Space Geodetic Techniques used in Crustal Deformation Studies at TUBITAK Marmara Research Center

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Presentation Plan

• Objectives
• Geodetical monitoring conducted in the Institute
• Future Plans
Multi-disciplinary continuous monitoring (seismological, geochemical and geodetical) for Earthquake and landslide risk mitigation
Geodetical monitoring conducted in the Institute

- GPS monitoring
- SAR Interferometry
- PSIInSAR Technique
- PSIInSAR Applications
Continuous monitoring stations of the TURDEP project

TUBITAK sites are mainly installed around the important tectonic regime. To obtain the best fault parallel velocities, GPS profiles are established along the fault zone. Unfortunately, the national CORS is established for the cadastral studies. The main purpose of it is to supply real time correction to mobile team and sites are equally distributed along Anatolia. The locations of them can not be good. But, we can use 40-50% of them in our studies.

Legend: NATIONAL CORS TUBITAK CORS TUBITAK Survey Sites
To increase the density, different data sets are merged. The main problem is to define a common reference frame. The main differences are in the Marmara region as a result of the post-seismic motion. In other parts of Turkey, differences are too small. The whole data set lets us understand the stress transfer along the major fault zone, based on the GPS profiles from east to west.
National CORS was only recently established and this velocity map is the first version result and it should be studied in detail. High accuracy data set will be obtained in the next 1 to 2 years. The distribution of GPS vectors shows nice coherence with other sites in the previous slides.
ERS1,2 radar satellite geometry

SAR produces a synthetic aperture by using the forward motion of the radar.

As it passes a given scatterer, many pulses are reflected in sequence.

By combining these individual signals, a synthetic aperture is created in the computer providing an improved azimuth resolution.
SAR can provide high resolution imagery of earthquake prone areas, high resolution topographic data and a high resolution map of coseismic deformation.

Crustal deformation is a direct manifestation of the processes that lead to earthquakes.

After an earthquake, SAR interferometry can be used to characterize the slip that occurred at the surface, slip from aftershocks and slip distribution at depth.
Fig. 3.4. Fringes produced by a small ($M = 5.1$) aftershock, as seen in an interferogram constructed from ERS-1 radar images acquired on April 24, 1992, and June 18, 1993 (left, [Massonnet et al., 1994]), and modeled using fault parameters estimated from the interferogram (right, [Feigl et al., 1994]). The interferometric signature is the sum of the main Landers shock (straight fringes in NE quadrant) and the aftershock (concentric fringes near center). One fringe represents 28 mm of range change.
Residual (observed - calculated) wrapped interferogram (28mm fringes) calculated from 12.08.99 and 16.09.99 ERS-1 SAR images, where fringes are cleaned with a power spectrum filter

Manually digitized fringes

Ground deformation in LOS

PSInSAR technique

• provides high precision measurements of ground deformations by processing satellite radar data acquired over an area of interest during a specific time span.

• uses outpoints of measurement on the ground that are good radar targets (referred to as permanent scatterers of PS), which are pre-existing, e.g.
  – rock outcrops, buildings, structures, dams, pipelines, etc.) or are
  – specifically designed and manufactured for this purpose (artificial reflectors)
PSInSAR technique

- For each PS displacement can be measured with a precision of a few millimeters, both vertical and east west components of the motion can be calculated with dual geometry acquisitions.
- analyzes ground deformation over large areas of land both remotely and cost effectively.
- Regular updates of PS data and their integration into a GIS environment significantly enhance the value of radar remote sensing for investigating and managing geohazards.
Basic Steps of PSInSAR Analysis

Time Series Analysis: Data Input

Akarvardar, S.E., 2007. Subsidence around Istanbul, Turkey measured by satellite radar interferometry, Université Paul Sabatier and Istanbul Technical University
Time Series Analysis: Output

Temporal Adjustment

Vertical Displacement in Time and Space

Distinguish phase contributions

- Atmosphere
- Topography

Akarvardar, S.E., 2007. Subsidence around Istanbul, Turkey measured by satellite radar interferometry, Université Paul Sabatier and Istanbul Technical University, Istanbul
Advantages of PSInSAR

- **Operational in all weather conditions** (PS measurements are obtained by active space-borne microwave sensors that are capable of operating in all weather and lighting conditions.)
- **Multiscale analysis** (The processing of single SAR scenes can cover areas of interest ranging from 1 km\(^2\) to more than 10000 km\(^2\))
- **Highly precise and spatially dense data** (Under optimal conditions PS density can exceed 1,000 PS/km\(^2\) and displacement rates can attain accuracies of up to 0.1 mm/yr)
- **Data fusion** (PS data complements other sources of information such as GPS, tiltmeters, optical leveling etc.)
- **Historical analysis** (Archives of raw SAR data reach as far back as 1992, enabling a historical review of movements)
- **Regular updates** (SAR data acquisitions can be scheduled to guarantee regular updates of ground movement behavior)
- **Cost-effective** (PS motion can be measured over areas of 1000s of km\(^2\) at a fraction of the cost of conventional surveys – while achieving much higher spatial densities of measurement data)

PSInSAR analysis is a routine analysis in the region supporting our other studies. ENVISAT data set between 2002-2010 and STAMPS software was used. In this slide, three results are shown for one full frame. The results reflect the fault boundaries, very well. To check the quality of the results, it is correlated with continuous GPS data in this frame. When the CGPS data is projected to LOS direction, correlation seems very high. In other words, our result has high quality under the control of ground based data.
Dominant subsidence area corresponding to ERS Satellite for Track 107.

BUY and BAK are sites, where time series is generated.

S. Ergintav et al., Investigation of Possible Active Faults in Istanbul Land Area and Development of Landslide Determination and Monitoring Methodologies by Multidisciplinary Researches in Istanbul Metropolitan Area, Interim report, TUBITAK MAM Earth and Marine Sciences Institute, August 2010
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Istanbul Deformation Area from ENVISAT

Dominant deformation area from ENVISAT for Track 107.

Time Series are generated at YAS, BUY, GUR and BAK locations

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Dominant deformations from ENVISAT

Dominant deformations according to ENVISAT satellite track 336. GPS velocity field shows horizontal deformations

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x, y and t components of time series of KANT permanent GPS station are drawn in red, their projection along LOS in blue and PSInSAR data of the same point in green.
PS points distribution colored according to average velocity variation at Çatalca.

CAT2, CAT3 & CAT4 are time series generation sites.
Time Series at Çatalca sites

Ground site: CAT2

Ground site: CAT4

Ground site: CAT3
PS points distribution at Yeniköy, İstanbul

Date of Acquisition: June 10, 2002        Latitude 41.323471 Longitude 28.715116 Altitude 41 m View altitude 3.57 km

PS points distribution in Çatalca colored according to average velocity variation at Yeniköy. YEN2, YEN3 & YEN4 are time series generation sites
Time Series at Yeniköy Sites

Ground site: YEN2

Ground site: YEN3

Ground site: YEN4
Turning double sided reflector towards LOS

Turning the symmetry axis of the designed double sided reflector in the LOS (radar view) direction
Placing reflectors at Çatalca Site
Placing reflectors at Yeniköy site
Future Plans

• Continuation of the land-based geochemical and seismological monitoring

• Continuation of Space-based Monitoring
  – Use of PsInsar for areal determination of crustal deformation
  – Use of GPS to calibrate PsInsar data
  – Use of Thermal Infrared (TIR) images to detect pre-EQ anomalies
  – Ionosphere density monitoring by GPS residuals
Processing Russian and European EARTH observations for earthquake precursors Studies.

Proposal acronym: PRE-EARTHQUAKES

Type of funding scheme:
Collaborative Project (Small scale focused research project)

Work programme topics addressed:
FP7-SPACE-2010-1; Activity 9.3: Cross-cutting activities; Area 9.3.2: International cooperation; SPA.2010.3.2-01 EU-Russia Cooperation in GMES (SICA)

Name of the coordinating person:
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# List of Participants in EU-Russia

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