Complexity of inverse and direct cascading of earthquakes

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Outline

- Uniform presentation of seismic dynamics prior to and after all the recent earthquakes of magnitude 8.0 or larger, 1985-2000
- What is in common and different?
- Witness to “transient phase changes” in system of blocks-and-faults?
19/09/1985 Mexico Earthquake

19 September 1985, M8.1
Mexico earthquake and its aftershocks

The IMA Workshop
"Complexity in Geophysical Systems"
20/10/1986 Kermadek Earthquake

20 October 1986, M8.3 Kermadec earthquake and its aftershocks

The IMA Workshop
"Complexity in Geophysical Systems"
23/05/1989 Macquarie Earthquake

23 May 1989, M8.2 Macquarie earthquake and its aftershocks

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"Complexity in Geophysical Systems"
08/08/1993 Guam Earthquake

08 August 1993, M8.2
Guam earthquake
and its aftershocks
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

04 October 1994, M6.3 Shikotan earthquake and its aftershocks
07/04/1995 Samoa Earthquake

07 April 1995, M8.1 Samoa earthquake and its aftershocks

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"Complexity in Geophysical Systems"
03/12/1995 Iturup Earthquake

03 December 1995, M8.0 Iturup earthquake and its aftershocks
17/02/1996 New Guinea Earthquake

17 February 1996, M8.2 New Guinea earthquake and its aftershocks
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"Complexity in Geophysical Systems"
04/06/2000 South Sumatera Earthquake
Cascading of earthquakes

... detectable by reproducible earthquake prediction methods

- Case histories of the recent earthquakes of magnitude 8 or above prove it and evidence consecutive stages of inverse cascading of seismic activity to the main shock.
Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: Magnitude 8.0 or more.

<table>
<thead>
<tr>
<th>Test period</th>
<th>Large earthquakes</th>
<th>Percentage of alarms</th>
<th>Significance, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Predicted by</td>
<td>M8  M8-MSc</td>
<td>M8  M8-MSc</td>
</tr>
<tr>
<td>1985-2001</td>
<td>9  8  7</td>
<td>34.9 18.0</td>
<td>99.86 99.98</td>
</tr>
<tr>
<td>1992-2001</td>
<td>7  6  5</td>
<td>30.2 15.3</td>
<td>99.61 99.87</td>
</tr>
</tbody>
</table>

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

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Cascading of earthquakes

Apparently more complicated than so far suggested power-laws...
Benioff strain release in 20 years before the great shocks
Benioff strain release in 20 years before great shocks
(Log-scale)
Aftershock sequences of the great shocks
Activity in 10 years before + 3 years after the great shocks

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Aftershock sequences of the great shocks (summary)

<table>
<thead>
<tr>
<th>Date</th>
<th>Number 100 days</th>
<th>Number 3 years</th>
<th>Aftershocks decay 100 d</th>
<th>Aftershocks decay 3 y</th>
<th>Relaxation time, years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985/09/19</td>
<td>29</td>
<td>65</td>
<td>Omori Law</td>
<td>Modified OL 3</td>
<td>284 days</td>
</tr>
<tr>
<td>1986/10/20</td>
<td>151</td>
<td>205</td>
<td>Modified OL 3 (Omori Law)</td>
<td>Modified OL 3</td>
<td>3 years, &gt;1.5</td>
</tr>
<tr>
<td>1989/05/23</td>
<td>36</td>
<td>54</td>
<td>Modified OL 2</td>
<td>Modified OL 2</td>
<td>1.3 years, &gt;3</td>
</tr>
<tr>
<td>1993/08/08</td>
<td>121</td>
<td>247</td>
<td>Modified OL 2</td>
<td>Modified OL 3</td>
<td>65 days, &gt;1.5</td>
</tr>
<tr>
<td>1994/06/09</td>
<td>5</td>
<td>5</td>
<td>Modified OL 2</td>
<td>Modified OL 3</td>
<td>2 years, &gt;2.5</td>
</tr>
<tr>
<td>1994/10/04</td>
<td>515</td>
<td>919</td>
<td>Modified OL 2</td>
<td>Modified OL 3</td>
<td>14 days, &gt;2</td>
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<tr>
<td>1995/04/07</td>
<td>52</td>
<td>302</td>
<td>Modified OL 2</td>
<td>Modified OL 3</td>
<td>1 year</td>
</tr>
<tr>
<td>1995/12/03</td>
<td>311</td>
<td>483</td>
<td>Modified OL 2</td>
<td>Modified OL 2</td>
<td>2 years, &gt;2.5</td>
</tr>
<tr>
<td>1996/02/17</td>
<td>357</td>
<td>427</td>
<td>Modified OL 2</td>
<td>Modified OL 2</td>
<td>140 days</td>
</tr>
<tr>
<td>1998/03/25</td>
<td>38</td>
<td>46*</td>
<td>Omori Law</td>
<td>Modified OL 2</td>
<td></td>
</tr>
<tr>
<td>2000/06/04</td>
<td>278</td>
<td>278*</td>
<td>Modified OL 2</td>
<td>Modified OL 2</td>
<td></td>
</tr>
</tbody>
</table>

Note: Modified OL 3 = Modified Omori Law 3
Conclusions

- Earthquakes evidence consecutive stages of inverse cascading of seismic activity to main shock and direct cascading of aftershocks.
- The first may reflect coalescence of instabilities at the approach, while the second may indicate readjustment of a complex system of blocks-and-faults in a new state after a catastrophe.
- The cascades observed in seismic dynamics are by far more diverse than a power-law family.

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