates that an aftershock sequence in general cannot be well described by a single b-value.

Examples showing the different decay rate in different locations, but in the same aftershock sequence, are shown in Figure 9. These two curves differ more strongly than differences between bulk p-values of different aftershock sequences. We hope that detailed investigations of these variations of the p-value, and correlation with other geophysical and geological parameters will lead finally to an understanding of what physical processes govern the decay rate of aftershocks. In addition, it follows that the probabilistic estimate of the hazard for a given size aftershock varies strongly within the aftershock area. It would be important for the cases of great Alaskan earthquakes with their very large aftershock areas, if we can use this method to pinpoint the sections of the main rupture most likely to produce a sizable aftershock.

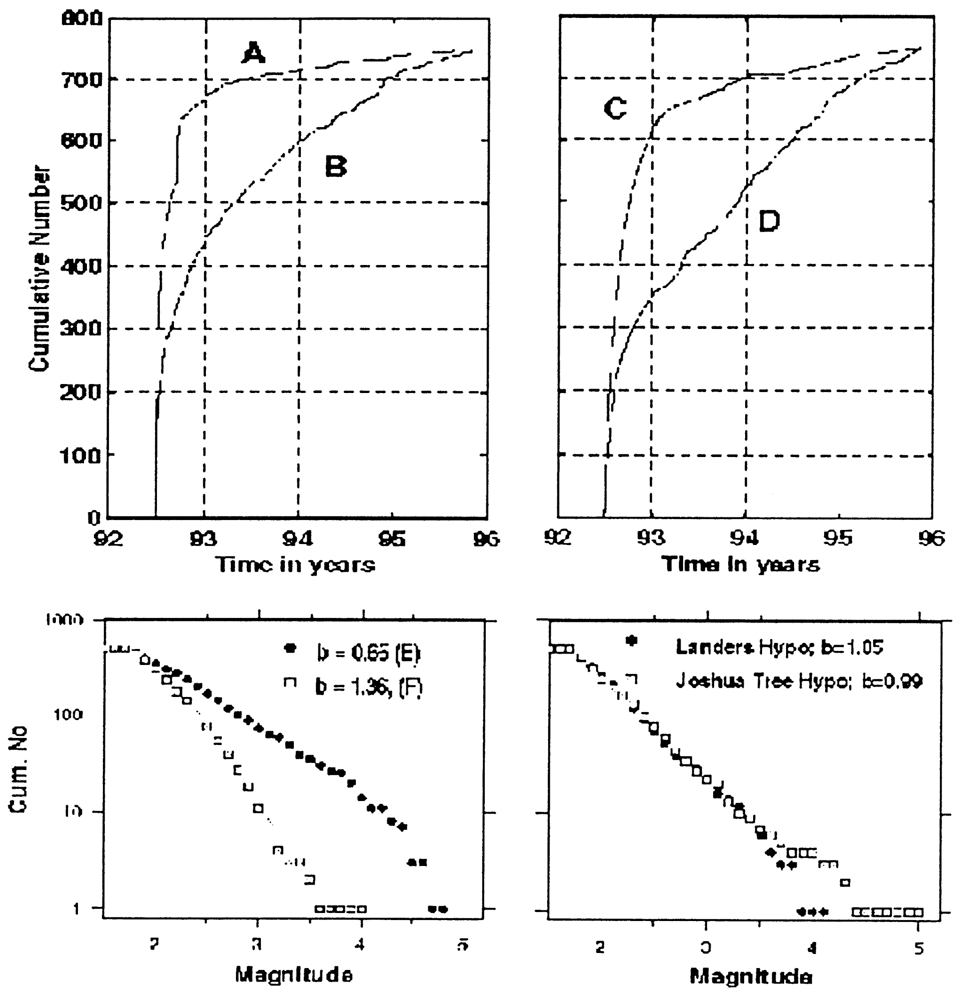

Figure 9: Cumulative numbers of earthquakes as a function of time in separate volumes of the Northridge aftershock sequence.

Rapid notification of seismic events: We distribute automated information on the location and magnitude of earthquakes, as they are processed with our near-real-time earthquake monitoring system analyzing the data from the ~250 seismographs in Alaska. We believe this is a vital tool for emergency service organizations and private lifeline operation companies. Since many faults in Alaska are capable of M>7 earthquakes, we have developed software to alert on-call analysts within seconds of large P-wave arrivals, to notify pagers and to distribute pertinent information by email within minutes of the origin.

The event parameters can be reviewed immediately by an analyst on a computer workstation. An example of the graphical system output is shown in Figure 10.

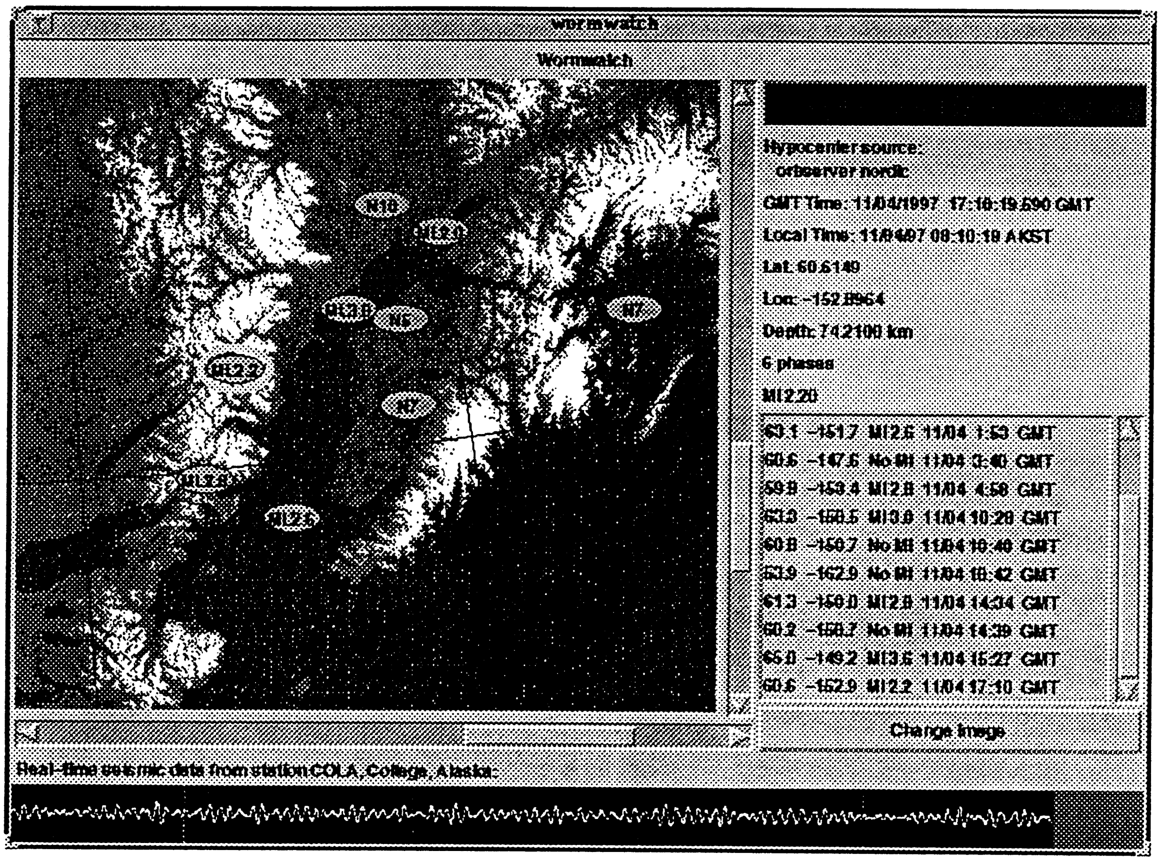

Figure 10: This is a snapshot of the wormwatch utility, which displays a synopsis of automatically generated near-real-time information on recent earthquakes. Within two to five minutes after the occurrence of an earthquake, a blue oval shows up indicating the location and magnitude of the earthquake superimposed on a satellite image of Alaska. The region shown in the above figure includes Cook Inlet, Anchorage, and part of Prince William Sound. The statistics windows on the right provide further information such as the GMT and local-time-zone times of the earthquake. The waveform at the bottom shows a real-time seismic trace from a station near Fairbanks, providing a quick check for the analysts. This utility is fully interactive: its connections to the relational-database core of the real-time system allow an analyst to review and modify the initial automatic analysis of the earthquake. This can speed up the total hazard response time by 10 to 30 minutes.

Results of the automatic system are also emailed to selected parties, in messages of the form shown here:

From bbanddat@giseis.alaska.edu Fri Oct 23 20:09 AKD 1998
Date: Fri, 23 Oct 1998 20:08:21 -0800
From: bbanddat@giseis.alaska.edu (bband data acquisition account)
To: bob@giseis.alaska.edu, guy@giseis.alaska.edu, kent@giseis.alaska.edu,
lalitha@giseis.alaska.edu, martin@giseis.alaska.edu,
max@giseis.alaska.edu, nan@giseis.alaska.edu,
pheuslr@tundra.wr.usgs.gov, roger@giseis.alaska.edu,
whammond@ptialaska.net

Subject: Ml 4.0 Earthquake at 61.50, -149.86

This is an automatic earthquake solution from the Alaska Earthquake Information Center. Location and magnitude estimates are subject to change upon review by a human analyst.

Lat: 61.50
Lon: -149.86
Depth: 52 km
Time: 10/24/1998 4:03:49.840 GMT
Ml: 4.0
22 phases used in solution

This earthquake was:
20 miles (31 km) N of Anchorage
119 miles (192 km) WNW of Valdez
240 miles (386 km) SSW of Fairbanks

For more information contact the Alaska Earthquake Information Center at 907-474-7320

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Nishenko, S.P. and Jacob, K.H., (1990). Seismic Potential of the Queen Charlotte-Alaska-Aleutian Seismic Zone, *Journal of Geophysical Research*, **95**, 2511-2532.

Wahr, J. and Wyss, M., (1980). Interpretation of postseismic deformation with a viscoelastic relaxation model, *Journal of Geophysical Research*, **85**, 6471-6477.

Non-technical Summary:

We developed a system to locate earthquakes in near real time and notify immediately government and private agencies responsible for seismic hazard mitigation. We investigated the homogeneity of the earthquake catalog in interior Alaska and mapped the minimum magnitude of completeness. We show that the M8, 1986 Andreanof islands earthquake was expected on the basis of the elastic rebound theory and the hypothesis of precursory seismic quiescence, and that it was not a violation of the seismic gap hypothesis. A detailed investigation of aftershock sequences, as a function of space and time, showed for the first time that the rate of decay as well as the magnitude distribution vary strongly. The implication for the understanding of generation of aftershock sequences are not understood yet, but they may be profound. We compiled a map showing the maximum intensities due to historical seismic shaking in Alaska.

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Lindquist, K., (1998). Seismic array processing and computational infrastructure for improved monitoring of Alaskan and Aleutian seismicity and volcanoes, University of Alaska, Fairbanks, 255 pp.

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