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Earthquake Prediction: Accuracy and Limitations

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Earthquake prediction: Accuracy and limitations

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"Undue precision of computations is the first symptom of mathematical illiteracy"

N.Krylov, famous Russian mathematician

The accuracy of an earthquake prediction method is essentially predefined by the accuracy of the data available, which is far from ideal. The unavoidable natural difficulties in observing seismic events as well as in correlating them with other geophysical phenomena and fields complicates the design and testing of a new generation of earthquake prediction technique.

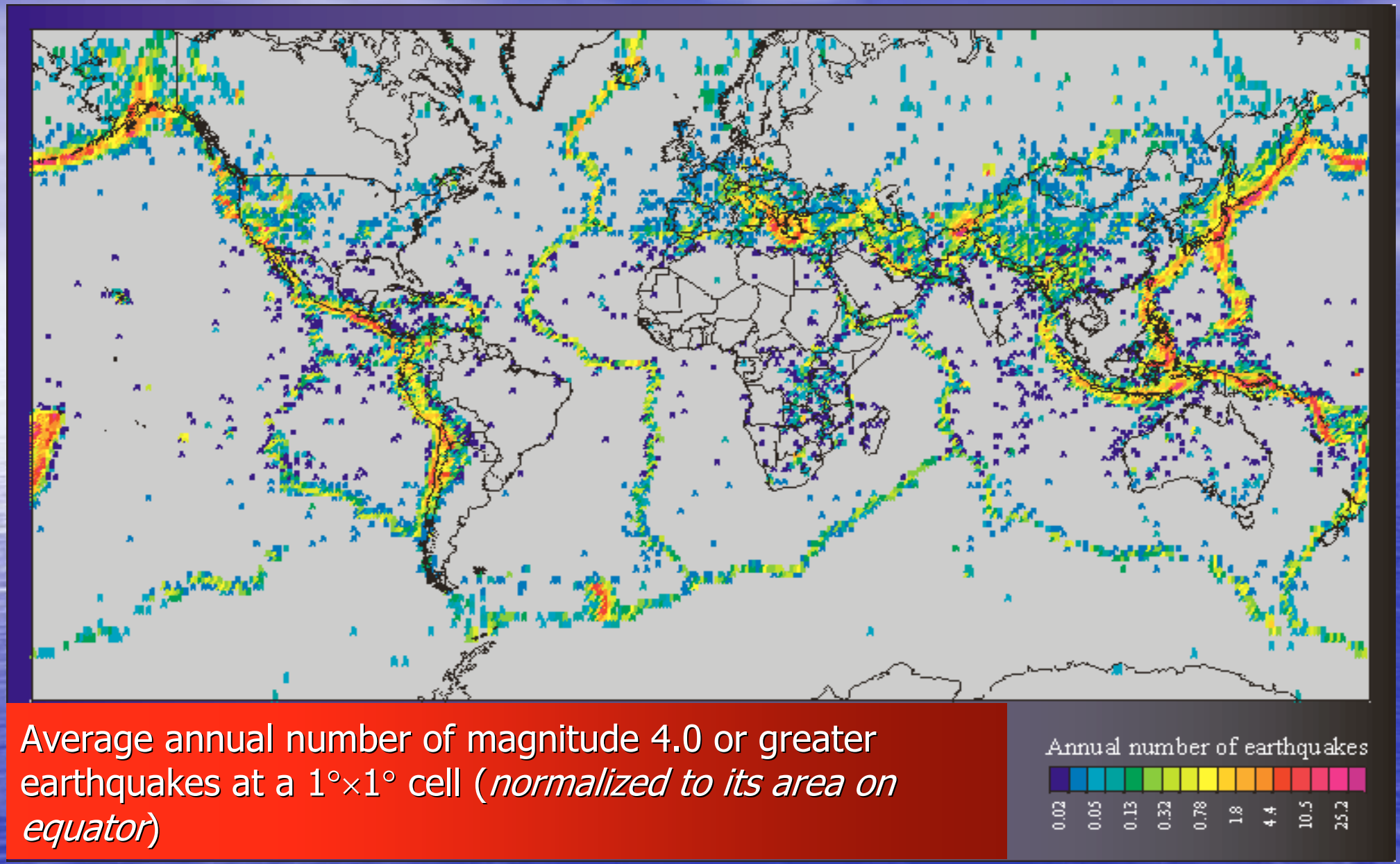
The accumulated case-histories of predicted and not predicted earthquakes provide us unique and so far very limited information that may help understanding the ultimate limits of seismic predictability.

Stages of earthquake prediction

- Term-less prediction of earthquake-prone areas
- Prediction of time and location of an earthquake of certain magnitude

Temporal, ***in years***		Spatial, ***in source zone size L***	
Long-term	10	Long-range	up to 100
Intermediate-term	1	Middle-range	5-10
Short-term	0.01-0.1	Narrow	2-3
Immediate	0.001	Exact	1

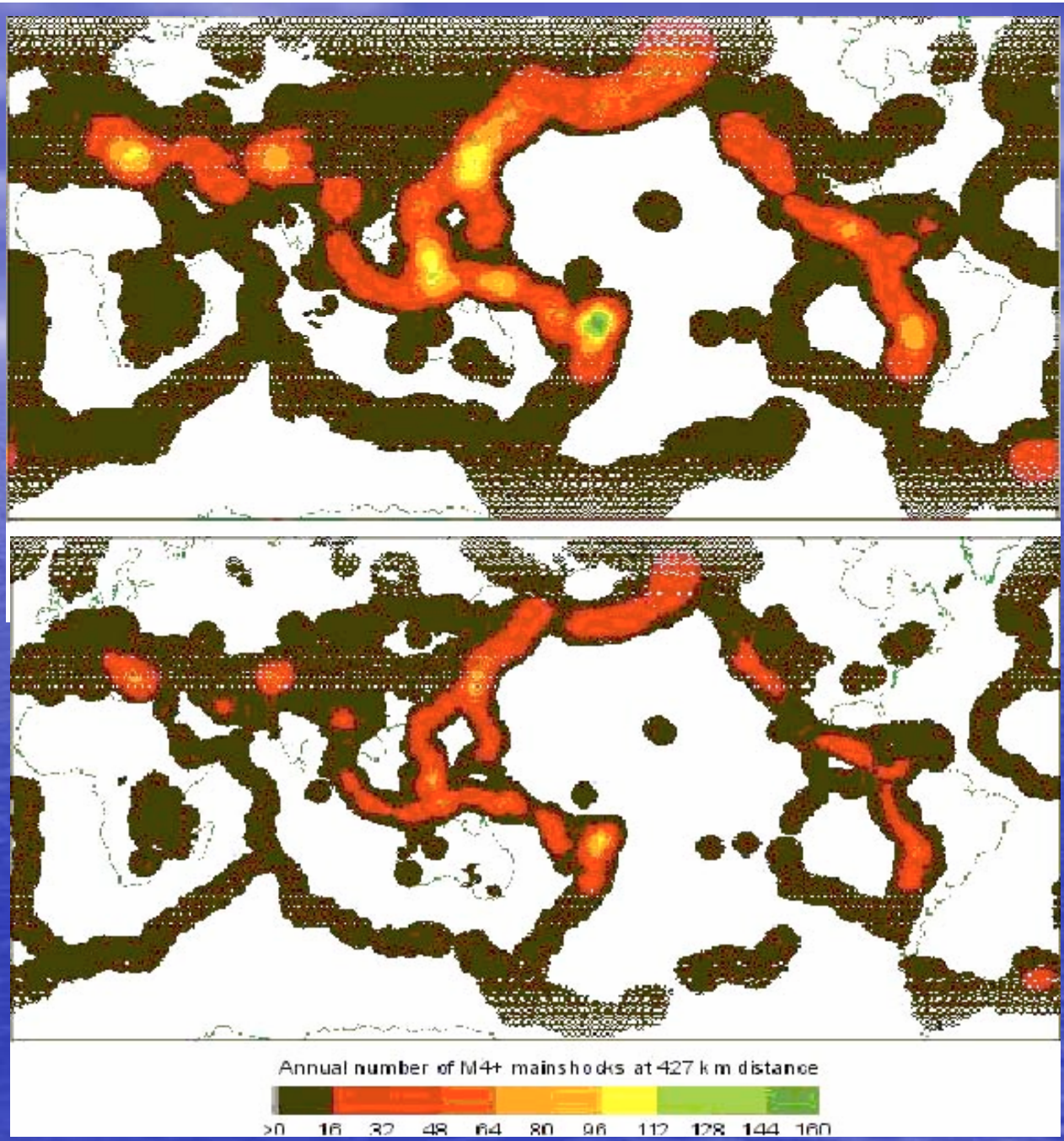
- Moreover, the Gutenberg-Richter law suggests limiting magnitude range of prediction to about one unit. Otherwise, the statistics would be essentially related to dominating smallest earthquakes.



Average annual number of magnitude 4.0 or greater earthquakes at a 1°×1° cell (*normalized to its area on equator*)

Earthquakes are rare events. Therefore, the application of the M8 algorithm is limited to the areas where reported earthquakes are large enough in number.

The color on the maps signifies the annual average number of earthquakes with magnitude 4 or larger in the 667-km (above) and 427-km (below) circles centered at the point.



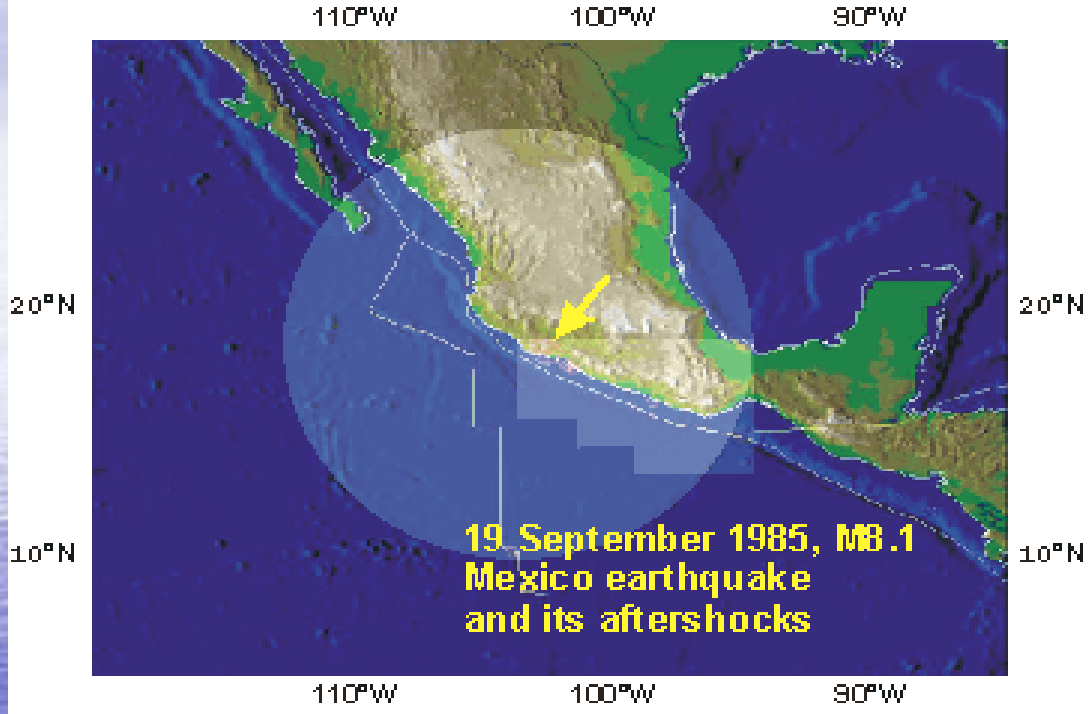
Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: Magnitude 8.0+.

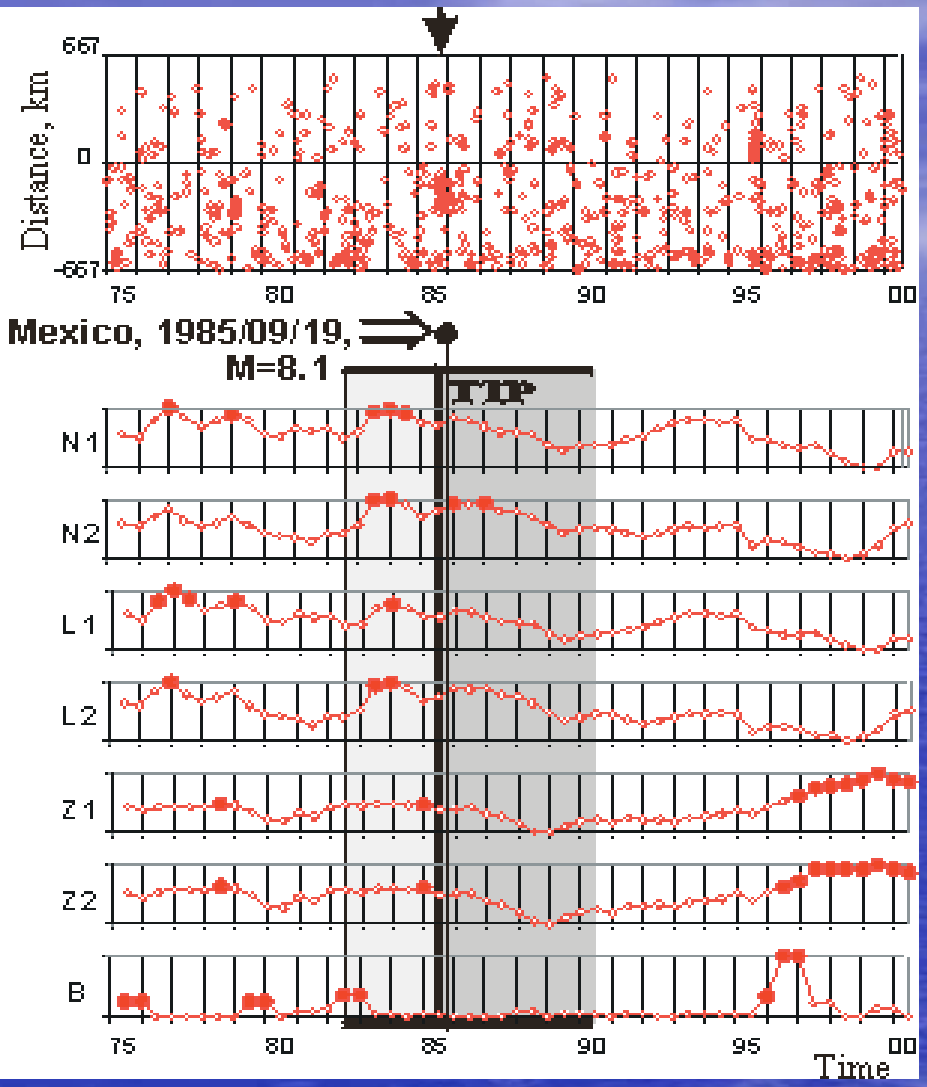
Test period	Large earthquakes Total	Predicted by M8	Predicted by M8-MSc	Measure of alarms,% M8	Measure of alarms,% M8-MSc	Confidence level, % M8	Confidence level, % M8-MSc
1985-present	11	9	7	$33._{24}$	$17._{14}$	$99._{87}$	$99._{92}$
1992-present	9	7	5	$28._{42}$	$14._{37}$	$99._{69}$	$99._{54}$

The significance level estimates use the most conservative measure of the alarm volume accounting for empirical distribution of epicenters.

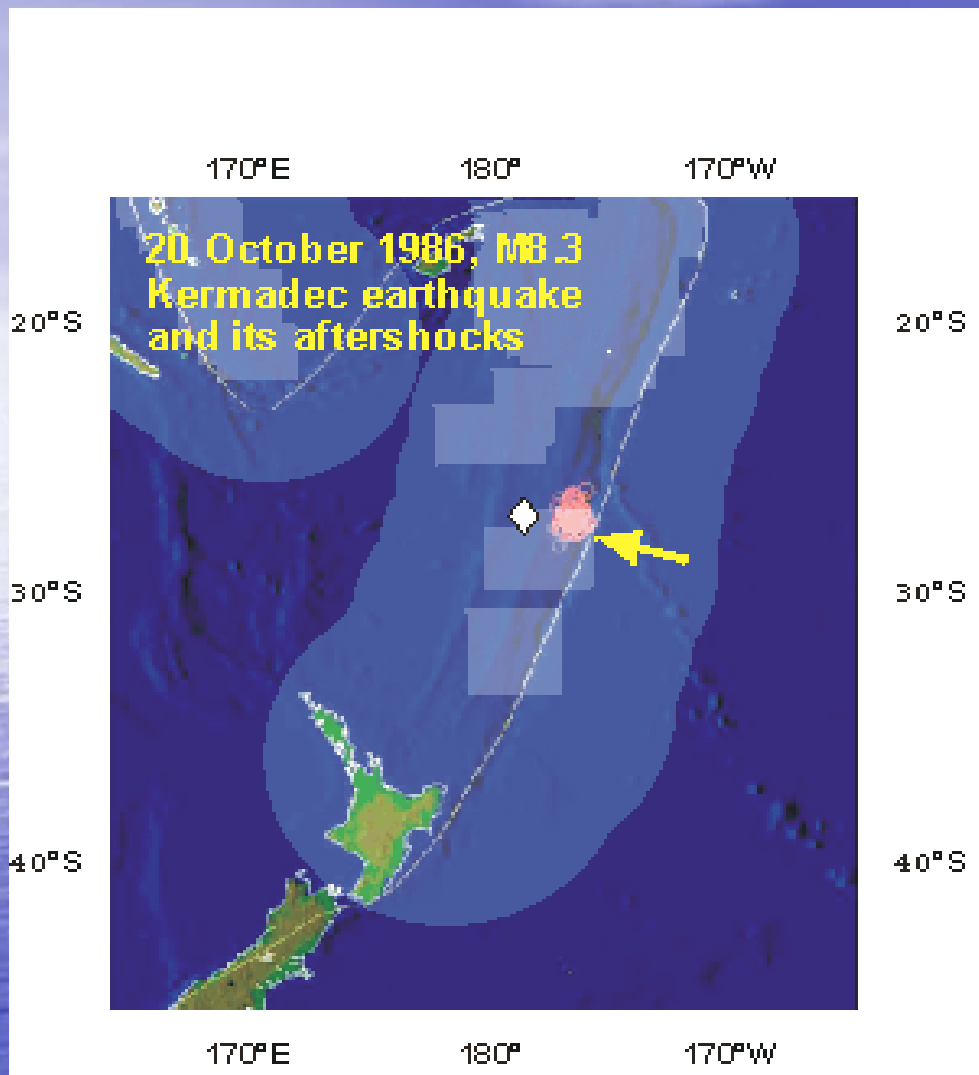
To drive the achieved confidence level below 95%, the Test should encounter four failures-to-predict in a row.

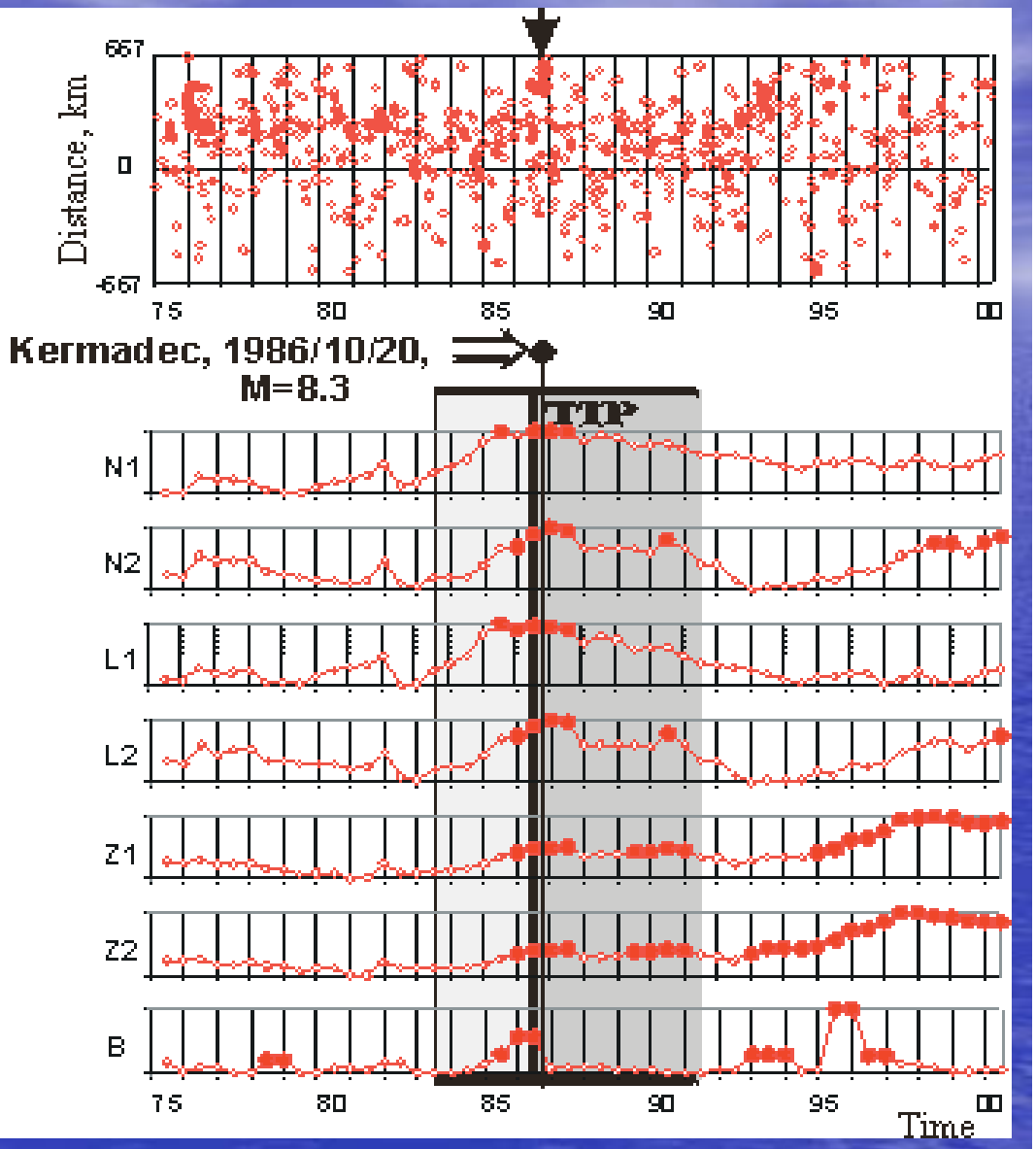
19/09/1985 Mexico Earthquake





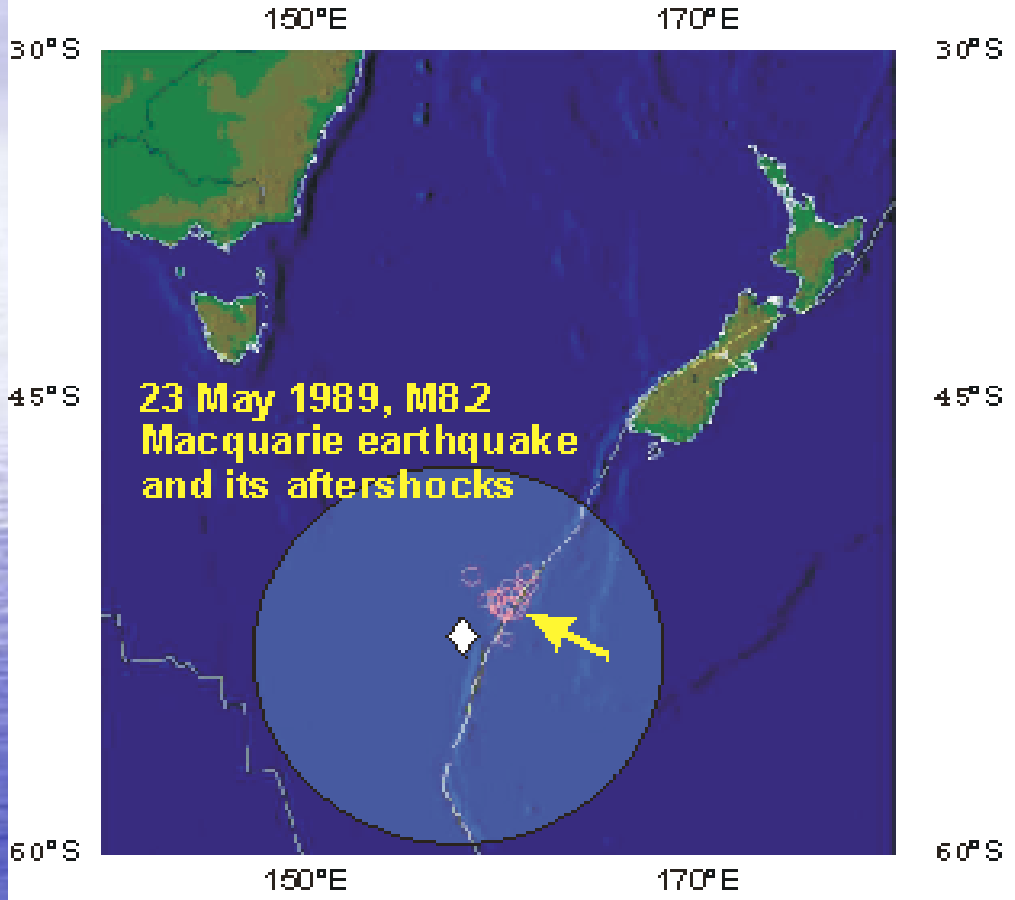
20/10/1986 Kermadek Earthquake

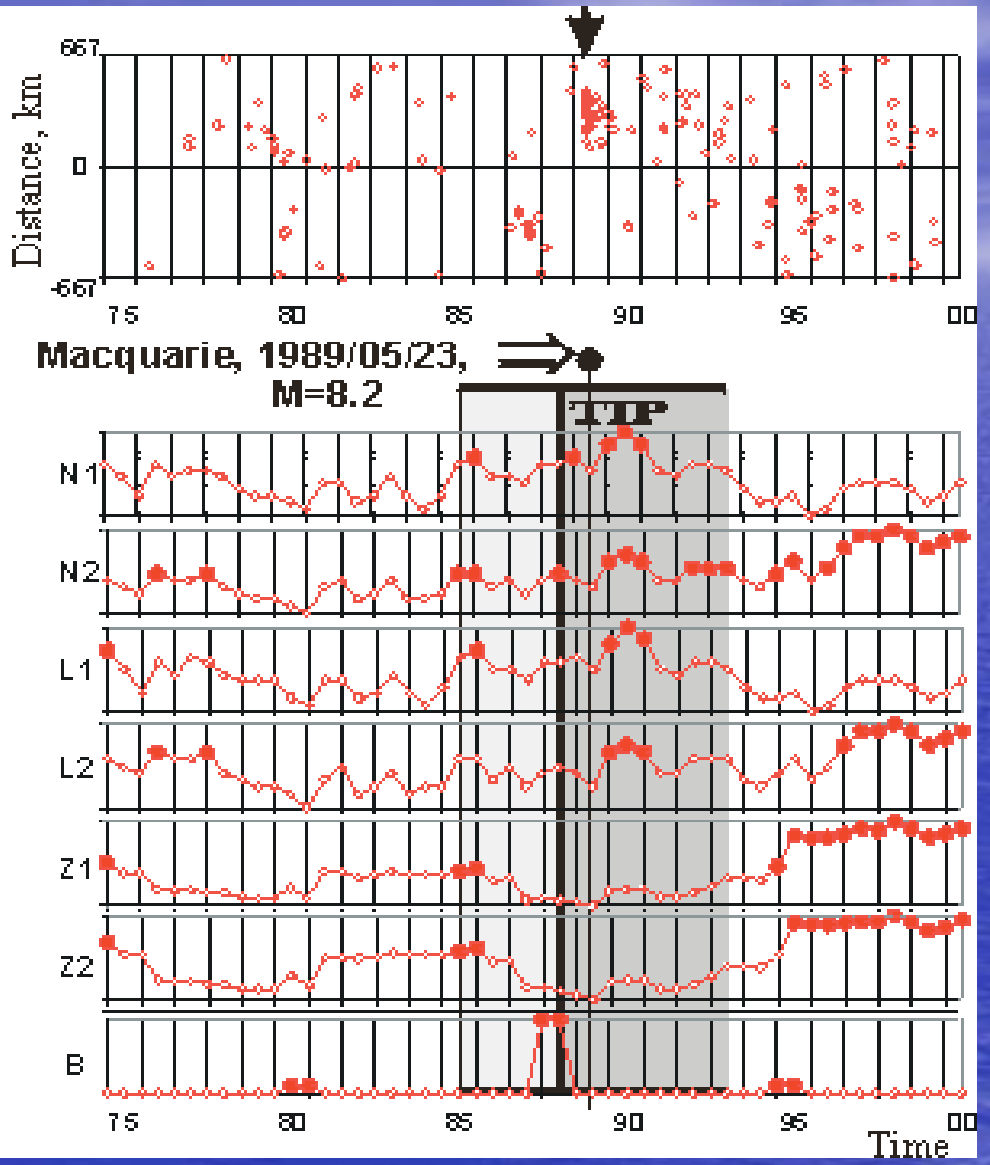




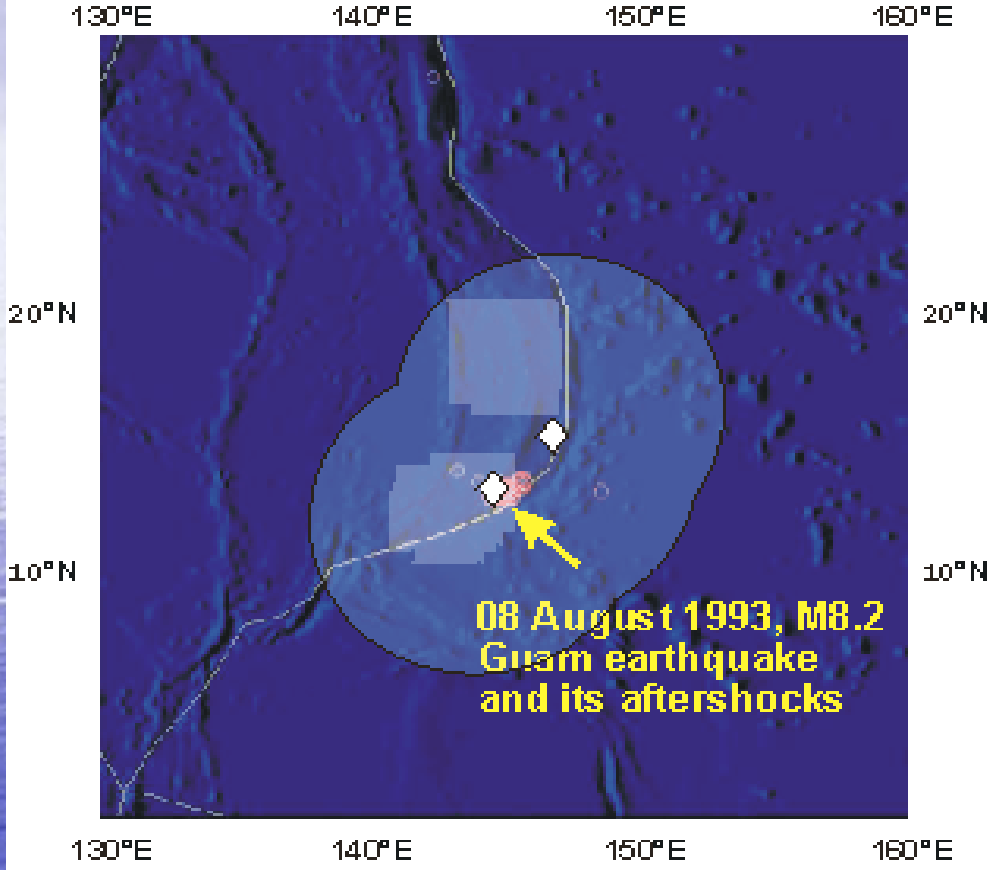
23/05/1989 Macquarie Earthquake

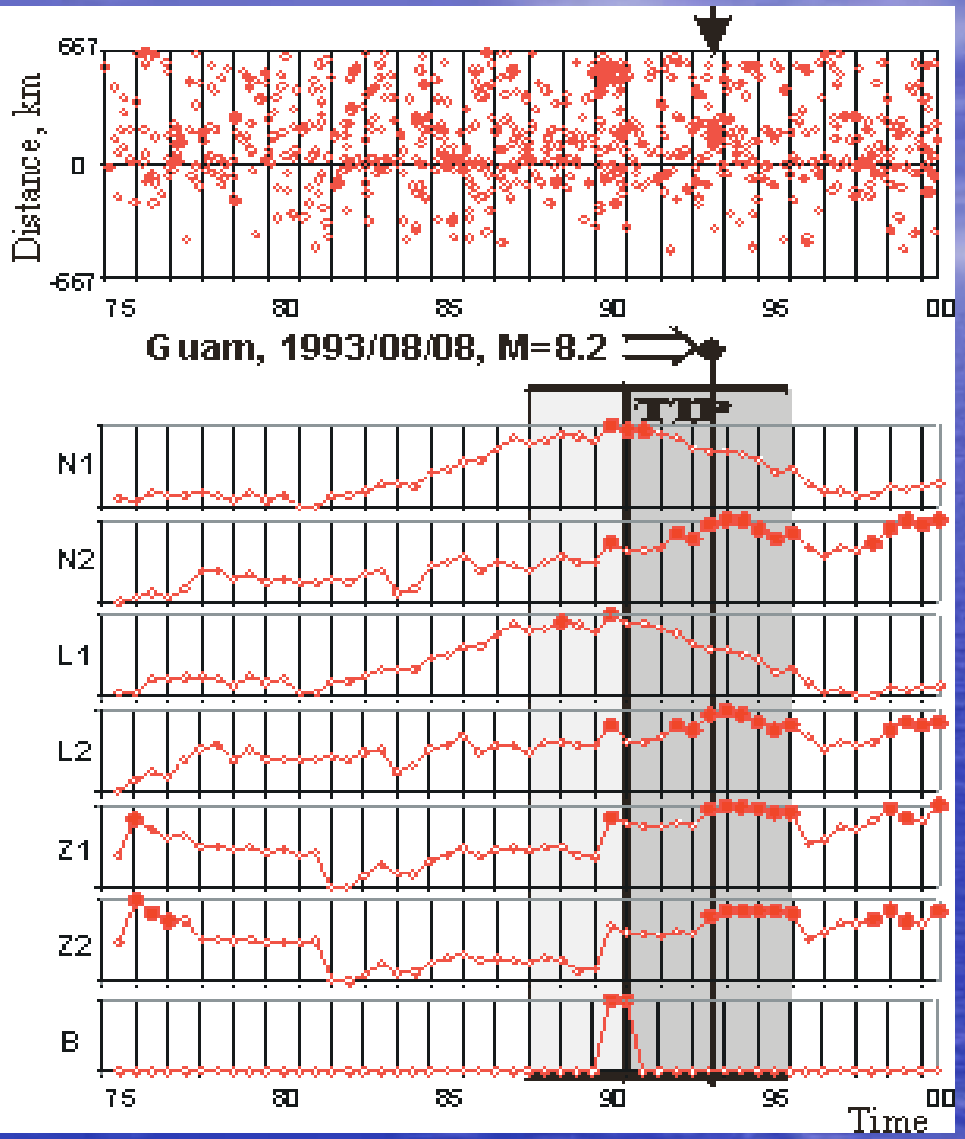
Outside Test Area,
NOT COUNTED in
the overall statistics





08/08/1993 Guam Earthquake



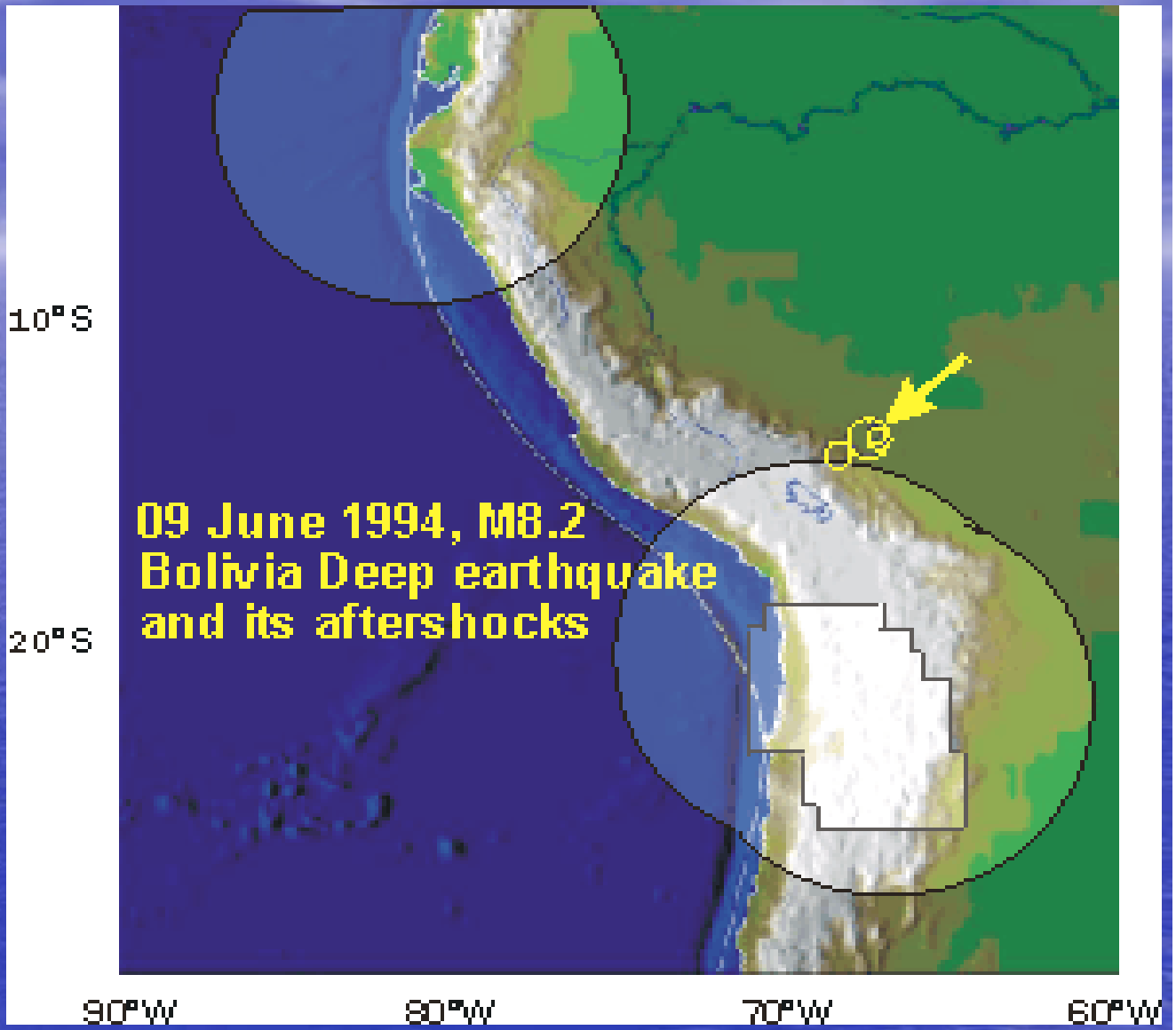


09/06/1994 Bolivia Deep Earthquake

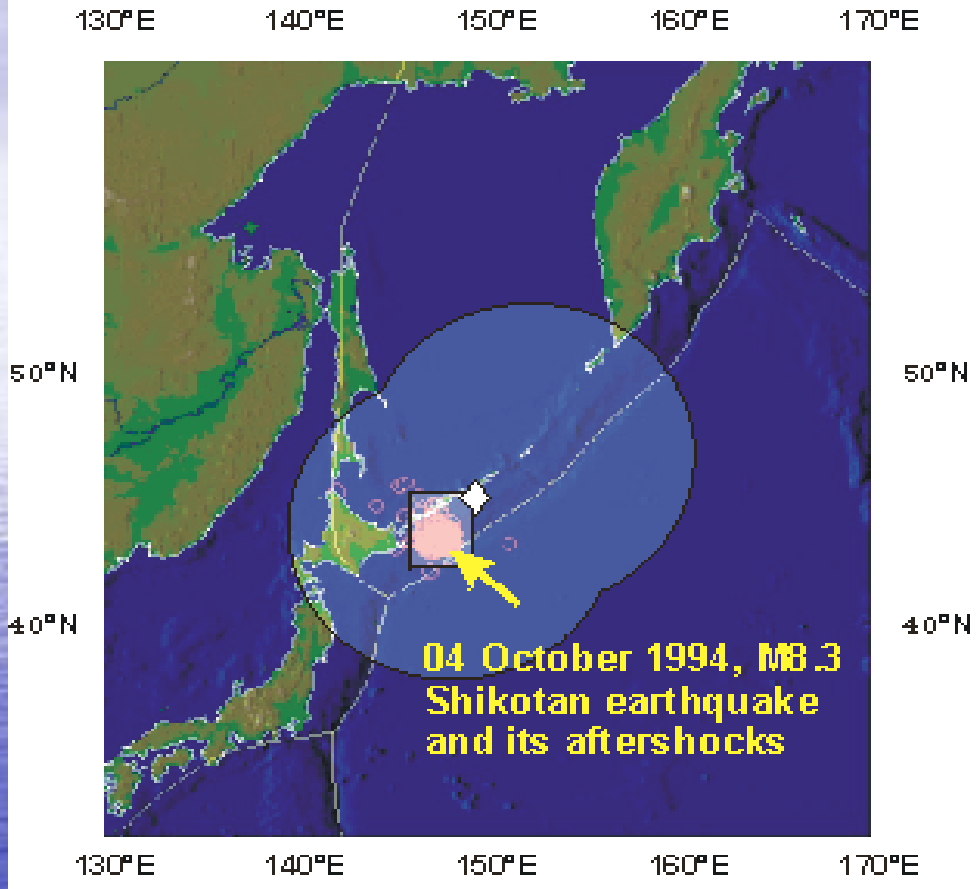
Outside Test Area, NOT COUNTED in the overall statistics

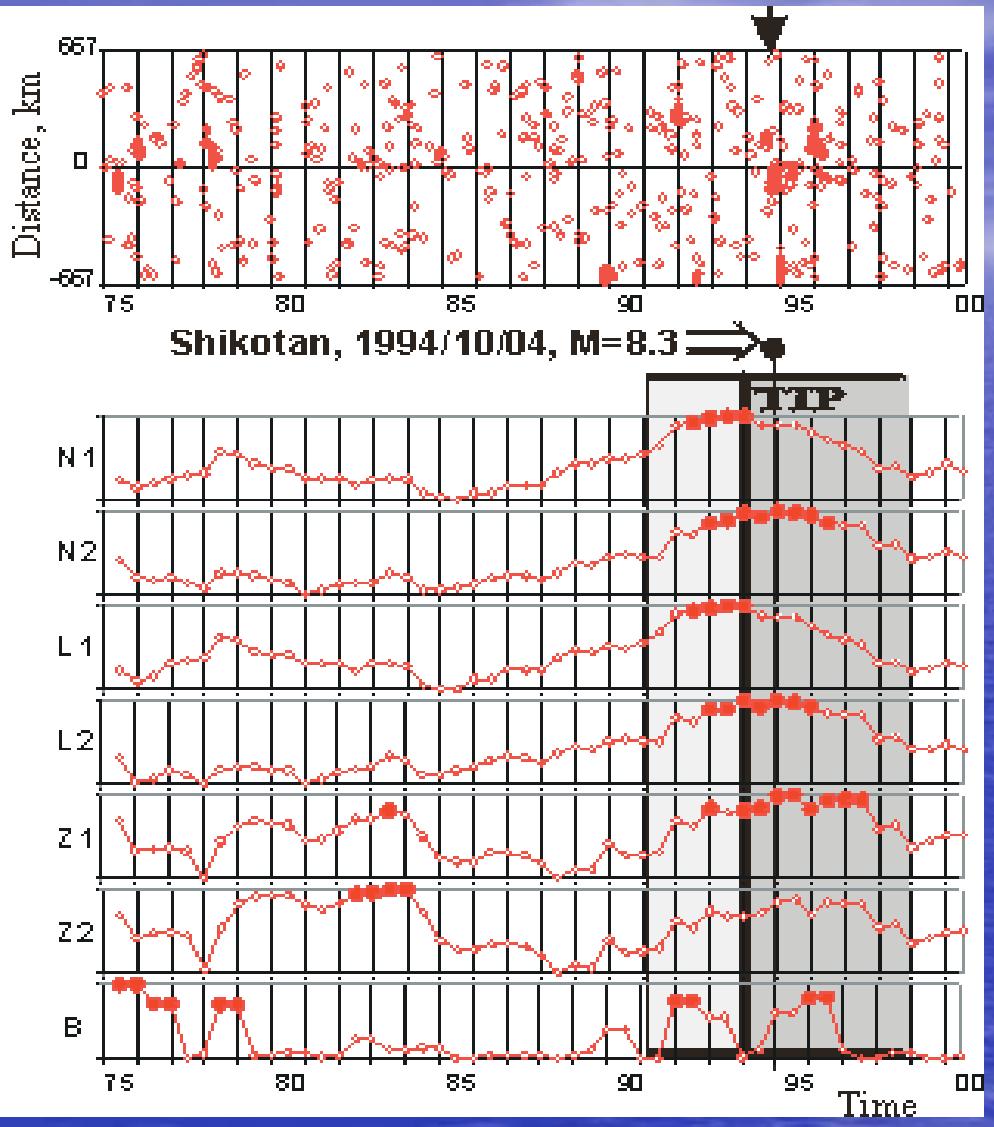
- The Great Deep Bolivia earthquake did occur after the January 10, 1994, magnitude 6.9, depth 595 km earthquake at distance of about 250 km.

The previous earthquake that deep happened here in 1963.

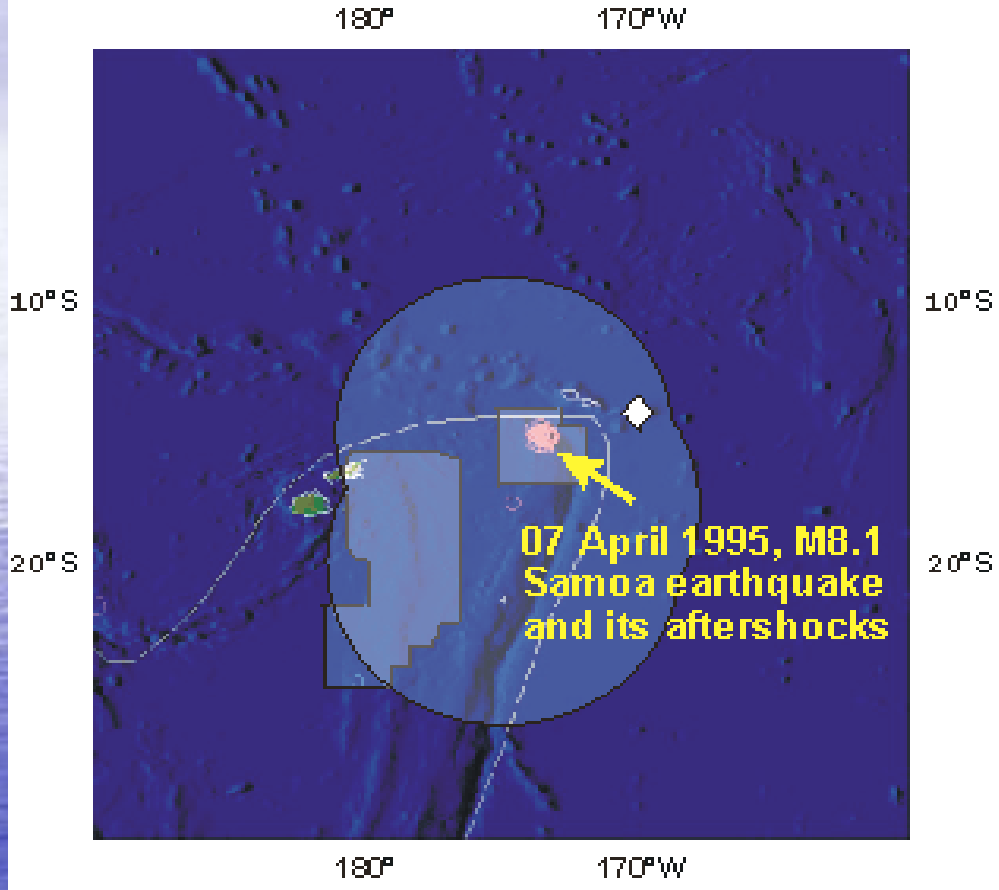


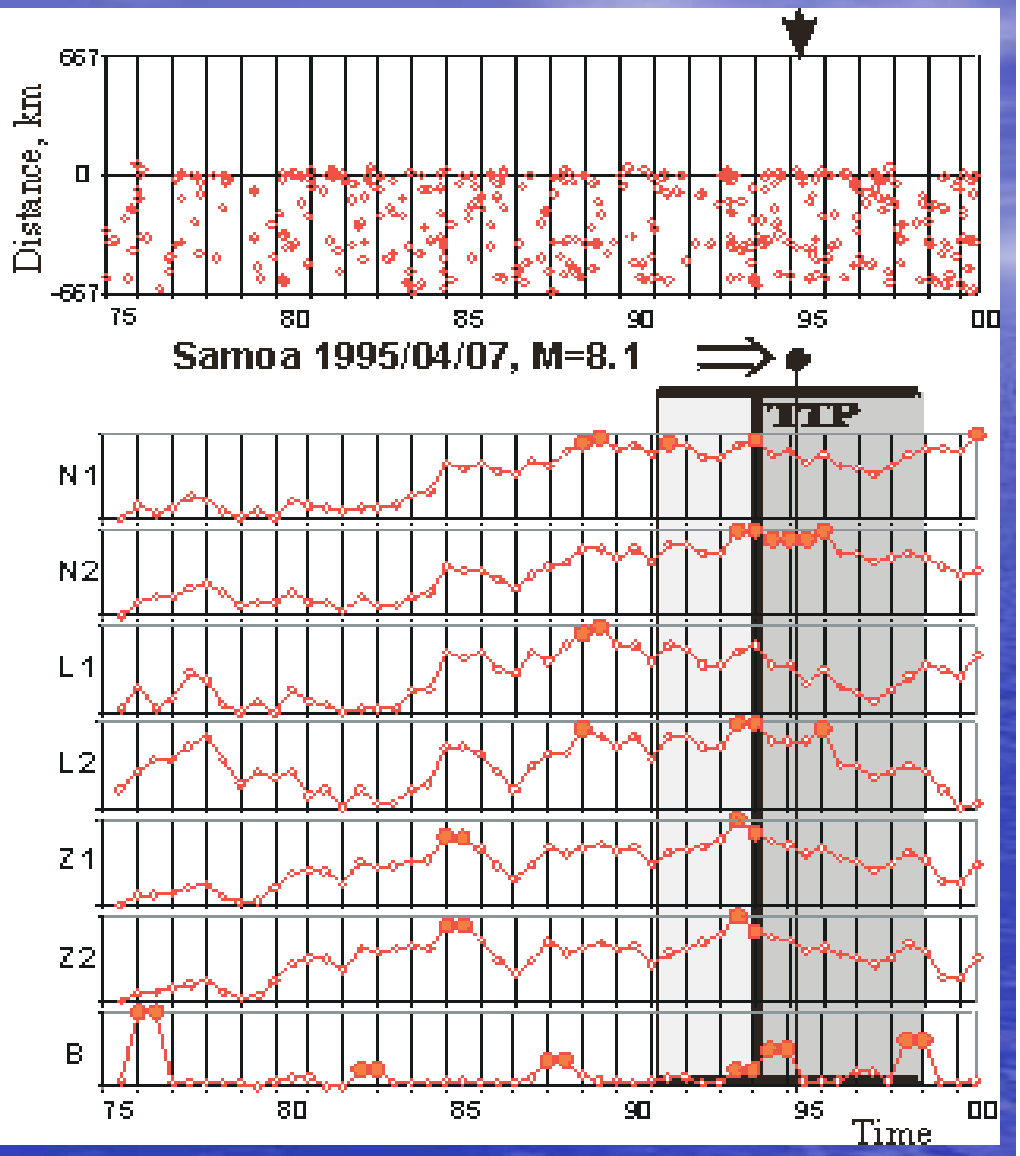
04/10/1994 Shikotan Earthquake



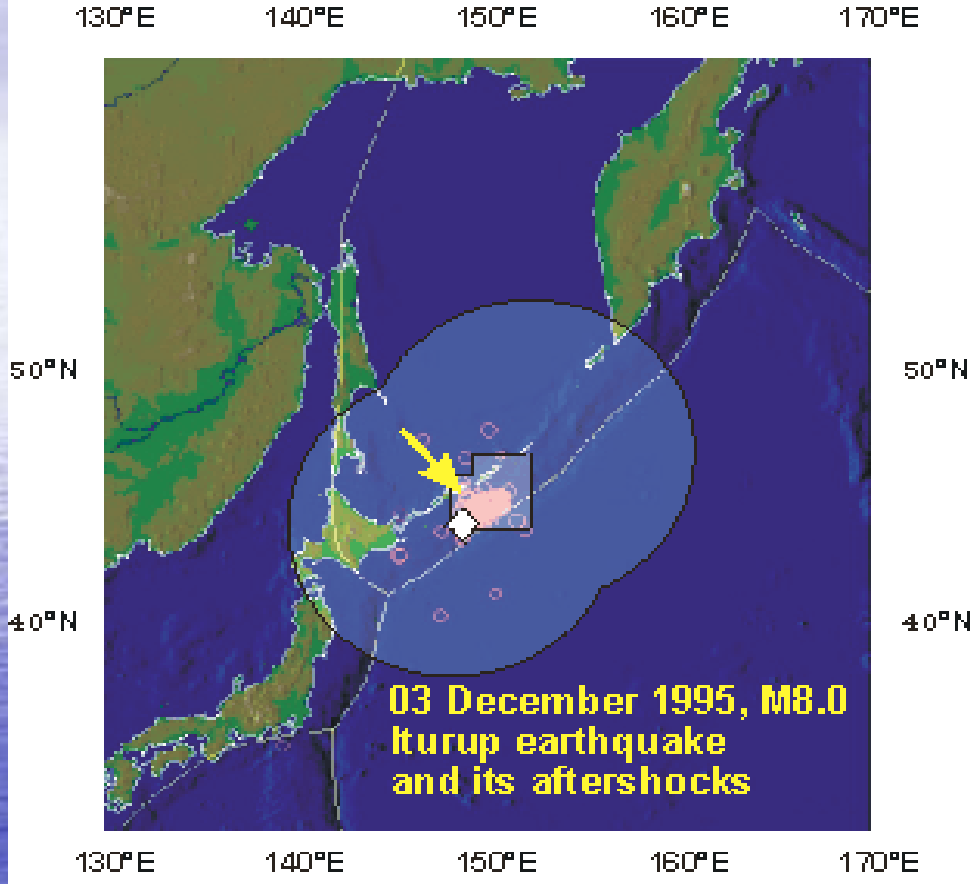


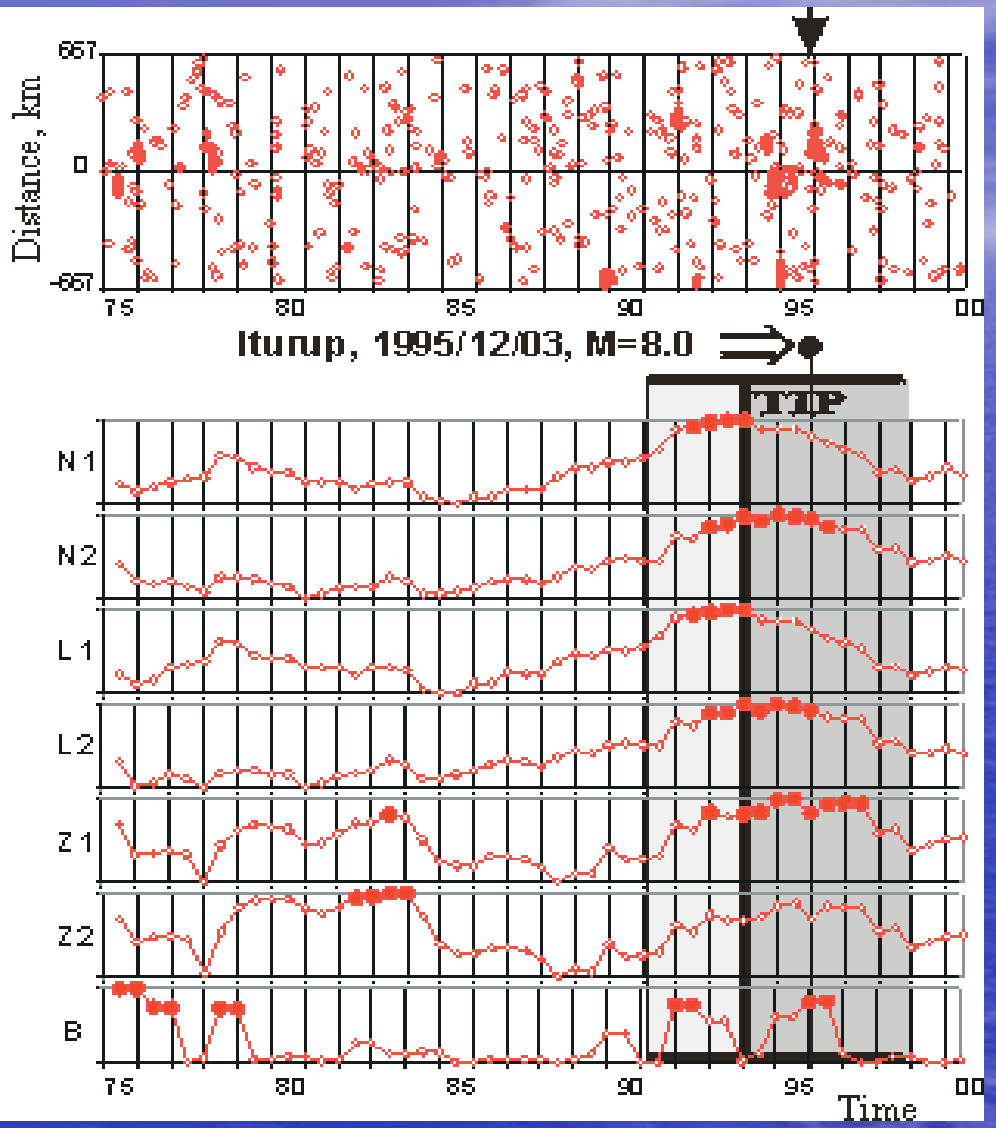
07/04/1995 Samoa Earthquake



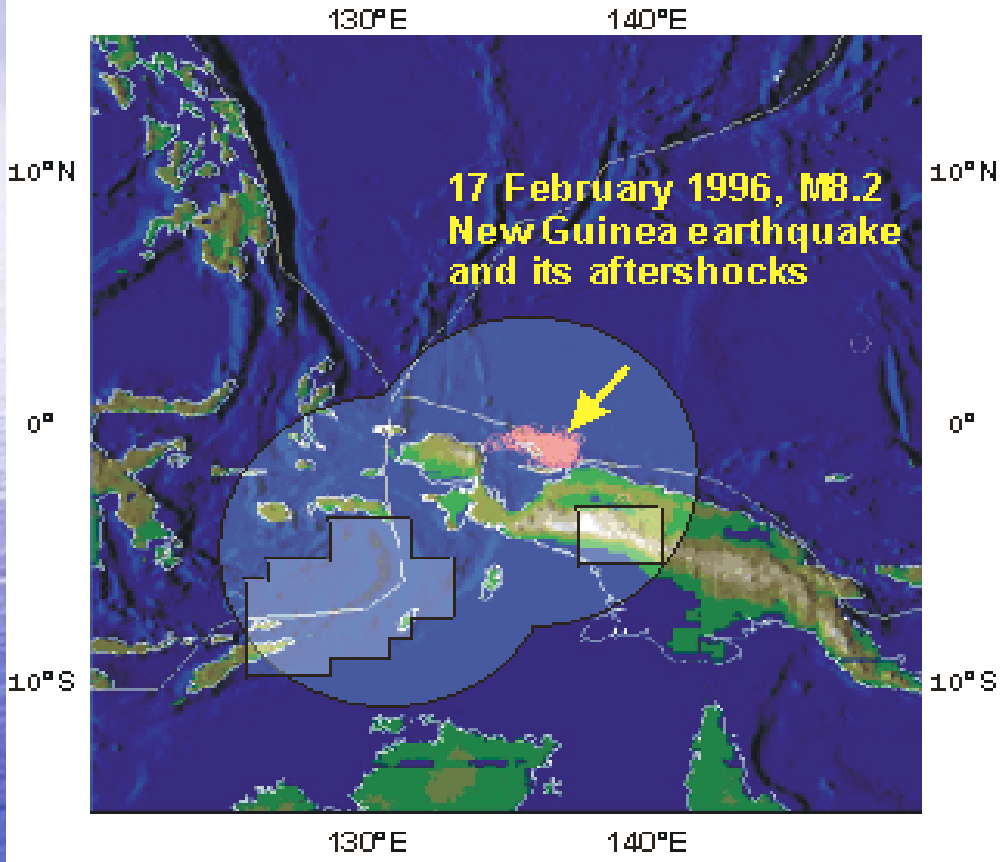


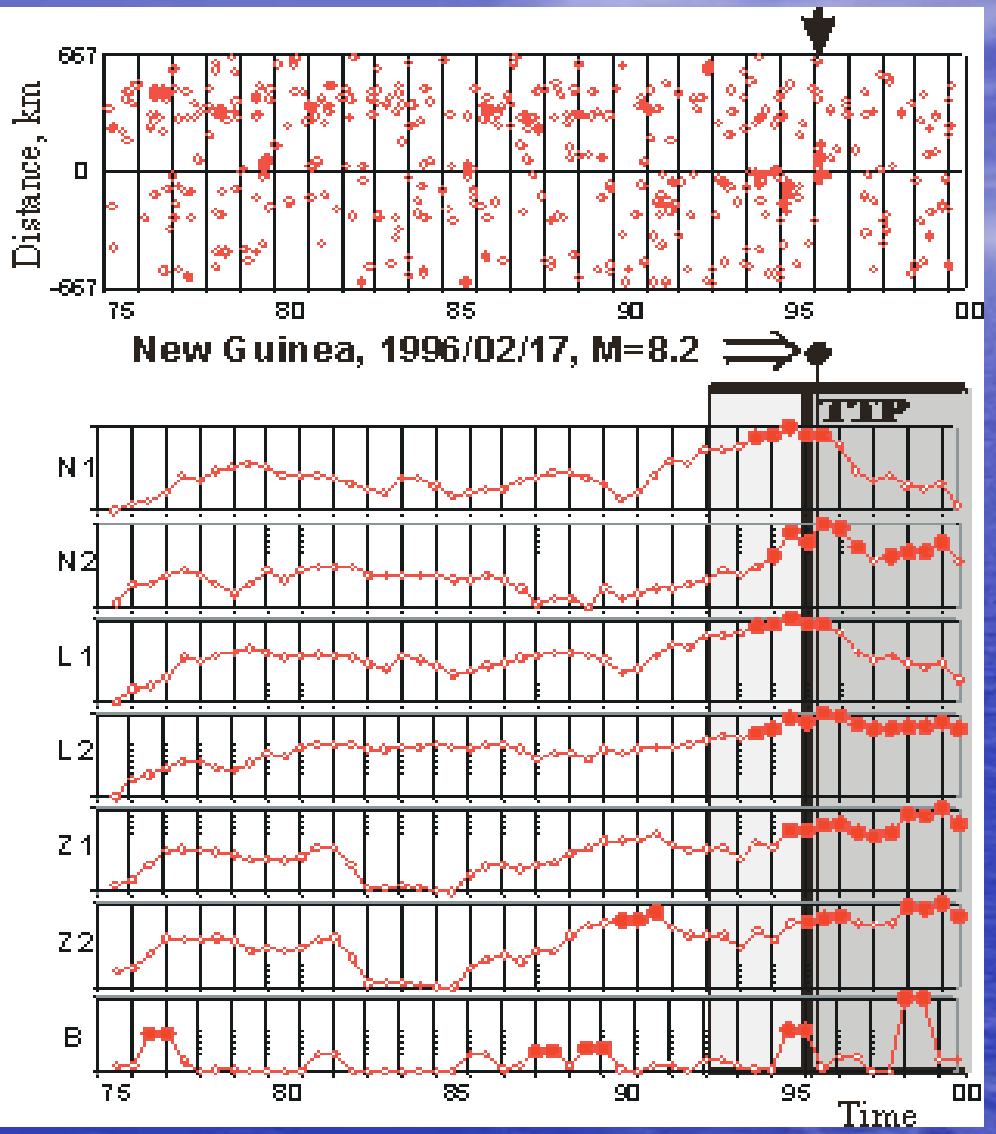
03/12/1995 Iturup Earthquake





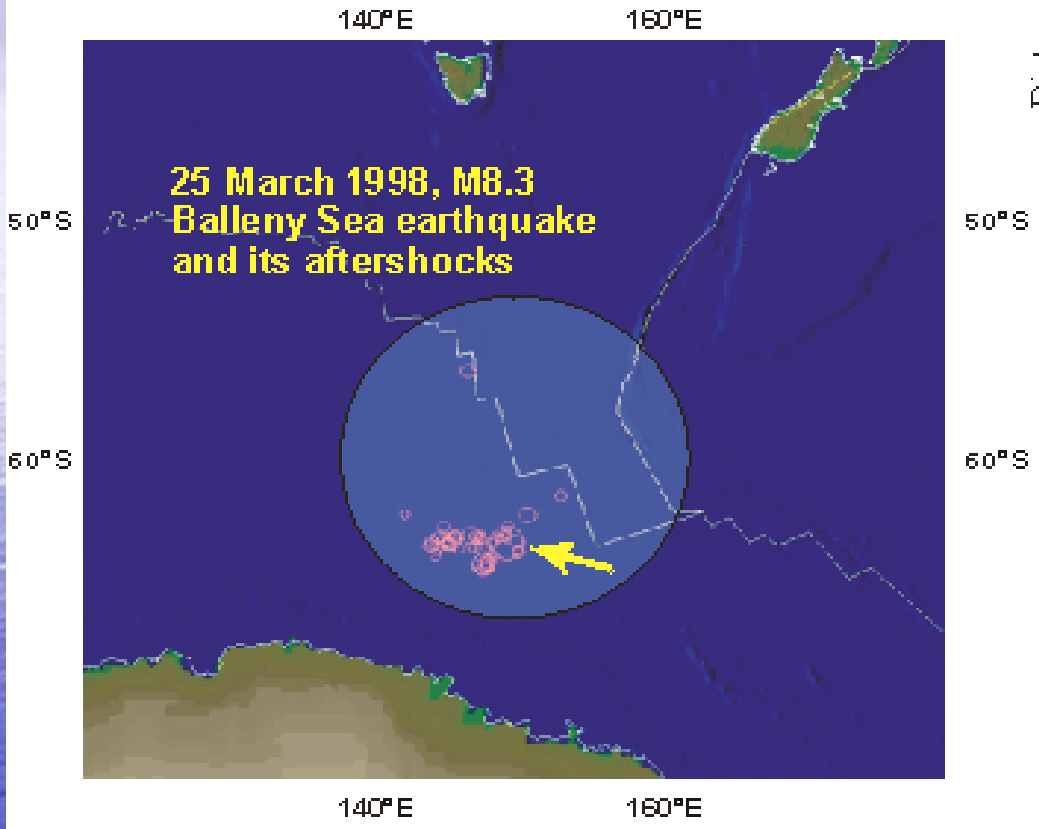
17/02/1996 New Guinea Earthquake

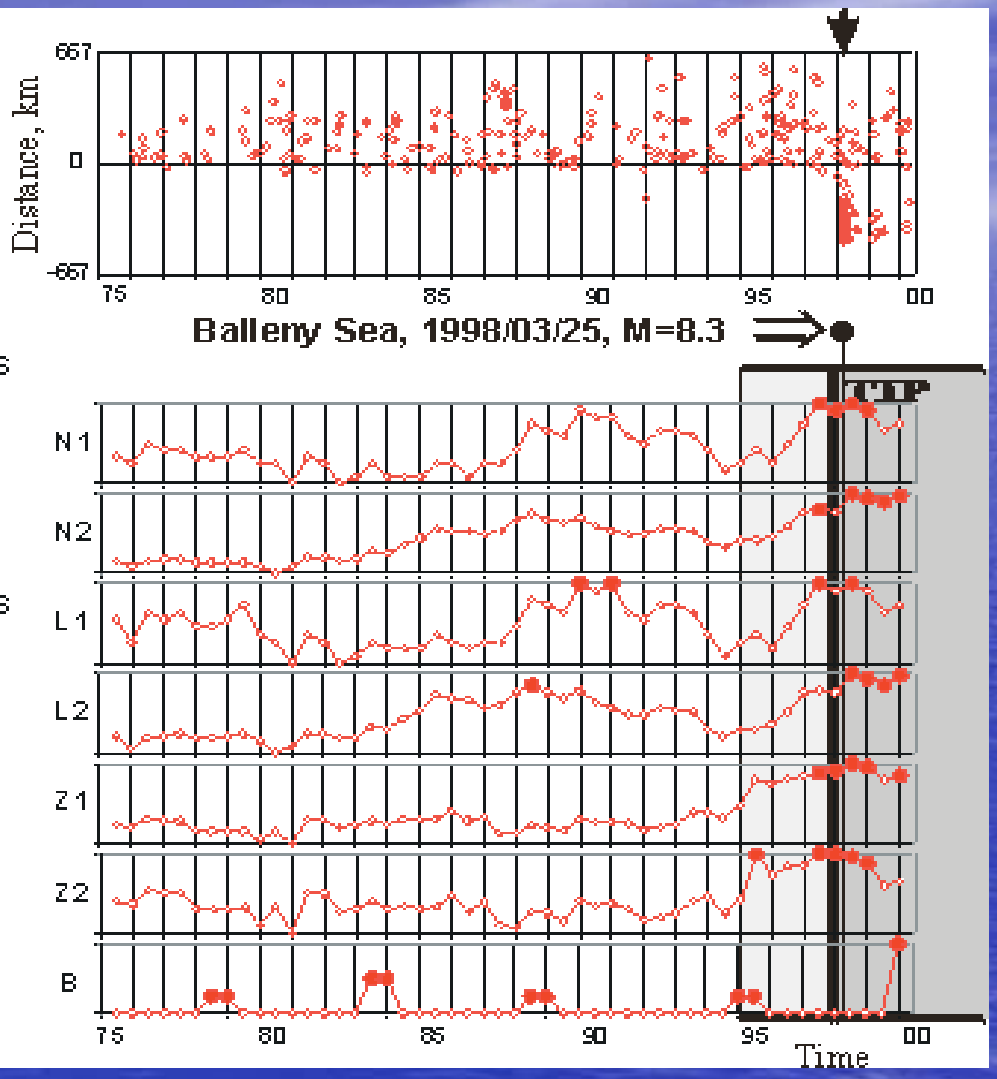




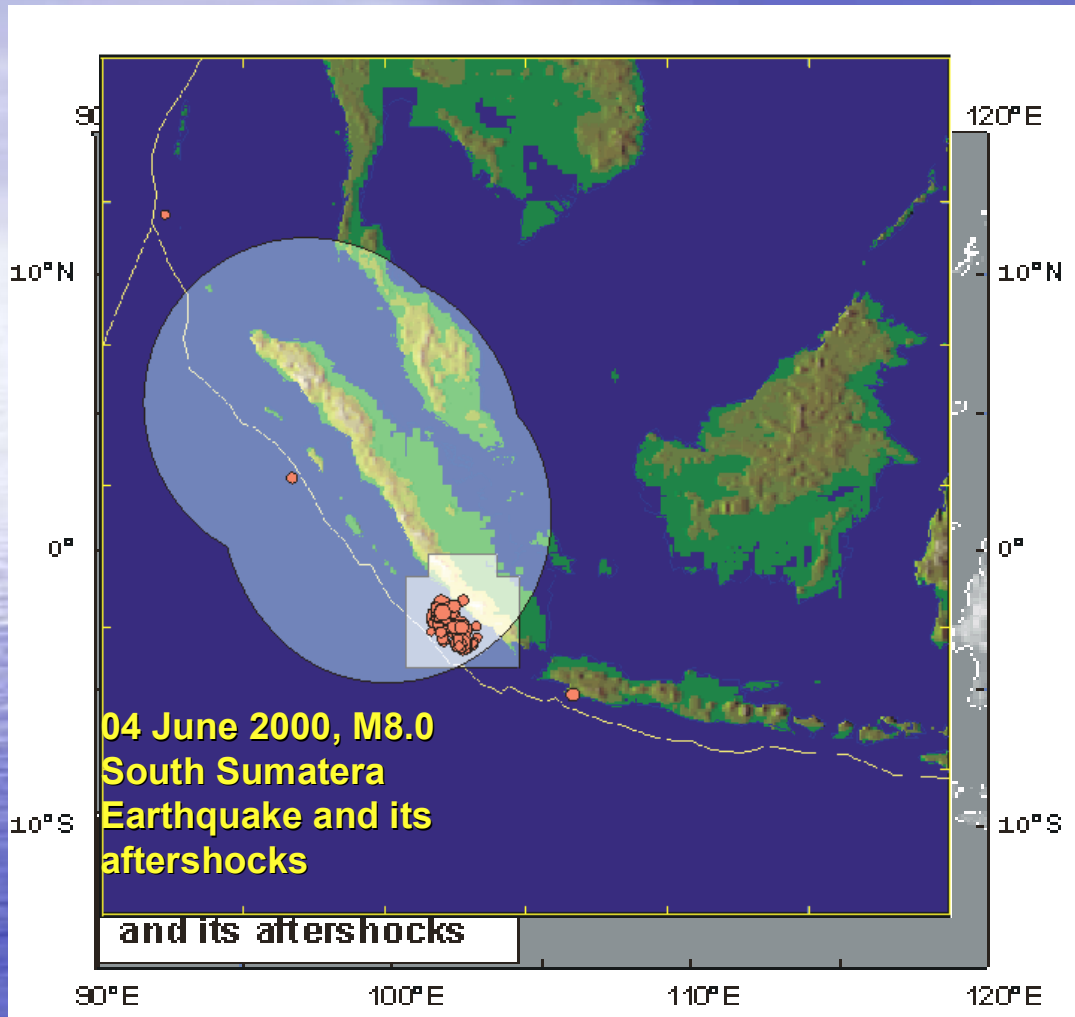
25/03/1998 Balleny Sea Earthquake

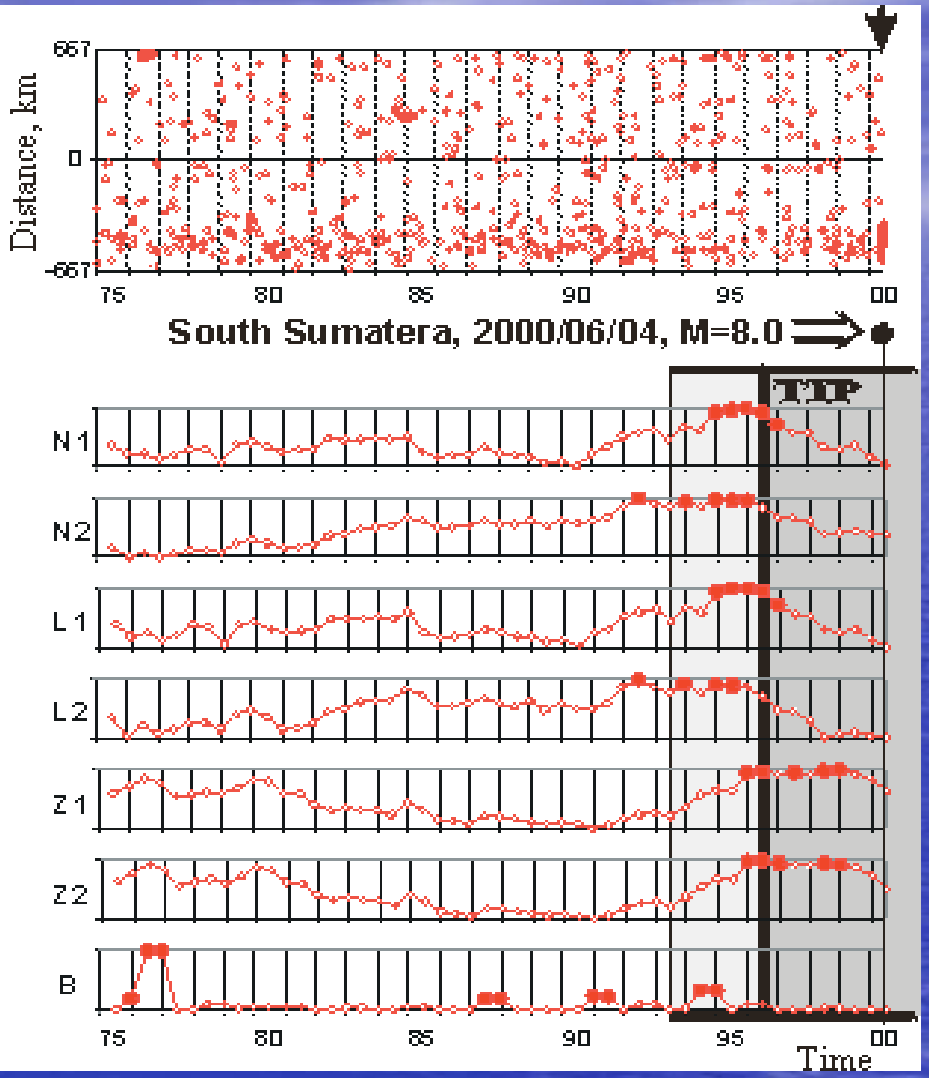
Outside Test Area,
NOT COUNTED in
the overall statistics



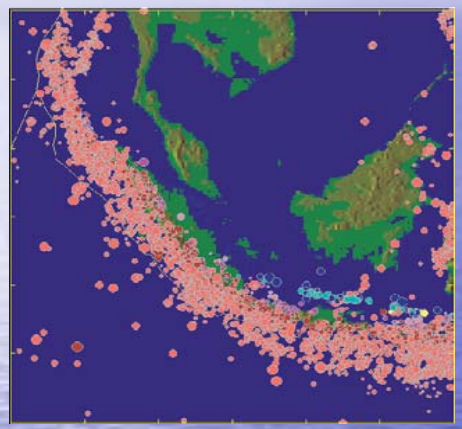


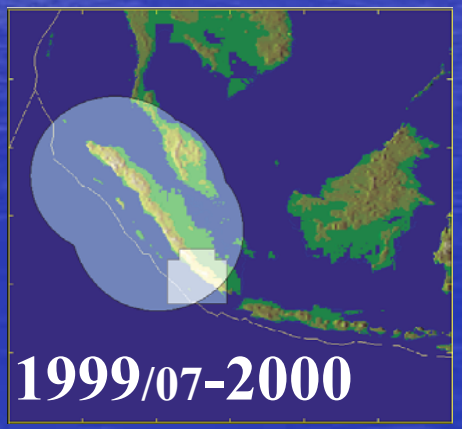
04/06/2000 South Sumatera Earthquake

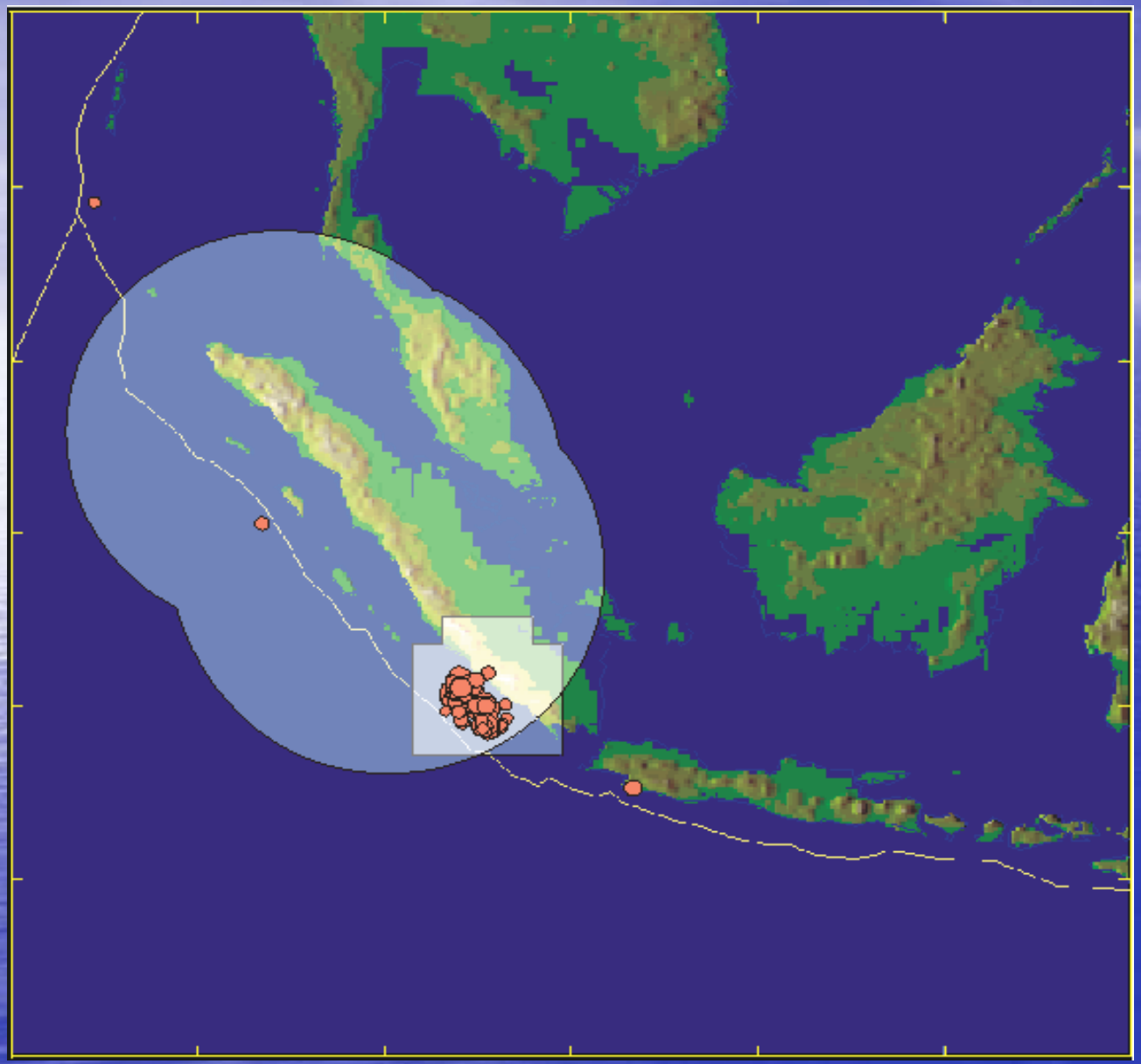




Case history of the South Sumatera Earthquake





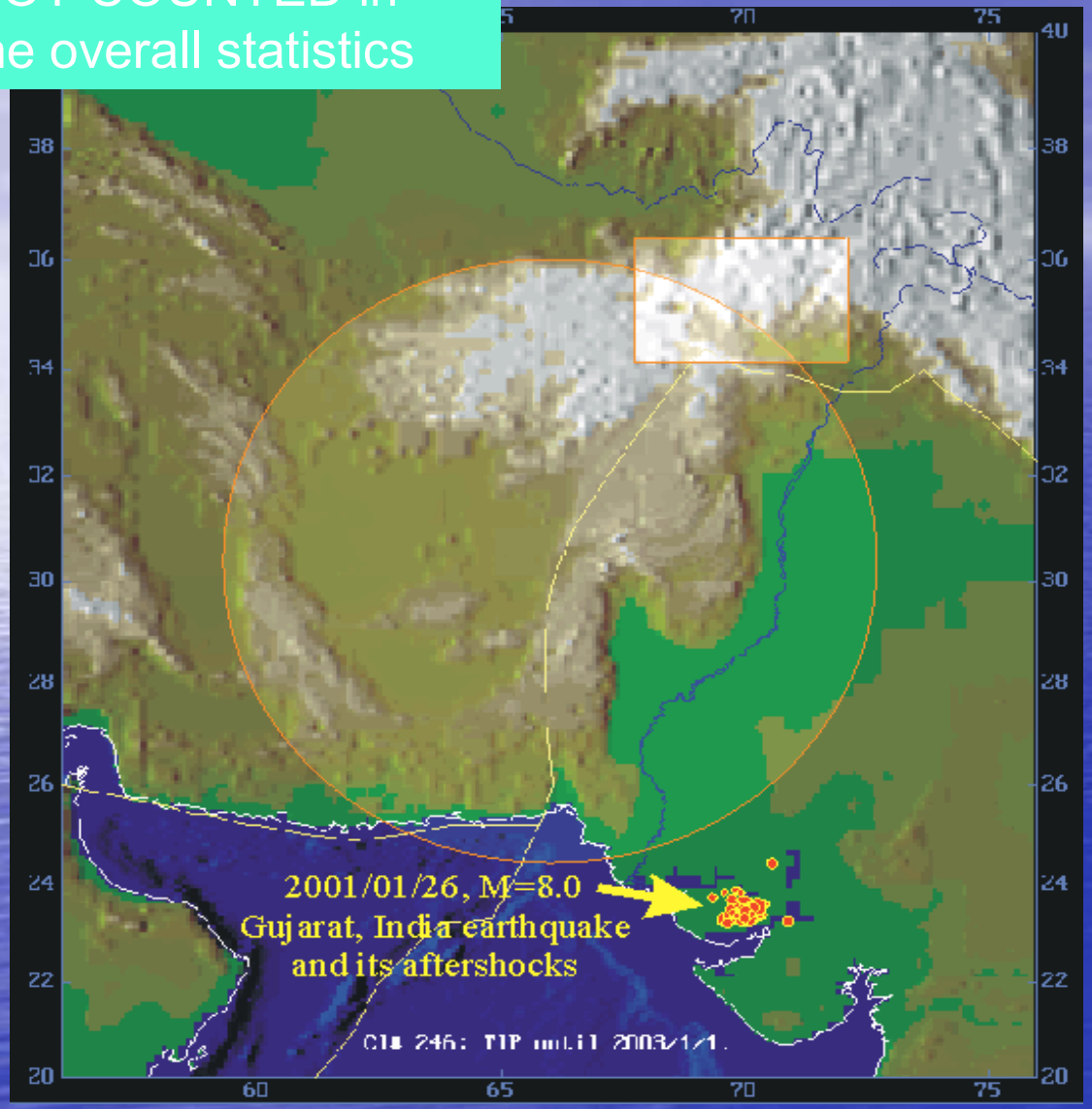


Seismic events that big were reported in the Indian Ocean subduction zones only twice in the 20th century:
These are
the 1941 Andaman, Ms8.1
and
the 1977 Sumbawa, Ms8.0
earthquakes.

This implies local probability gain of more than 20

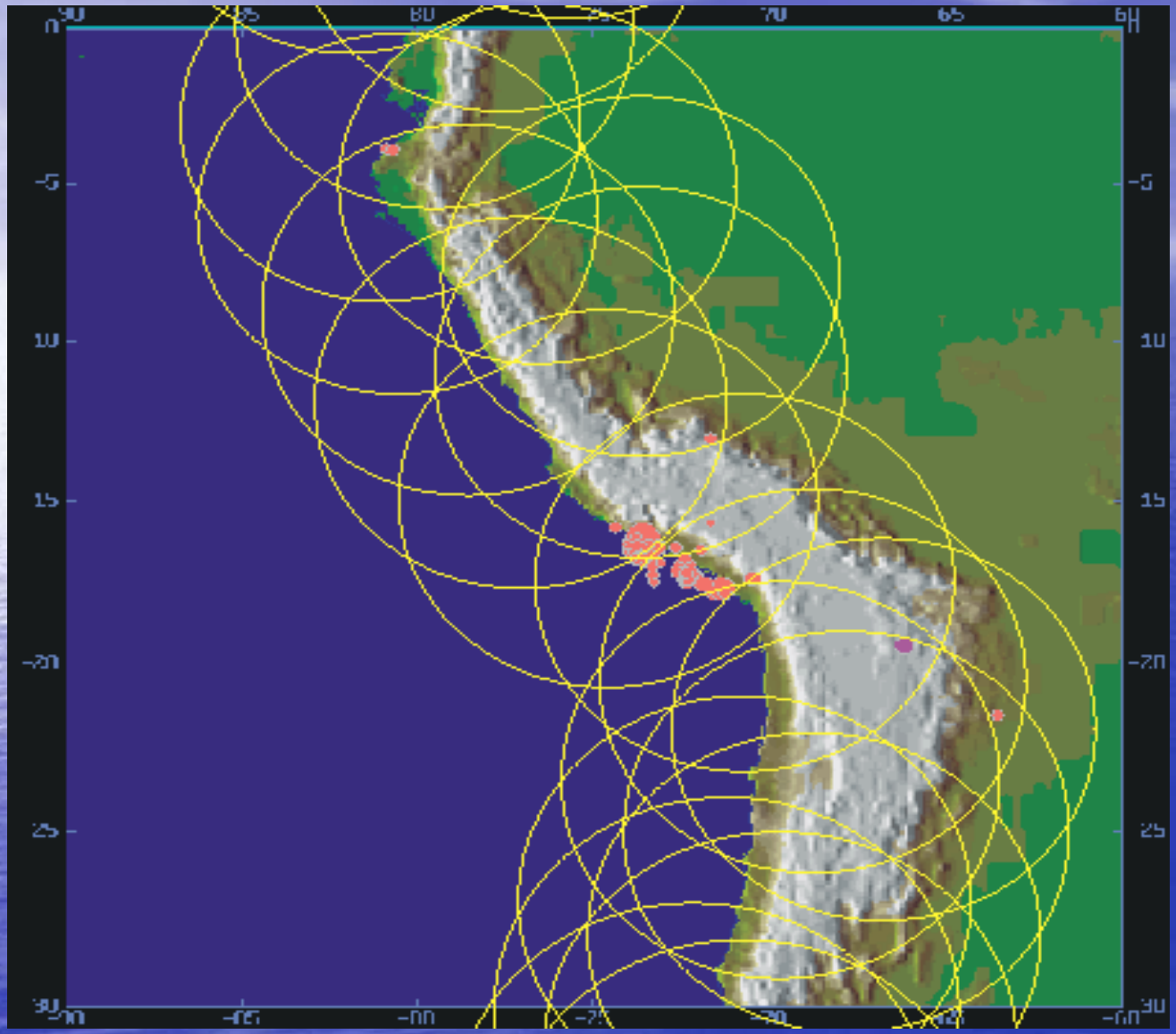
26/01/2001 Gujarat, India earthquake

Outside Test Area, NOT COUNTED in the overall statistics



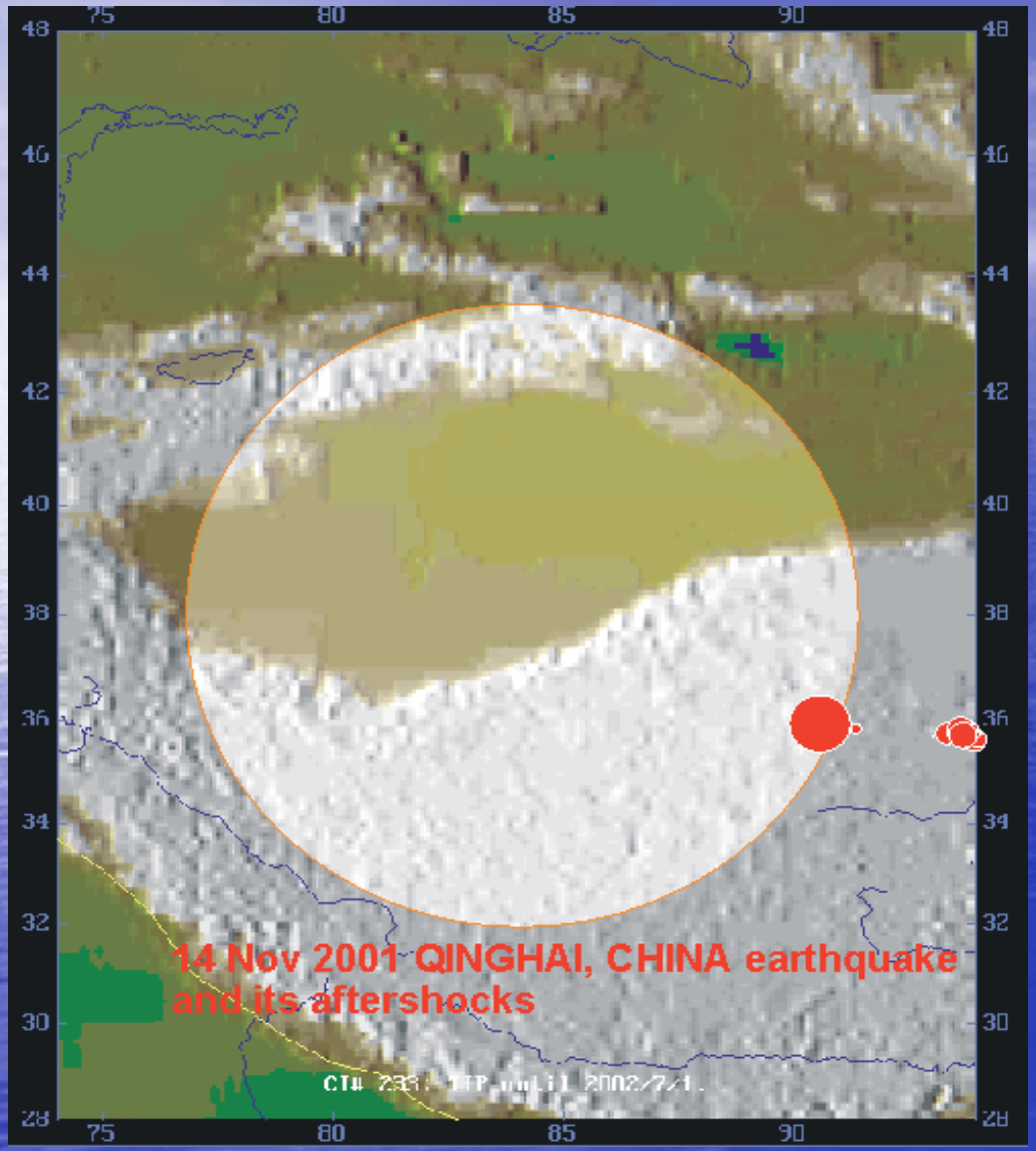
The 26 Jan 2001 Gujarat, India earthquake is just outside the area, where the NEIC data permits to run the original version of the M8 algorithm. Note that one of the circles, nearest to the epicenter of the 2001 Gujarat earthquake was in state of alarm, although the MSc predicts an opposite side of it as the most dangerous area.

23/06/2001 earthquake NEAR COAST OF PERU



This earthquake is the first failure-to-predict in M8-MSc testing aimed at magnitude 8.0+.

14/11/2001 QINGHAI, CHINA earthquake



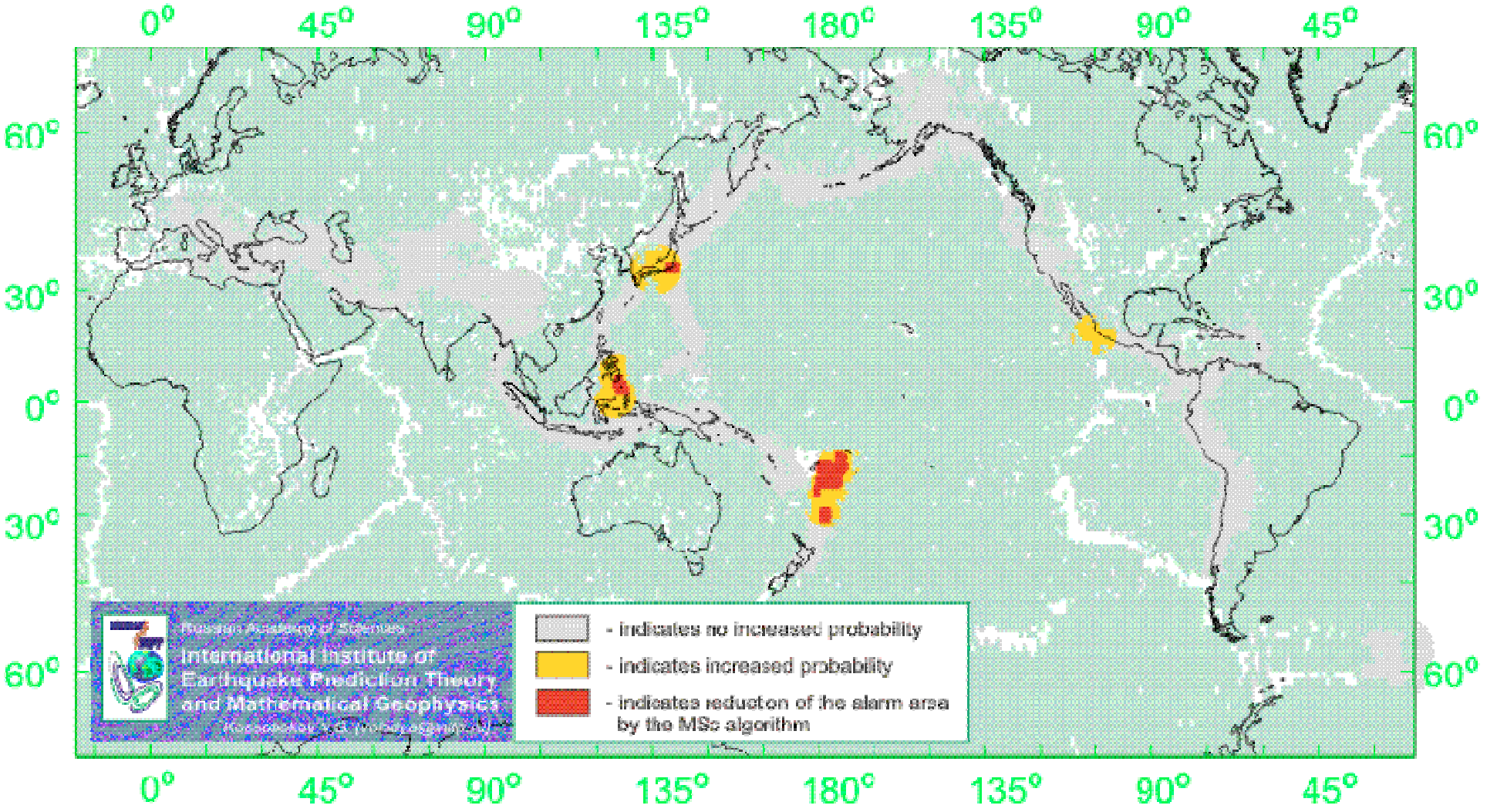
No earthquake of such magnitude had been ever reported inside CI#233 before the 2001 Qinghai earthquake.

The largest one in the 20th century has magnitude MS= 7.9 and happened on November 08, 1997 four months after declaration of the M8 alarm in our Test. (The next largest magnitude is 7.3.)

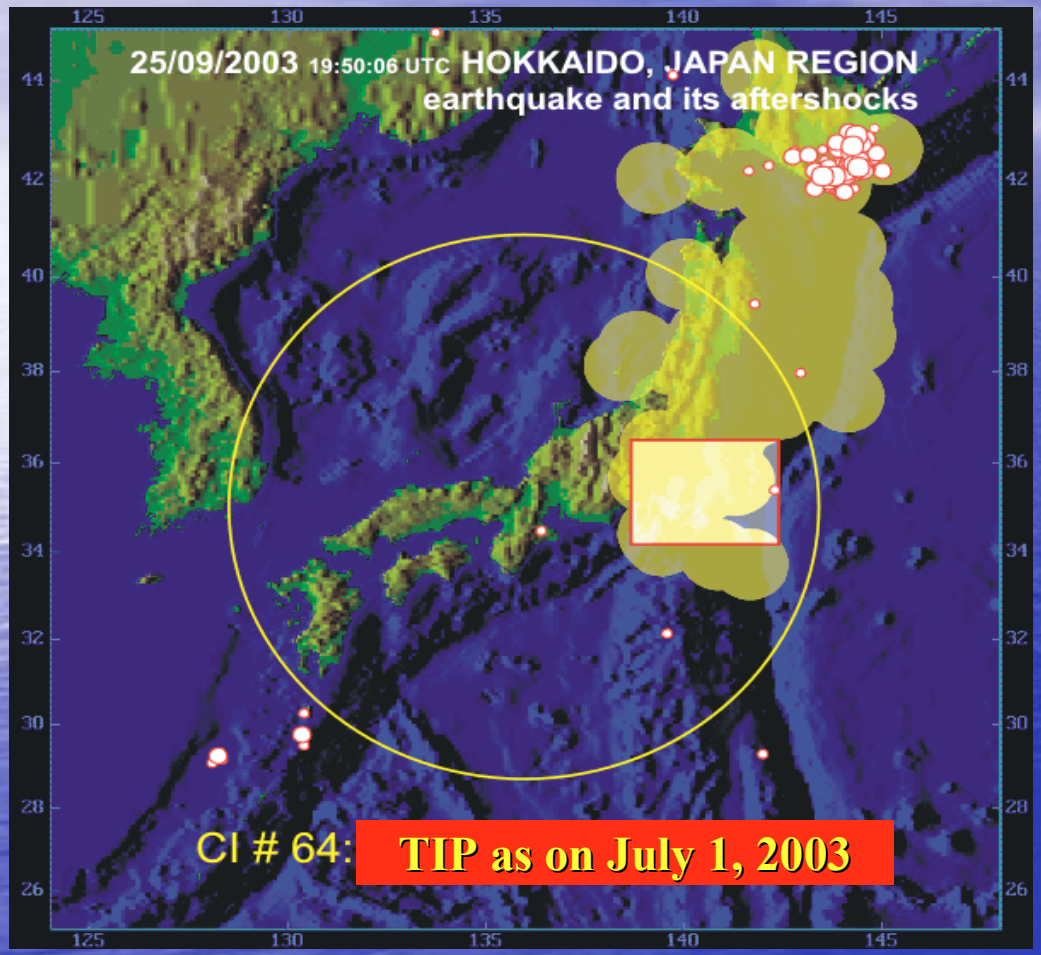
A conservative estimation of probability gain is about 20, so that the prediction is not trivial indeed.

The nearest magnitude 8.0+ earthquake happened on November 18, 1951 near Lhasa, Xizang (Tibet) 375 miles (600 km) south of the November 14, 2001 epicenter.

Regions of Increased Probability of Magnitude 8.0+ Earthquakes as on July 1, 2003 (*subject to update on January 1, 2004*)

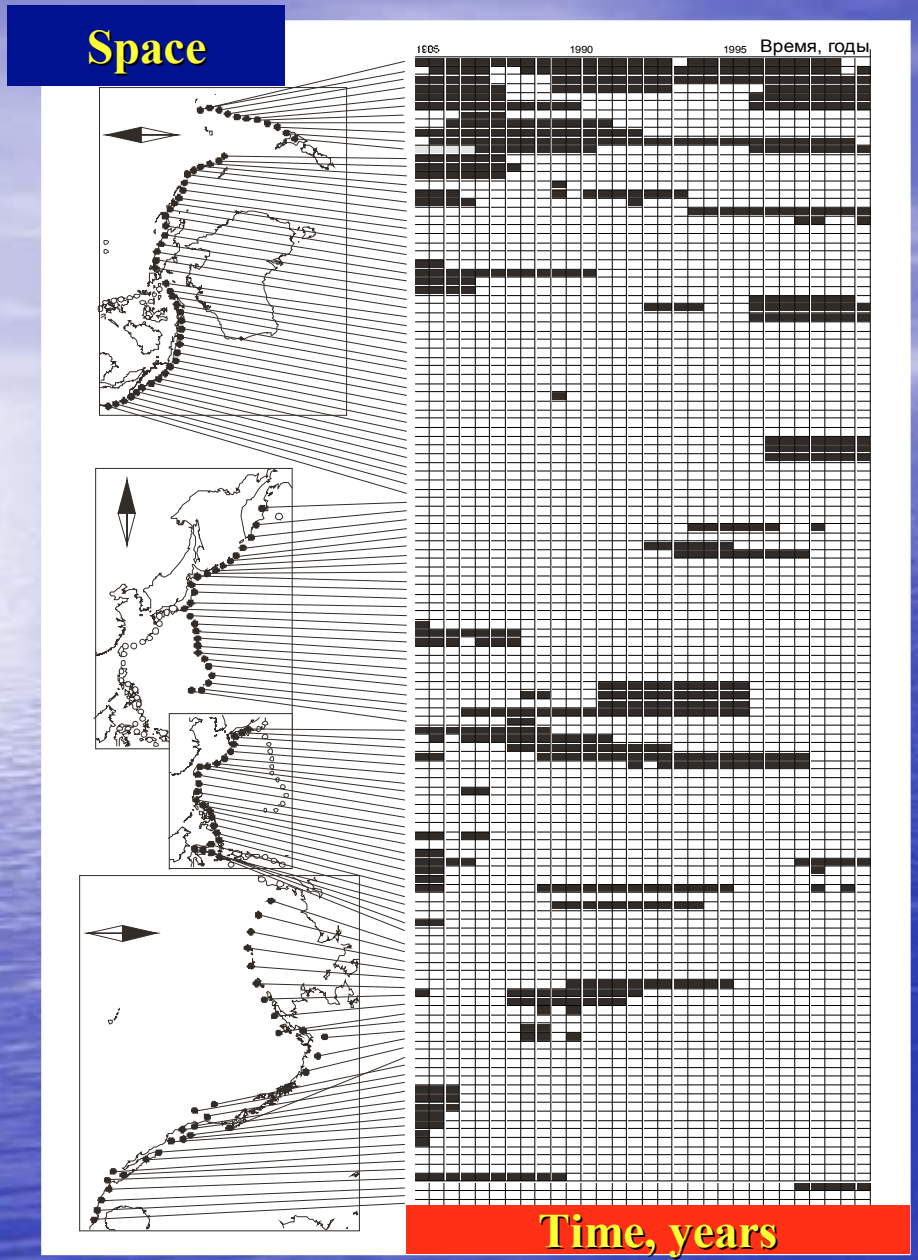


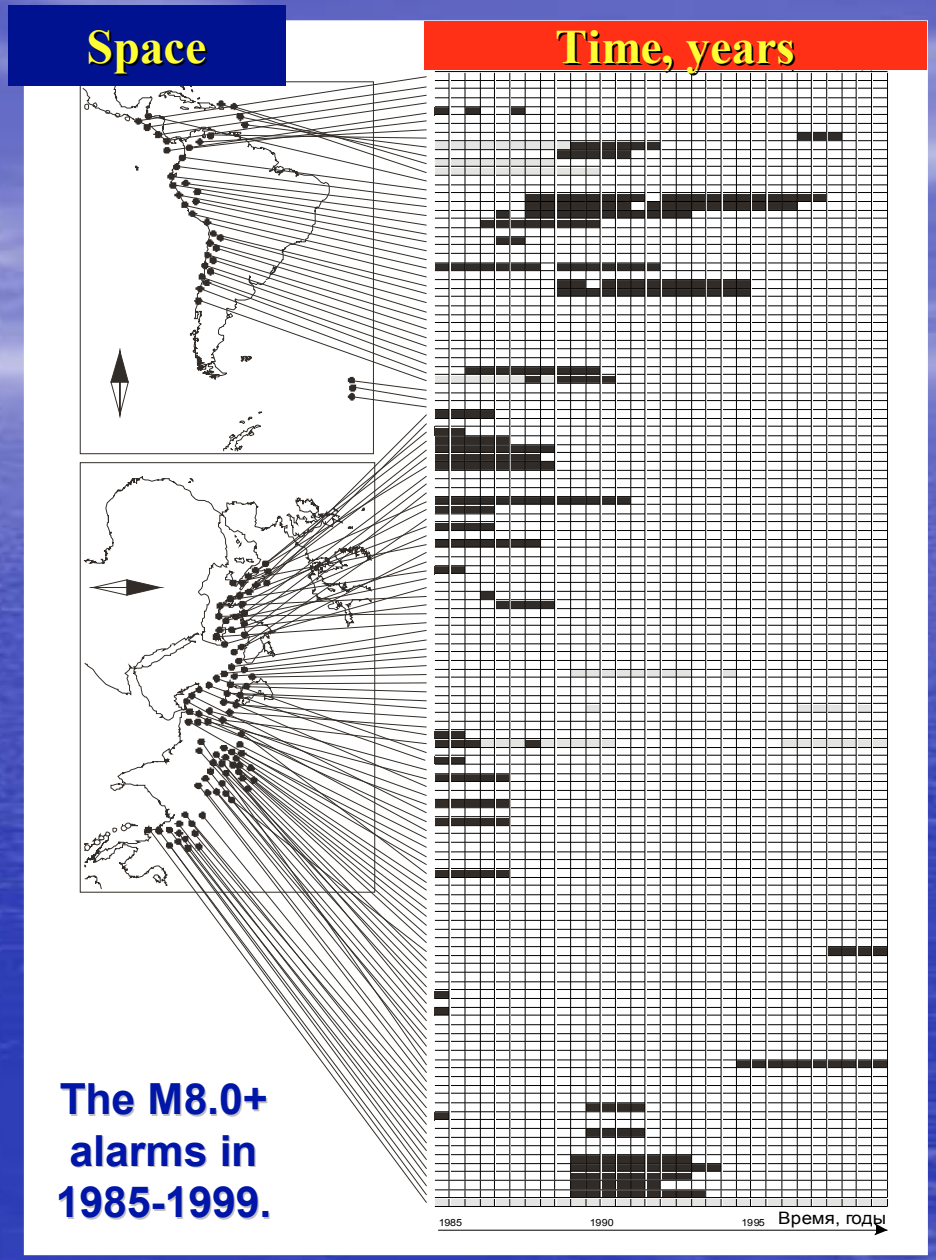
25/09/2003 19:50:06 UTC HOKKAIDO, JAPAN REGION earthquake

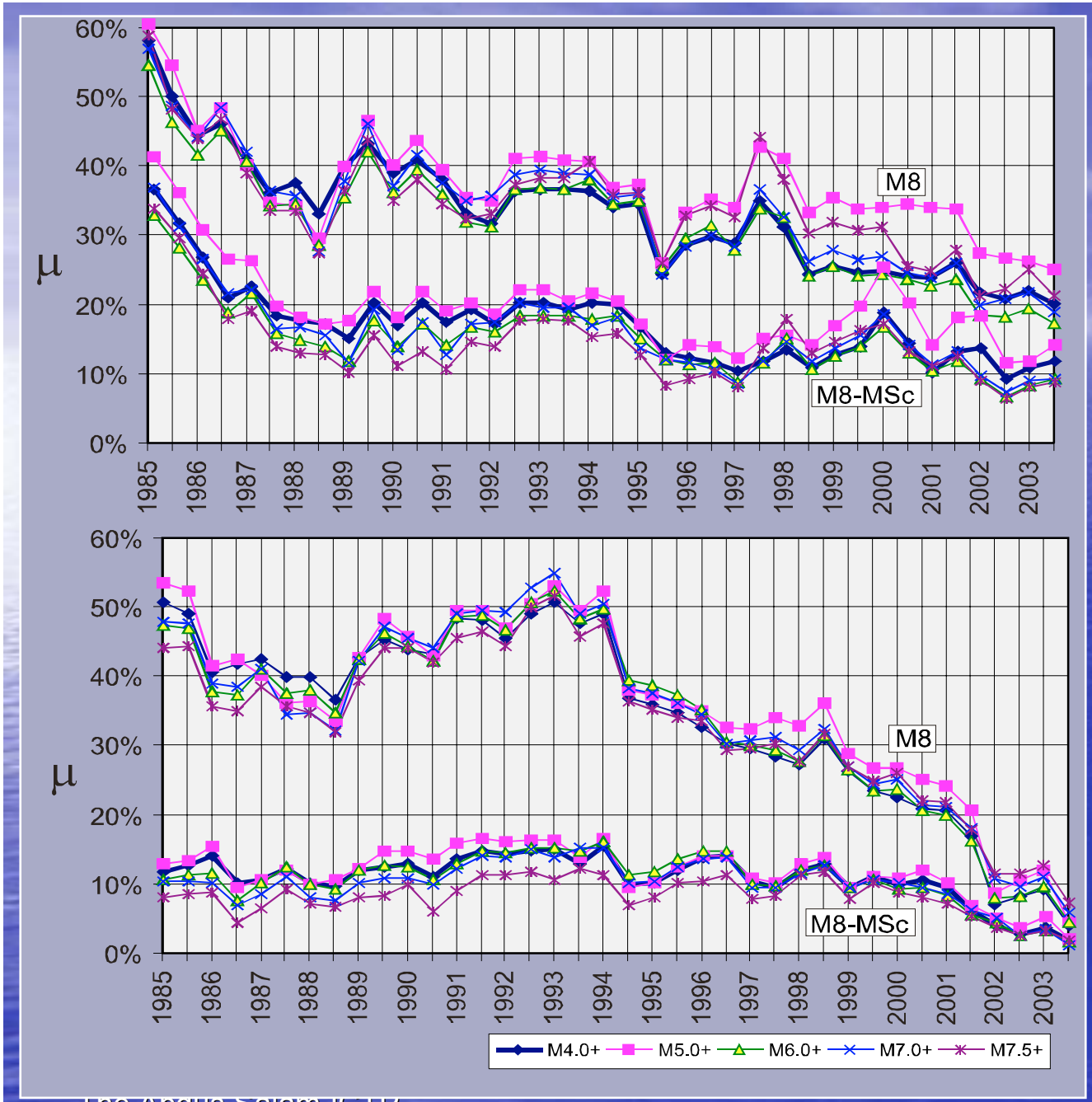


This is the second failure-to-predict the world largest earthquakes in course the Global real-time prediction experiment aimed at M8.0+ events.

Can we exclude a possibility that the *Time of Increases Probability*, TIP, in CI#64 is related to the occurrence of 25 September 2003 great quake?
The analysis at a shorter-term lower-magnitude scales [*Shebalin, Keilis-Borok, Zaliapin, Uyeda, Nagao, Tsybin, 2003. Short-term Premonitory Rise of the Earthquake Correlation Range. In IUGG2003, June 30 – July 11, 2003* **] suggests that, perhaps,**
we can not.


Space
1985
1990
1995
Время, годы
Time, years


Space
Time, years
The M8.0+ alarms in 1985-1999.
1985
1990
1995
Время, годы



The percentage of alerted area as a function of time for M8.0+ (above) and M7.5+ (below).

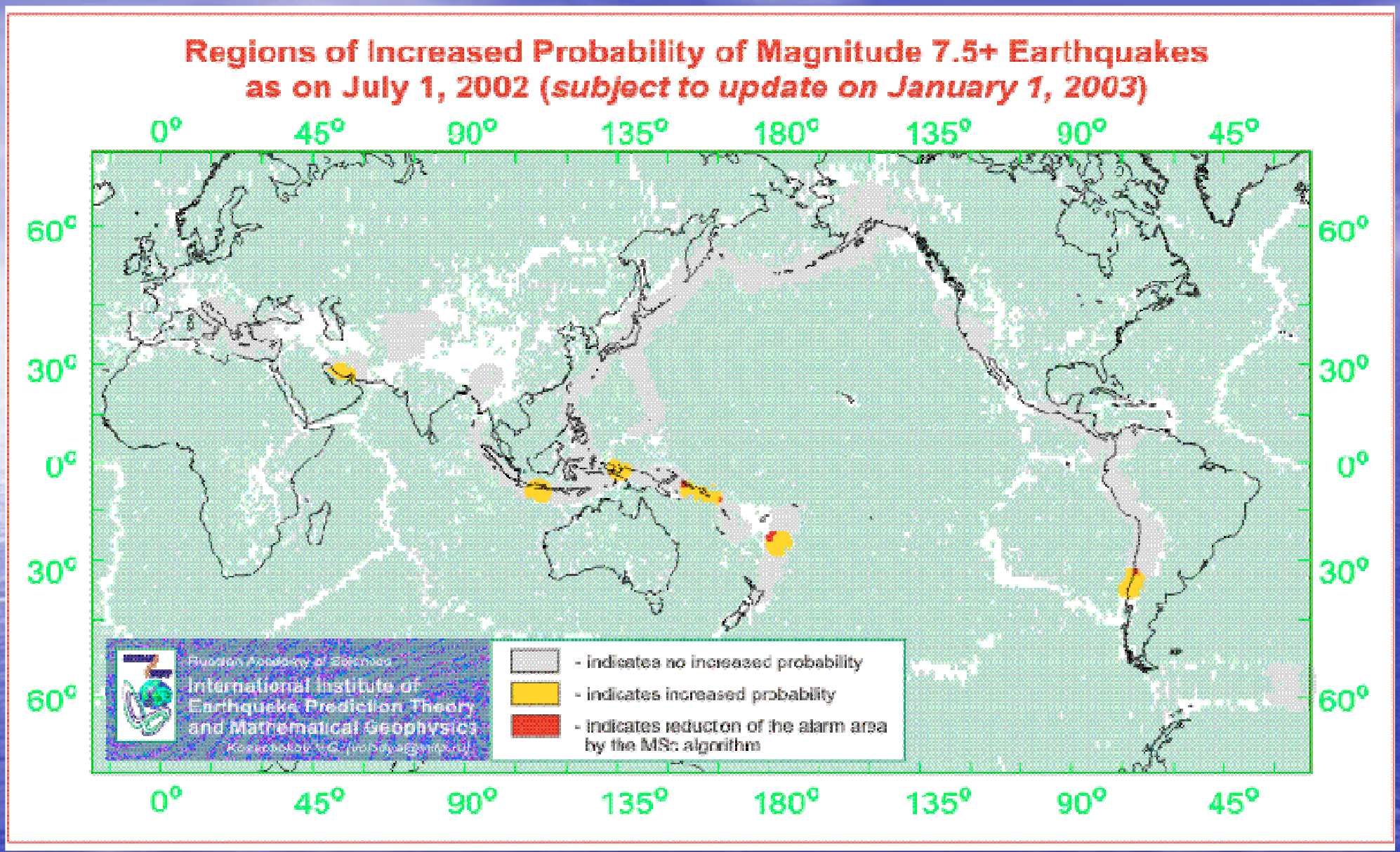
The obtained estimates are based on the counts of magnitude 4 or more and 5 or more earthquakes in the period from 1964 through 1984, while the counts of magnitude above 6.0, 7.0, and 7.5 in 1900-1984

Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: Magnitude 7.5 or more.

Test period	Large earthquakes Total	Predicted by M8	Predicted by M8-MSc	Measure of alarms,% M8	Measure of alarms,% M8-MSc	Confidence level, % M8	Confidence level, % M8-MSc
1985-present	53	30	16	$34._{35}$	$11._{05}$	$99._{93}$	$99._{98}$
1992-present	40	19	10	$28._{77}$	$10._{45}$	$99._{07}$	$99._{31}$

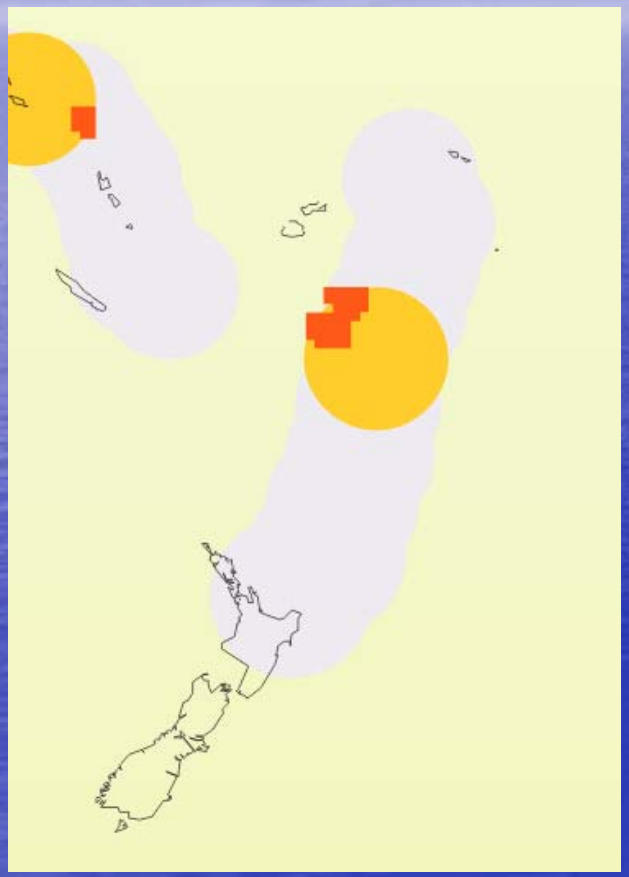
The significance level estimates use the most conservative measure of the alarm volume accounting for empirical distribution of epicenters.

The prediction for M7.5+ is less effective than for M8.0+. Nevertheless, we continue testing the algorithms for this and smaller magnitude ranges.


Regions of Increased Probability of Magnitude 7.5+ Earthquakes
as on July 1, 2002 (subject to update on January 1, 2003)
0°
45°
90°
135°
180°
135°
90°
45°
60°
30°
0°
30°
60°
International Institute of
Earthquake Prediction Theory
and Mathematical Geophysics
- indicatea no increased probability
- indicates increased probability
- indicates reducton of the alarm area
by the MSc algorithm

Sent on Monday, July 15, 2002 (Subject: The 2002b Update of the M8-MSc predictions) along with the updated predictions of major earthquakes worldwide.

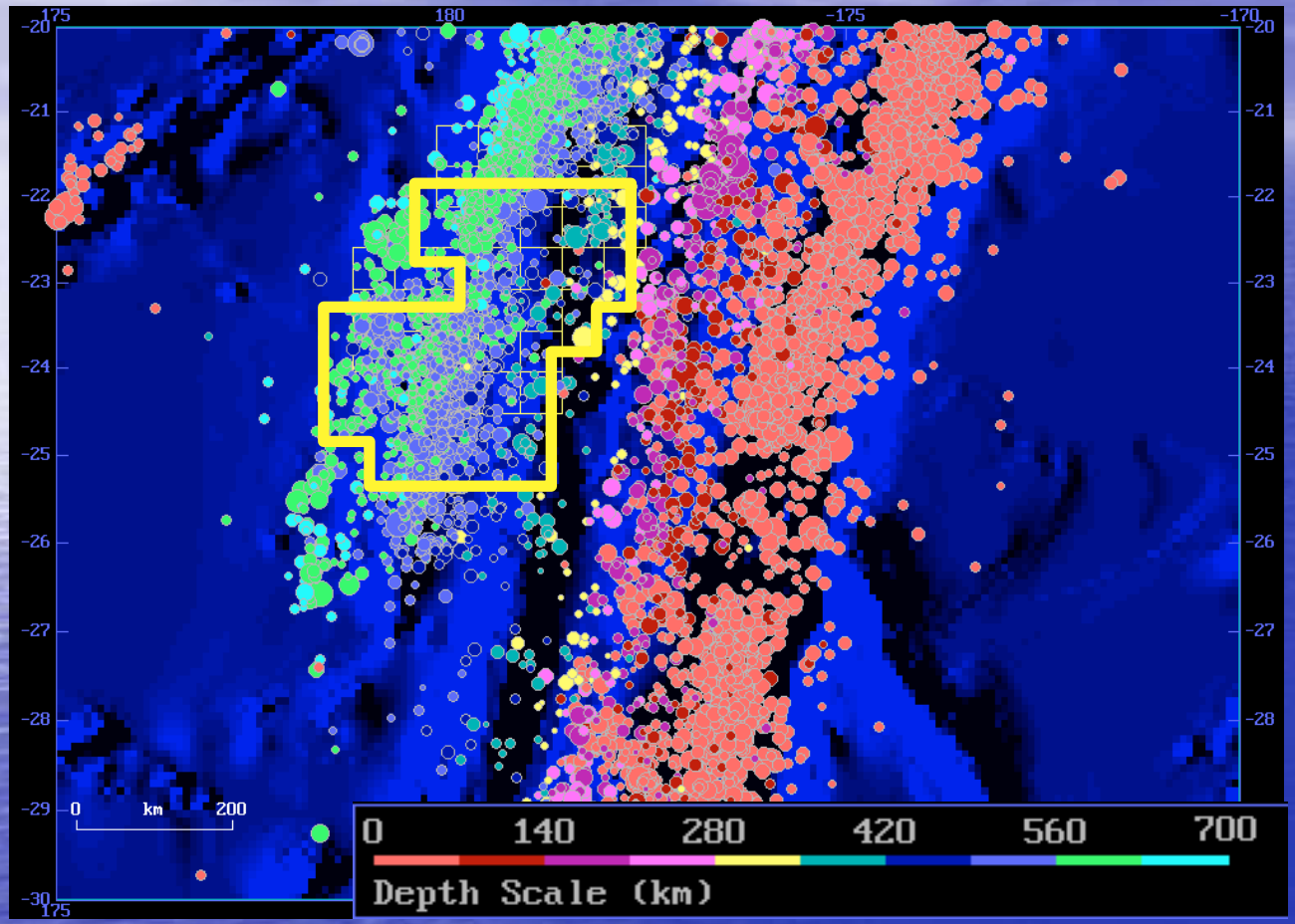
What was predicted…



- Earthquake(s) with magnitude 7.5 or more will occur in CI #5 (yellow) during the time period from July 2002 through July 2003.
- In the second approximation the MSc algorithm has identified the area (red) that stretch between

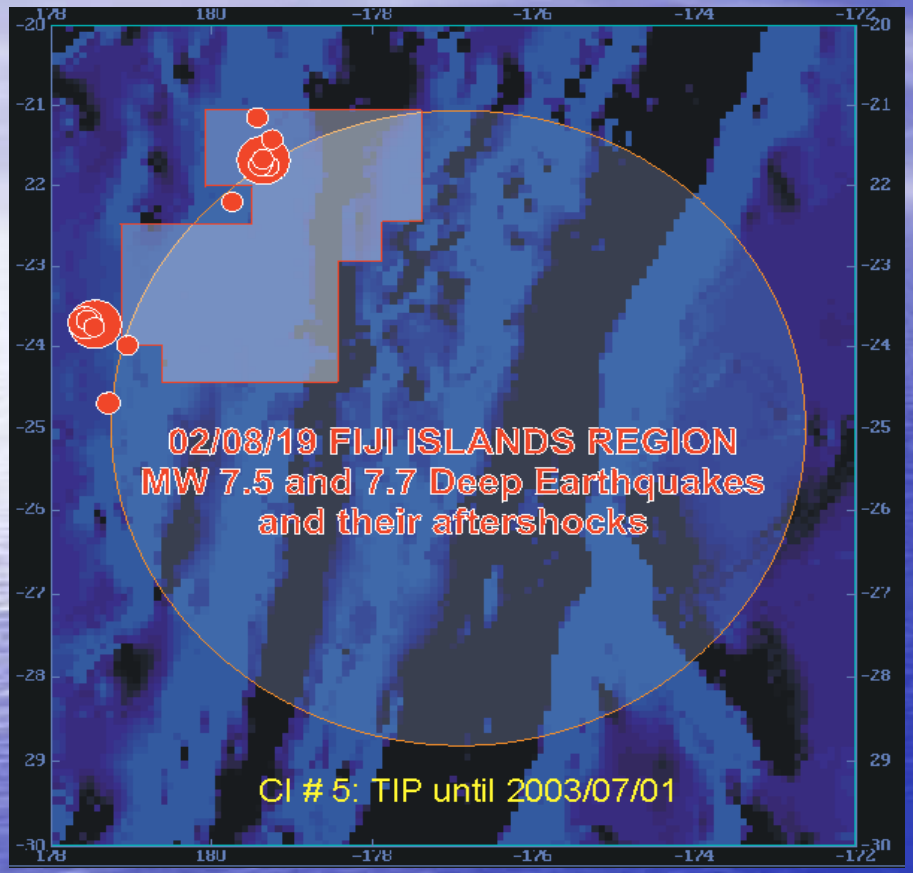
  24.52S - 21.16S and 178.76E - 177.53W.

What was predicted…



- The position of the M8-MSc alarm that narrow down substantially the prediction area suggested the occurrence of the great deep earthquakes (**depth of about 240-700 km**).

What happened…



- EARTHQUAKES:
  - Origin times -
    2002/08/19 11:01:01
    2002/08/19 11:08:25 ;
  - Coordinates –
    21.80S 179.49W
    23.85S 178.41E;
  - Depths - 586.8 and 693.7 km;
  - Magnitudes –
    MwGS (MeGS)
    7.5 and 7.7 (7.7 and 7.4);
  - F-E Regions –
    FIJI ISLANDS REGION and
    SOUTH OF FIJI ISLANDS.

The two August 19 main shocks mark both northern and southern edges of the prediction area. Does it mean that sometimes exact prediction is not possible?
This reduction of the uncertainty provides probability gain of more than 25.

Thus, the accuracy achieved by M8 and MSc algorithms in the on-going Global testing is intermediate in time domain and varies from middle to exact in space domain.

In some cases, the accuracy could be improved by making use of additional short-term monitoring of seismic activity and, perhaps, other geophysical fields in the alerted area of investigation.