Monitoring the Earth from space
And earthquakes

Doç. Dr. Ziyadin Çakır
Satellite imaging systems

Passive system

**Optical**
- Landsat
- IKONOS
- QuickBird
- RapidEye
- SPOT
- WorldView-1
- WorldView-2
- GeoEye-1
- ALOS-Prisme

Active system

**Radar**
- ERS
- JERS
- ENVISAT
- RADARSAT
- ALOS-PALSAR
- TerraSAR-X
- COSMO-SkyMed
SAR ≠ Landsat or Spot
Locations of earthquakes from 1980 to 1990

These zones mark the edges of tectonic plates

Broad bands are subduction zone earthquakes, narrow are MOR
Plate tectonics theory holds that interiors of plates are rigid... deformation only occurs at boundaries...

Global seismicity correlates with plate boundaries.
major plates
earthquakes

what is an earthquake?

ground shaking caused by sudden release of energy stored in rocks beneath surface

tectonic forces produce stresses on rocks that exceed elastic limits and cause brittle failure (rupture along a fault plane)

seismic waves released from breaking point
what happens along the fault?

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elastic rebound theory

A

B

Fault

C

Earthquake

D

1906 San Francisco earthquake

3 m offset

Photo by G. K. Gilbert, U.S. Geological Survey
Large earthquakes release all strain accumulated on locked fault between earthquakes.

Stein & Wyssession, 2003
ELASTIC REBOUND MODEL OF STRIKE-SLIP FAULT AT A PLATE BOUNDARY

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ELASTIC REBOUND MODEL OF STRIKE-SLIP FAULT AT A PLATE BOUNDARY

Large earthquakes release all strain accumulated on locked fault between earthquakes.

Fault parallel interseismic motion on fault with far field slip rate $D$, locked to depth $W$, as function of cross-fault distance $y$:

$$s(y) = \frac{D}{2} + \left(\frac{D}{\pi}\right) \tan^{-1}\left(\frac{y}{W}\right)$$

Width of strain accumulation zone comparable to locking depth.
Large earthquakes release all strain accumulated on locked fault between earthquakes.

Coseismic and interseismic motion sum to plate motion.

Interseismic strain accumulates near fault.

Stein & Wysession, 2003
Large earthquakes release all strain accumulated on locked fault between earthquakes.

Coseismic and interseismic motion sum to plate motion.

Interseismic strain accumulates near fault.

Stein & Wysession, 2003
offset lettuce rows - El Centro, CA

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Photo by Univ. of Colorado; courtesy National Geophysical Data Center, Boulder, CO
earthquakes

hypocenter (focus)
location of first rupture along fault

epicenter
point on Earth’s surface above rupture

seismic waves radiate from focus (hypocenter)
earthquakes

seismic waves -- energy released from earthquake

two types of seismic waves

body waves
  travel outward from focus through body of Earth

surface waves
  travel away from epicenter on surface of Earth
body waves

**P (primary) waves**

*compressional body wave*

- vibration is back and forth in direction wave travels (Slinky)
- fast (4–7 km/s); first to arrive
- pass through solids and fluids

**S (secondary) waves**

*shear body wave*

- vibration is perpendicular to direction the wave travels (rope)
- slower (2–5 km/s); secondary arrival
- pass only through solids
body waves

Seismic Waves

P wave

displacement parallel to wave motion

S wave

displacement normal to wave motion

from: http://www.personal.umich.edu/~vdpluijm/gs205.html

P (primary) waves faster than S (secondary) waves
surface waves

*slowest seismic waves*

**Love waves**
side to side motion of ground surface

cannot travel through fluids

**Rayleigh waves**
ground moves in elliptical path
In direction opposite to direction of travel of wave

*very destructive to buildings*
moment magnitude and energy released

note for any year # small >>> # big
4.95m
Tectonics of the Eastern Mediterranean Region

(After Armijo et al., 1996)
Westward earthquake migration
Westward earthquake migration
Westward earthquake migration
Westward earthquake migration
Westward earthquake migration
Westward earthquake migration
Westward earthquake migration
Westward earthquake migration
Westward earthquake migration
GEODESY FOR TECTONIC AND EARTHQUAKE STUDIES

Geodesy is the science of the earth’s shape

Find precise positions

Monitor changes due to tectonic processes:

- Plate motion
- Plate boundary deformation
- Intraplate deformation
- Earthquake cycle
- Volcanic processes
- Land Subsidence
  etc
GLOBAL POSITIONING SYSTEM

24 Satellites
5-8 overhead most of the world

Each GPS satellite transmits data that indicates its location and the current time. All GPS satellites synchronize operations so that these repeating signals are transmitted at the same instant. The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are farther away than others. The distance to the GPS satellites can be determined by estimating the amount of time it takes for their signals to reach the receiver. When the receiver estimates the distance to at least four GPS satellites, it can calculate its position in three dimensions.
Determining Position

A GPS receiver "knows" the location of the satellites, because that information is included in satellite transmissions. By estimating how far away a satellite is, the receiver also "knows" it is located somewhere on the surface of an imaginary sphere centered at the satellite. It then determines the sizes of several spheres, one for each satellite. The receiver is located where these spheres intersect.

Conceptually the same as locating an earthquake from arrivals at multiple seismometers.
SURVEY (EPISODIC)

GPS

GPS antennas are set up over monuments for short periods, and the sites are reoccupied later.

In early GPS days, it was thought necessary to operate all sites at the same time and locate sites relative to each other.

Presently, positions are so precise that this is no longer necessary, because sites located using global GPS network (point positioning).

GPS = Great Places to Sleep
CONTINUOUS (PERMANENT) GPS

Continuously recording GPS receivers permanently installed

Give daily positions

Provide significantly more precise data:
No errors in setting up equipment and reoccupying sites
Very stable monuments
Many more positions to constrain time series

Higher cost (in U.S., 25-site network can be occupied in survey mode for the cost of a single continuous station)

Can observe transient signals such as due to earthquake
Tectonics of the Eastern Mediterranean Region

(After McClusky et al., 2000)
InSAR?

- Synthetic Aperture Radar interferometry
  - Radio detection and ranging
What are the sources of SAR data?

- Airplane
- Space Shuttle
  - SIR-C
  - SRTM
- Satellites
  - ERS
  - JERS
  - RADARSAT
  - ENVISAT
InSAR geometry

\[ \text{Beamwidth} = \frac{\lambda}{D} \]

\[ \text{Azimuth beamwidth} = \frac{\lambda}{L} \]

\[ \begin{align*}
\theta & \quad \text{(mid-range)} \quad 19.354' \\
\phi & \quad \text{(near-range)} \quad \text{Look angle (right)} \quad 23.002' \\
\Psi & \quad \text{(far-range)} \quad 26.496' \\
\beta & \quad \text{Angle from equator} \quad 81.784' \\
\lambda & \quad \text{Wavelength} \quad 5.66 \text{ cm} \\
T_0 & \quad \text{Pulse duration} \quad 3.71 \times 10^{-10} \text{ second (15.55 MHz)} \\
\text{Frequency bandwidth} & \quad 1.555 \times 10^5 \text{ Hz} \\
\text{Pulse repetition frequency range} & \quad 1640-1720 \text{ Hz} \\
\text{Repeat Cycle} & \quad 35 \text{ days} \\
\text{Ground Track Velocity} & \quad 6,628 \text{ km/s} \\
\text{Frequency} & \quad 5.3 \text{ GHz (C band)} \pm 0.2 \text{ MHz} \\
\end{align*} \]

\[ \begin{align*}
L & \quad \text{Antenna length} \quad 10 \text{ m} \\
D & \quad \text{Antenna width} \quad 1 \text{ m} \\
S_w & \quad \text{Swath width} \quad 100 \text{ km} \\
D_n & \quad \text{Nadir distance} \quad 244.5 \text{ km} \\
H & \quad \text{Altitude of satellite} \quad 785 \text{ km} \\
R_{nm} & \quad \text{(near-range)} \quad 826.5 \text{ km} \\
R_{mm} & \quad \text{(mid-range) Range} \quad 844.5 \text{ km} \\
R_f & \quad \text{(far-range) } \quad 865.5 \text{ km} \\
\end{align*} \]

Real Aperture Radar

5x14 km pixels
Earthquake deformation from two different look angle
How to interpret interferograms?
Displacement vectors observed and predicted by the GPS model.
\[ v_p = 24.0 \pm 2.9 \text{ mm/y} \]
\[ d = 12.8 \pm 3.9 \text{ km} \]
\[ s_h = 15.1 \pm 2.6 \text{ km} \]

\[ v_p = 16.3 \pm 2.3 \text{ mm/y} \]
\[ d = 8.1 \pm 3.3 \text{ km} \]
\[ s_h = 3.7 \pm 1.6 \text{ km} \]

\[ v_p = 18.5 \pm 2.2 \text{ mm/y} \]
\[ d = 9.4 \pm 3.5 \text{ km} \]
\[ s_h = 4.0 \pm 2.7 \text{ km} \]

\[ v_p = 20.1 \pm 2.4 \text{ mm/y} \]
\[ d = 12.5 \pm 3.5 \text{ km} \]
\[ s_h = 6.2 \pm 4.0 \text{ km} \]