SAR INTERFEROMETRY WITH ERS

1995

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An exciting and promising technique for the application of remote sensing data to emerge in recent years is that of Synthetic Aperture Radar (SAR) Interferometry, or INSAR.

Using the INSAR technique, it is possible to produce directly from SAR image data, detailed and accurate three-dimensional relief maps of the Earth's surface. In addition, an extension of the basic technique, known as Differential INSAR, allows the detection of very small (centimetre-scale) movement of land surface features. Furthermore, recent research has established the potential of INSAR to monitor changes in time of the Earth's surface scattering properties.

These possibilities open up many new potential application areas of space borne SAR data in the areas of global and regional cartography, volcanology, seismotectonics, agriculture/land use, forestry, and glaciology/ice sheet monitoring.

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The ERS-1 platform is flying a single SAR instrument. However, a SAR Interferometer can be 'synthesised' with ERS-1 by ingenious use of the repeat feature of the ERS-1 orbit, where, after a fixed number of days the satellite images the same area of ground. The corresponding images are superimposed (or interfered) as though they were from a single SAR Interferometer.

The INSAR technique exploits the phase information in SAR imagery by taking the difference in phase for each pixel corresponding to the same area of ground. The resulting phase difference image is known as an Interferogramme.

This phase difference is a measure of the difference in path length from a given pixel to each antenna of the SAR Interferometer. Using a knowledge of the orbit parameters, the phase interferogramme can be related directly to the altitude of the satellite above the ground on a pixel by pixel basis to generate a Digital Elevation Model (DEM) of the terrain surface. The resulting accurate surface topographic data are required to investigate a wide variety of geophysical processes.

By using 3 or more passes of satellite imagery, the resulting DEMs themselves can be differenced to reveal changes in the Earth's surface topography on a scale compatible with the wavelength of the SAR instrument; ie. a few centimetres for ERS-1.

There are constraints on the repeat orbit separation in applying the INSAR technique. At ESRIN, the complete set of ERS-1 orbits to date have been processed and an INSAR orbit listing has been produced. Using this listing (available on-line), one can identify those repeat orbit combinations for which the INSAR technique is possible (an orbit separation of < 600 m).

All ERS-1 INSAR activity is co-ordinated within the framework of a mission-dedicated Working Group, called FRINGE, set up by ESA/ESRIN at the beginning of 1992 and currently comprising about 70 groups world-wide.

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Lines of constant colour correspond to constant phase difference and therefore constant terrain altitude; i.e. height contours. The phase difference is coded on a colour wheel corresponding to approximately 40 m of altitude. One can clearly identify areas of tightly packed contours around Vesuvius which correspond to rapidly varying terrain topography. Note that no phase differences are given over the sea as these differences are meaningless due to the motion of the sea surface between passes.

This area is under study to detect the small motion of the Campi Flegrei area, which is currently experiencing a surface relaxation of a few centimeters per year.

Figure 2 (*114 Mb*) is an example of a DEM computed by POLIMI from ERS-1 SAR data via the INSAR technique. This DEM is a section of the FRINGE INSAR reference data set of Gennargentu (Sardinia). The area consists of vegetated peaks rising rapidly from the coastline to a height of about 1 200 m.

A first quantitative estimate of the height accuracy associated with ERS-1 INSAR has come from a comparison with Global Positioning System (GPS) measurements. These initial results are very encouraging and show excellent agreement with differences in terrain height of approximately 10 m.

There has recently been a spectacular validation of small terrain movement measurement by the ERS-1 SAR for the region of the Landers Earthquake, which occurred in California in the summer of 1992. Working with SAR images acquired both before and after the earthquake, the group of D. Massonet and F. Adragna at the French Space Agency (CNES) have produced an Interferogramme which measures directly the terrain surface displacement field across the fault line (Figure 3a, *160 Mb*). The area covered by this interferogramme is approximately 100 x 150 km. Each fringe of the interferogramme corresponds to movement of 28 mm. This represents an unprecedented level of available information for the study of geodynamics. These measured displacements are in excellent agreement with both in-situ field measurements and the predicted motion from an elastic dislocation model of the Earth's surface for that region (Figure 3b, *160 Mb*).

The group at CNES are continuing to explore geophysical applications of INSAR with ERS-1 through the monitoring of the volcanic site of Mount Etna in Sicily and have recently reported results concerning surface displacement of the volcano and lava emission (see *Nature* Issue of June 95).

The topographic applications of INSAR discussed above are valid provided that there have been no changes between images in the scattering properties of the Earth's surface, eg. due to wind effects, vegetation growth, variations in soil moisture, etc. However, these very effects that corrupt topography can themselves be studied within INSAR by looking at a quantity called coherence; a measure of the average value of the phase difference for small areas within the Interferogramme. Recent research conducted in the group of D. Nuesch at the Remote Sensing Laboratories (RSL) of the University of Zurich shows coherence to be a powerfull tool for land surface classification and change detection.

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and backscatter radiometry for two ERS-1 SAR acquisitions of an area west of Bonn (Germany). In this image, forests appear as dark green, urban areas as bright green or yellow, water as dark blue and agriculture as orange or yellow. Areas where changes occurred appear as green-blue (mechanical cultivation of fields) and pink (variation in soil moisture).

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Finally, the successful launch of ERS-2 earlier this year presents an exciting opportunity to fly both ERS-1 and ERS-2 in tandem as a single Interferometer. The ERS Tandem mission began in September 95 and will last for a period of 9 months. Currently, the two satellites are in both in 35 day repeat orbits (for global coverage) but in a configuration such that there a 1-day interval between ERS-1 & ERS-2 observing the same area of ground. A number of Groups are already reporting high values of interferogram quality (phase coherence) from this 1-day Tandem configuration.

Figure 6 (*345 Mb*) shows an un-wrapped ERS-1/ERS-2 phase interferogramme for the region of Etna in Sicily produced by the group of Ph. Hartl at the Insitiute for Navigational Studies (INS) in Stuttgart. Colour corresponds to the terrain height. In Figure 7 (*242 Mb*), the ERS-2 intensity image is projected on to the resulting DEM.

In conclusion, ERS-1 & ERS-2 deliver the overall performance in terms of platform, SAR instrument and orbit maintenance, required for the application of the INSAR technique.

INSAR provides accurate values of surface height with high spatial resolution and independent of cloud cover. These are significant advantages when compared with the conventional techniques of aerial photography or space borne optical stereo photogrammetry. Preliminary results indicate terrain height errors of less than 10 metres are achievable with ERS.

The capability of ERS to measure centimetre-scale movement of land surfaces through Differential INSAR has been clearly demonstrated for the Landers Earthquake. Interferogrammes of surface motion have also been produced for Anatrtic Ice Flows and some Glaciers. In addition, the use of phase coherence is emerging as promising tool for land surface classification and change detection.

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