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Strike-Slip Earthquakes:

SURFACE RUPTURE

Denali Earthquake, Alaska

7m offset at surface

BURIED (blind)

Bam Earthquake, Iran

20 cm offset at surface
2 m at depth
Examples:

- Bam, Iran. (Funning et al, 2005, etc)
- Aiquile, Bolivia. (Funning et al, 2005a)
- Nenana Mountain, Alaska. (Wright et al, 2003)
- Al Hoceima, Morocco, 1994. (this study)
- Al Hoceima, Morocco, 2004. (this study)

Difficult to identify from surface observations.
MAJOR UNIDENTIFIED SEISMIC HAZARD.
Seismology
Compression

Tension

Fault Plane

Auxilliary Plane
10 km Fault ~ M6

NW-SE Fault

NE-SW Fault

Ascending

Descending
1 km Fault ~ Point Source

NW-SE Fault

NE-SW Fault

Ascending

Descending
2004 Earthquake
Alpine-Himalayan belt

http://www.gly.fsu.edu/~salters
2004 Al Hoceima Earthquake

$M_w$ 6.3. 24\textsuperscript{th} February 2004.

~600 dead. ~40,000 homeless.
2004 Al Hoceima: Surface Observations

Institut Cartografic de Catalunya
Rapport : GS-192/04 (fr)
2004 Al Hociema: Damage Map

Ait Brahim et al, 2004
Preliminary Aftershock Locations
Nodal Planes:

$\sim 25^\circ$

$\sim 295^\circ$
2004 Coseismic Interferogram
Ascending Track

First Image: 10th December 2003
Second Image: 7th July 2004
Descending Interferogram

First Image: 13\textsuperscript{th} April 2003
Second Image: 6\textsuperscript{th} June 2004

[Diagram showing interferogram with color scale indicating changes from -11.0 cm to 184 cm]
Fault Length: 8.8 km
Slip: 1.4 m
Root Mean Square Misfit: 21 mm
Interferograms

NE-SW Model
Fault Length: 1.1 km
Slip: 12.9 m

NE-SW Residual
Root Mean Square Misfit: 23 mm
Slip to Length Ratios

From Funning (2005).
Synthetic Experiment
Is this a general result or specific to Al Hoceima?

Test effect of:
- fault orientation,
- atmospheric noise,
- coherence pattern.
Fault Length: 10 km
Slip: 1 m
Root Mean Square Misfit: 0.2 mm
Fault Length: 2.0 km !!
Slip: 9.1 m !!

Root Mean Square Misfit: 6 mm
1994 Earthquake
1994 Al Hoceima Earthquake

$M_w 6.0$. 26th May 1994.
2 dead. Significant Damage
Preliminary Observations:
Surface Observations
Preliminary Observations: Intensity Map
Location from Seismology

- Harvard CMT
- NEIC
- El Alami 1998
- Calvert 1997
1994 Coseismic Interferogram.

ifm1: 23-Sep-93 -> 30-Dec-95

los cm

10 km
Earthquake Sequence
Combining Seismology + InSAR to study earthquake sequences

- **Seismology**
  - Detect Small Events
  - Poor absolute location (but good relative location)

- **InSAR**
  - Accurate absolute locations
  - Events with significant surface deformation (i.e. shallow, M5-6+)
Step 1: Relative locations of events within cluster using seismology.

Step 2: Absolute location of entire cluster use InSAR as ground truth.

Relocate 58 Events:
- 10 associated with 1994 event
- 19 associated with 2004 event
Aftershocks not consistent with NW-SE fault plane for 1994 event.

=> Pair of conjugate faults.
Conjugate Fault System

Plate Convergence Vector (from GPS)

1994

2004
Al Hoceima Earthquake Sequence: 1994-2004
Regional Context

- Tectonics of transition zone between Al Hoceima and El Asnam remains unclear.
- May only become clear once further larger earthquakes have occurred.
Conclusions

- Al Hoceima Earthquakes occurred on a conjugate fault system.
- 2004 Al Hoceima Earthquake occurred on a NW-SE right-lateral fault.
- 1994 Al Hoceima Earthquake occurred on a NE-SW left-lateral fault.
- Significant seismic hazard associated with the region between Al Hoceima and El Asnam.
Variable Slip Model

Peak Slip = 2.1 m
At 8 km depth.
Errors on Slip Model.
Monte Carlo Error Analysis

Create 100 perturbed datasets and analyse.

Identify tradeoffs and errors
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Strike</td>
<td>295.4° ± 1.1</td>
</tr>
<tr>
<td>Dip</td>
<td>87.4 ° ± 1.5</td>
</tr>
<tr>
<td>Rake</td>
<td>-179.2 ° ± 1.2</td>
</tr>
<tr>
<td>Slip</td>
<td>1.4 m ± 0.1</td>
</tr>
<tr>
<td>Length</td>
<td>8.8 km ± 0.4</td>
</tr>
<tr>
<td>Min Depth</td>
<td>2.1 km ± 0.2</td>
</tr>
</tbody>
</table>
Resolution

Inversion

Depends on geometry between observation point and fault patch and smoothing factor.
Recent Large Earthquakes

Strike-slip

Thrust

Al Hoceima 1994
Al Hoceima 2004

El Asnam 1980
Zemmouri 2003

Strike-Slip Fault
Thrust Fault