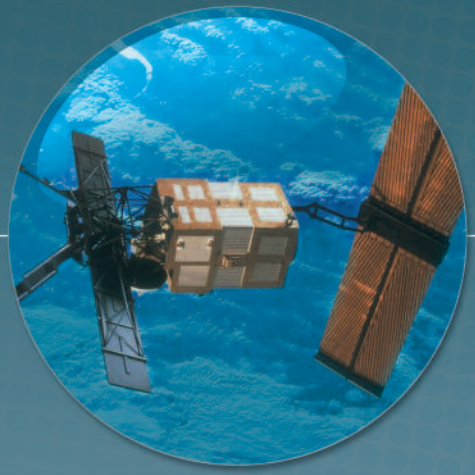
ERS-2 INSAR RESTORED TO LIFE

ZERO-GYRO MODE
AND
TANDEM OPERATION WITH ENVISAT



European Space Agency
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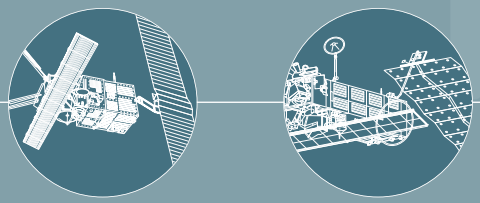
INDEX

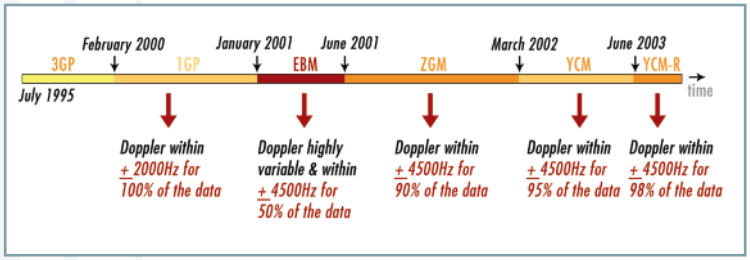
With the degradation of the gyroscopes on ESA's European Remote Sensing platform, ERS-2, the satellite's attitude stability was being impaired to an extent previously thought detrimental to Synthetic Aperture Radar Interferometry (InSAR) applications. Nevertheless, the onboard radar instrument has continued to add data to the long-term C-band SAR archive, which now contains more than 1 petabyte of data. The implementation of new navigational strategies that have partially recovered attitude stability, coupled with the efforts of scientists throughout Europe and beyond to overcome the limitations of the data, has ensured that the ERS-2 mission will continue to provide valuable data until 2011.

This brochure shows how worthwhile ERS-2 InSAR results have been achieved, particularly in the absence of alternative C-band data. Secondly, it looks at the potential for synergy between ERS-2 and Envisat, with examples of cross interferometry performed under dedicated orbit conditions.



ERS-2 has been operating since 1995. Now in its fourteenth year in orbit, it has survived well beyond it's design lifetime and the Active Microwave Instrument (AMI) continues to work well. There is ample hydrazine for continued operation and preventative measures have been implemented to compensate for ageing of the rest of the satellite. Operation is currently approved and foreseen until 2011.

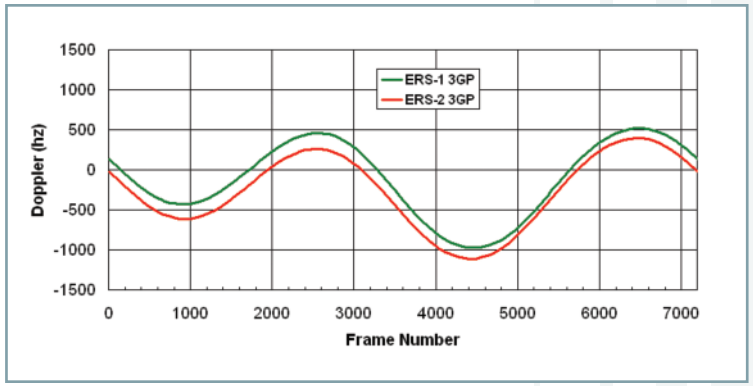
- In the first years of its operation, ERS-2 was piloted in nominal yaw steering mode using 3 out of 6 available gyroscopes (3GP), thus maintaining an extraordinarily stable and predictable attitude (see plot).
- In February 2000, following serious degradation of several gyroscopes, a mono-gyro piloting mode of operation (1GP) was implemented, to ensure mission continuity even in the case of additional gyro problems.



ERS-2 Piloting Modes Timeline.

- In January 2001, the last reliable gyroscopes deteriorated and a work-around solution, developed to pilot the satellite using the Digital Earth Sensor (DES) instead, known as Extra Backup Mode (EBM), was put into practice.
- In June 2001, a new open loop system for attitude control called Zero-Gyro Mode (ZGM) was established. ZGM performance has since been further refined with the implementation of Yaw Control Monitoring (YCM) in March 2002: yaw measurements derived in near-real time from Wave Mode or Scatterometer data are used to automatically correct large attitude deviations - the objective is to maintain yaw values within ±2°. Since the failure of the onboard tape recorders in June 2003, global low bit rate data acquisition is no longer assured, so YCM is now based on a limited set of orbit data, in the so-called Regional YCM mode (R-YCM).

Since its launch in 2002, Envisat's Advanced Synthetic Aperture Radar (ASAR) has provided an alternative source of data for InSAR applications, but the multi-mode nature of its operation limits the number of usable products (i.e. IS2 VV) being added to the archive. Because ERS-2 consistently acquires data with the same geometry and polarisation, it often contributes more to InSAR datasets over particular sites and can be especially useful to resolve user conflicts. Latterly, it functions more in synergy with Envisat, and as a back-up resource.

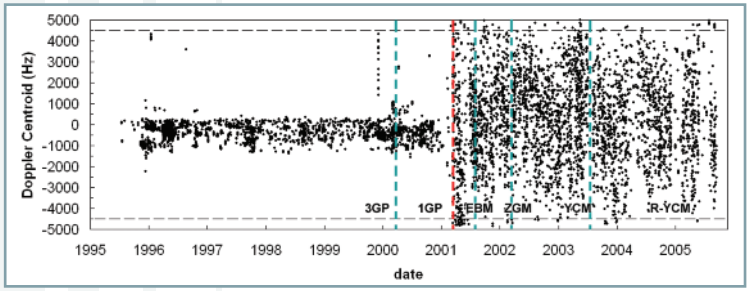


Doppler centroid frequency evolution around the orbit in nominal yaw steering mode (3GP).

To carry out its mission and maximise the use of the data it acquires, ERS-2 must orbit with a steady attitude, so that its instruments can scan along predetermined paths. To this end, the satellite was designed with 6 gyroscopes (2 on each axis) (as well as a narrow-field Sun sensor) to detect the slightest variations in orientation. Such variations are corrected by reaction wheels, which can be set in motion to generate compensating angular momentum, and magneto-torquers, which interact with the Earth's magnetic field.

Gyroscopes are set spinning at the beginning of a mission, but cannot physically spin forever - in fact, many satellites have their operational lifetime determined by onboard gyroscope degradation.

Zero-Gyro Mode piloting is a strategy to prolong the life of ERS-2 by utilising other onboard navigation equipment to quantify pitch, roll and yaw so that these can be maintained according to the stipulated orbit control parameters, even in the absence of reliable gyroscopes. However, the achievable attitude is not as good as for 3GP: whilst 1GP operation had a small but manageable impact on attitude stability, ZGM piloting resulted in more severe degradation of pointing accuracy and hence reduced Doppler centroid frequency consistency (see plot).

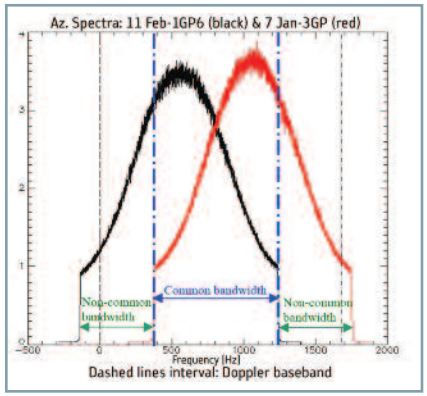


Distribution of the Doppler centroid frequency with time for ERS-2; the attitude was much less stable after the end of the mono-gyro piloting mode (1GP).

Doppler centroid frequency is a key parameter for SAR image processing and InSAR because it establishes the location of the SAR azimuth spectrum (the centre frequency of the image azimuth bandwidth). Very large Doppler centroid frequencies (i.e. >±4 500Hz) are difficult to estimate, requiring correct quantification of the ambiguity number. Errors result in image de-focussing and mis-location in azimuth.

The Doppler centroid difference between potential InSAR pairs determines the common azimuth bandwidth available to make an interferogram. The larger the difference, the smaller the overlap and the worse the InSAR coherence. Total decorrelation occurs when the Doppler centroid difference equals or exceeds the bandwidth (1 378Hz for ERS-2 SLC products).

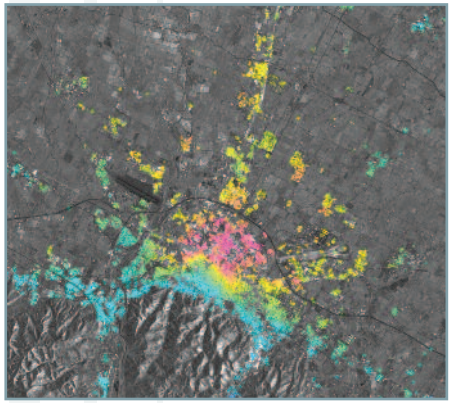
The value of ZGM data can be enhanced by adding more detailed Doppler centroid information, and ESA is in the process of adding such information to the archive of acquired data. Once this information is known, processing can be performed with some data to overcome the limitations of attitude variation. Filtering out the non-overlapping part of the spectra reduces decorrelation, but by reducing the available bandwidth, the azimuth resolution is degraded (inversely proportional relationship). Another solution is to reprocess the raw SAR data pair, focussing with the mean Doppler centroid to maximise coherence; however, some image de-focussing is then inevitable.



Azimuth spectra of two ERS-2 SAR images; only the overlapping bandwidth can be used to generate an interferogram.

Repeat-pass Differential SAR Interferometry (DInSAR) is a powerful technique for mapping deformation. It is ideally suited to subsidence monitoring in urban areas because of the high density of coherent scatterers provided by buildings. The unchanging nature of the urban environment allows coherence to be maintained over longer periods, but this effect is only measurable by DInSAR as long as the conditions of SAR data acquisition do not change. Therefore, to continue benefiting from long-term urban coherence in the ERS SAR archive, ERS-2 ZGM is a crucial source of new data.

The city of Bologna, Italy, is known to be affected by subsidence. The phenomenon is well documented from levelling measurements and has more recently been the subject of SAR interferometry studies. Scientists have used DInSAR to show evidence of subsidence until 2000: significant rates of up to several centimetres per year are most likely to be related to ground-water extraction, although inter-seismic activity may also play a part. Scientists found that the rate of subsidence was decreasing with time, so there was particular interest in continued monitoring of the city to confirm the trend towards stability.



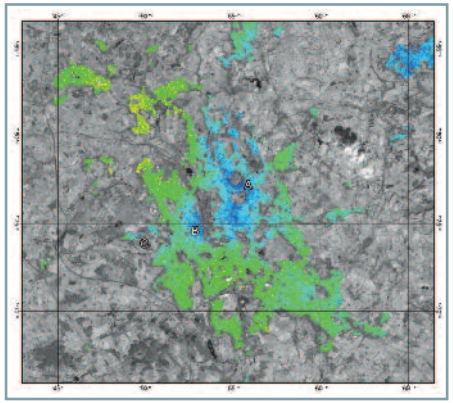
Beyond 2000, ERS-2 ZGM data represent the only source of C-band SAR over this site to allow the continued exploitation of the long-term data archive. Three interferograms comprising one image acquired during 1GP operation in 2000 and one from the ZGM-YCM piloting phase in 2003 were used: the criteria for selecting suitable data pairs from the archive were comparable Doppler centroid frequencies and short spatial baselines.

Averaged interferogram over Bologna, showing the deformation rate for the period June 2000 to December 2003; the distribution of high-coherence urban areas is sufficient to give a good overall impression of the subsidence pattern.

The interferograms were stacked to improve accuracy by reducing the relative deformation rate estimation error caused by heterogeneous atmospheric path delay in the individual products. Subsidence rates are seen to peak at 2.2cm to 2.4cm per year, a lower rate than was observed in studies for earlier periods, thus confirming that the subsidence phenomenon is diminishing.

Stoke-on-Trent in the UK has been affected by a history of coal mining over several hundred years. Subsidence related to undermining, settlement of made ground, alluvial soil compression and salt extraction is countered by elastic rebound from groundwater recharge of disused mine workings. Such phenomena have been measured by previous studies, but DInSAR techniques using recent data would provide an opportunity to efficiently update the latest survey data.

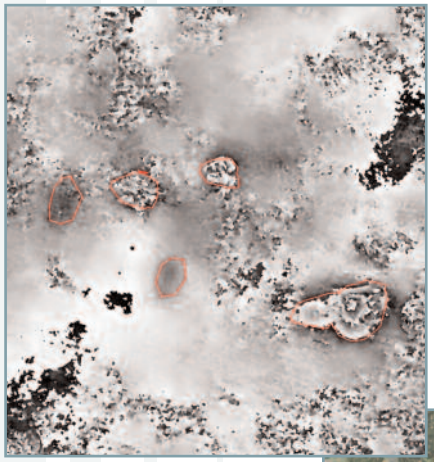
A pair of ERS-2 ZGM images with a small baseline and Doppler centroid frequency difference were used to form an interferogram showing a predominance of uplift features (up to 17mm per year, see A, B and C) which, compared to earlier results, demonstrate a stabilisation whilst highlighting the non-linear nature of the deformation experienced in the region.



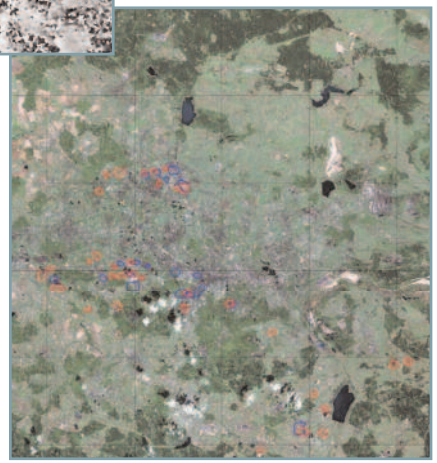
Filtered unwrapped differential interferogram of the Stoke-on-Trent area from October 2001 to February 2003. The deformation has been converted to an annual displacement rate in mm per year in the satellite line-of-sight.

reference: ***GAMMA REMOTE SENSING, Fugro NPA Ltd***

The benefits of the DInSAR technique are particularly appropriate for the study of surface deformation caused by underground mining activity: potentially complex patterns of variable-rate surface movement can be measured continuously and in detail over large areas. Monitoring typically relies on long time series of data, so the contribution of archived ERS-2 data is crucial for such activities.



Filtered differential interferogram of the Sosnowiec area for June to July 2003 showing a number of circular areas of subsidence (typically 50mm or more). Not all of these can be confirmed as mining-related subsidence, and some may be due to decorrelation or atmospheric effects.



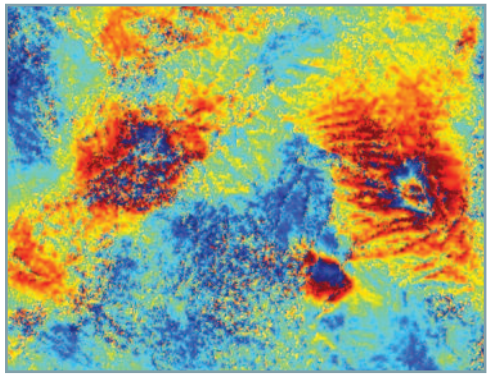
Identifiable mining subsidence features for 35-day periods in 2003 and 2005 overlaid on a Landsat Geocover image (courtesy of USGS). It is evident that the subsidence features have migrated substantially in location in the 2-year period between the interferograms.

Sosnowiec is one of the largest and most important industrial centres in the Voivodeship of Silesia, Poland. Active mining in the area causes localised subsidence that can have major effects on buildings and other structures. Many of the active mines are beneath urban areas and subsidence rates can be as high as 10-20cm per year, posing a serious threat to the public.

ERS-2 SAR data pairs from the archive that fitted the selection criteria of short temporal separation (35-70 days), suitable perpendicular baseline (< 300m) and suitable Doppler centroid frequency difference were processed, taking account of possible ambiguities in the annotated Doppler centroid frequency. The results can be used to analyse the impact of the mining activity.

El Bages is located in the central part of Catalunya, Northeast Spain. The area is influenced by underground potassic salt mining.

Two ERS-2 image pairs were selected to make interferograms, based on low Doppler centroid differences. Despite the vegetated mountainous terrain in the study area, pairs with short temporal baselines still demonstrated sufficient coherence to yield results, which show maximum deformation of about 3cm per month.

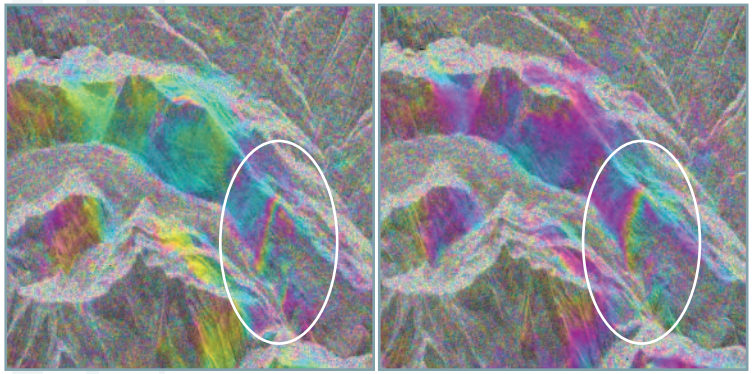


Interferometric displacement patterns for April to May 2005 at El Bages.

reference: ***Fugro NPA Ltd, ALTAMIRA INFORMATION***

Landslides and rockslides are natural hazards with potentially severe human and economic consequences. In Alpine regions, the decline of permafrost and retreat of valley glaciers leads to increased slope instability. Therefore, efficient surveying of unstable slopes in these regions is increasingly necessary. Under favourable circumstances, DInSAR is a powerful tool in this domain and ERS-2 ZGM data can make an important contribution to motion rate histories.

A landslide above the Aletsch Glacier, Switzerland, has been monitored since 1993 using a combination of ERS-1, ERS-2, JERS, Envisat and ALOS DInSAR. Measurements since 2005 (from Envisat and ALOS) show much higher rates of movement than those before 2001 (from ERS-1/2 and JERS); knowledge of what occurred in the intervening period is therefore crucial to properly understand the evolution of this feature: ERS-2 ZGM data are a valuable resource to close this temporal gap.

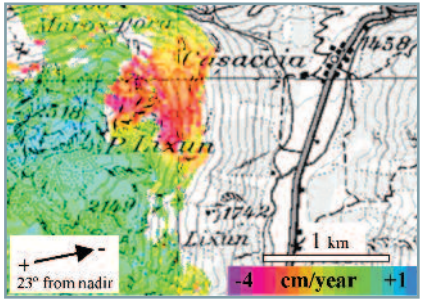


ERS-2 interferograms of Aletsch Glacier landslide: September 2002 to August 2003 (left) and August 2003 to July 2004 (right); white ellipses mark slope instability which, once quantified, is added to the multi-sensor time series plot (circled in red).

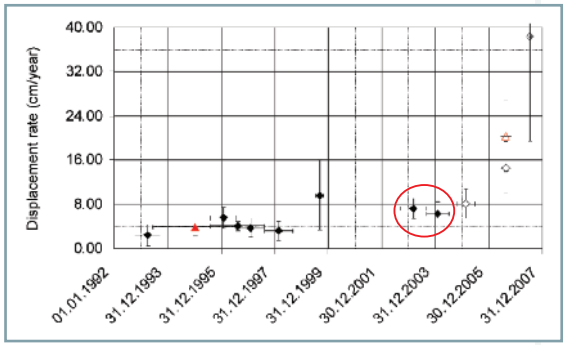
Two consecutive interferograms were processed using three ERS-2 ZGM-YCM images selected from the archive. The average displacement rates for the landslide, derived from interferograms of 2002-3 and 2003-4, were plotted onto a time series including all measurements. Hence, it can be concluded that the displacement rate did not accelerate significantly until after 2005.

Coherence in Alpine territory is typically good due to characteristically low or absent vegetation. However, seasonal snow cover causes decorrelation, and areas of very rugged terrain can cause other technical difficulties.

In an example in the Bregaglia region of Switzerland, an ERS-2 ZGM interferogram over a deep-seated rock mass movement shows that it is very limited in extent, but nevertheless confirms a relatively constant displacement rate for the feature of about 4cm per year in the line-of-sight direction.



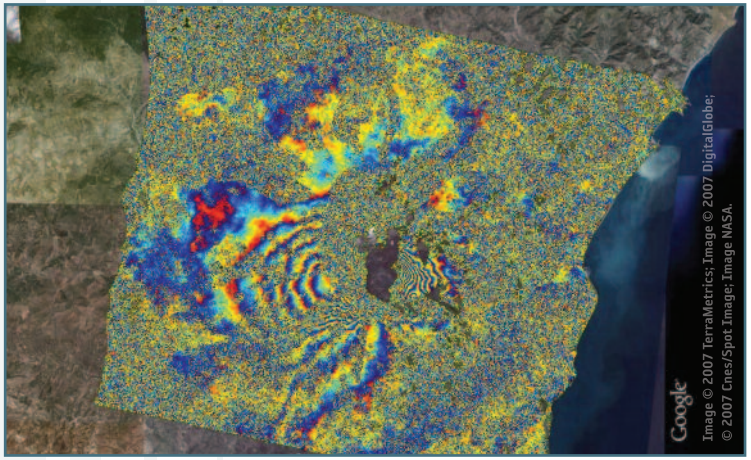
ERS-2 interferogram of June 2003 to August 2004 over Piz Lizun, Bregaglia, Switzerland (perpendicular baseline 24m) showing instability on the valley side.



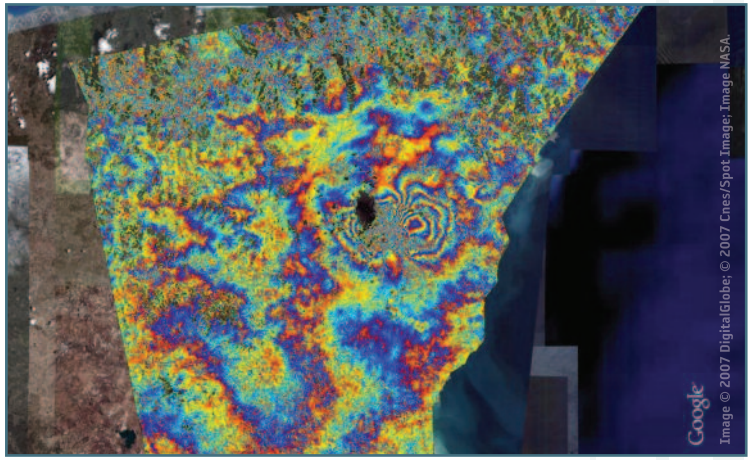
Surface deformation monitoring is an essential component of volcanology. The surface movements observed are an important input for risk assessment, a vital task where volcanoes pose a threat to human populations. The temporal development of volcanic deformation is crucial; identifying acceleration and deceleration is key to predicting eruptions. Therefore, a series of regular and frequent SAR data acquisitions is required for DInSAR studies, and ERS-2 ZGM data are essential for studies of volcanoes that have been active since 2001.

Mount Etna, in Italy, already the subject of many InSAR studies prior to 2001, erupted in 2001 and again in 2002-3.

Using data carefully selected from the ERS-2 archive, it has been possible to perform DInSAR processing on ascending as well as descending images, thus allowing both sides of the volcano to be studied. Interferograms were generated using both 1GP-ZGM and ZGM-ZGM pairs. The results show spectacular evidence of the changing shape of the mountain before and then during and after the eruptions.



A 560-day interferogram on a descending orbit showing deformation between April 2000 and October 2001.

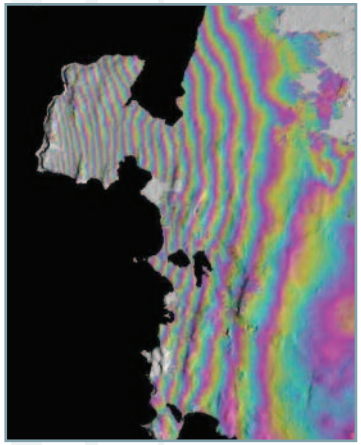


A 35-day interferogram on an ascending orbit showing co-eruptive deformation between July and August 2001: there is excellent coherence despite both images having been acquired in ZGM.

DInSAR has long been associated with earthquake studies. Among the most useful results are co-seismic interferograms (obtained from images acquired just before and after the earthquake), which allow ground deformation that occurred during the event to be differentiated from pre- and post-seismic motion; such interferograms should have short spatial - as well as temporal - baselines. For all earthquakes that occurred after 2001, ERS-2 ZGM data therefore represent an important resource for seismologists, if the baselines and Doppler centroid differences are favourable.

A magnitude 8.0 earthquake occurred along the South American subduction zone near Pisco, Peru, on 15 August 2007, causing the loss of more than 500 lives. The earthquake was very well imaged by the Envisat, ERS-2 and ALOS satellites. ERS-2 imagery is of particular importance because data were acquired rapidly - just 2 days after the earthquake.

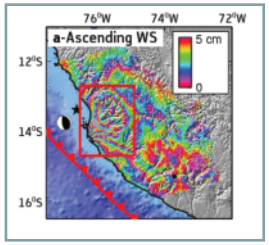
Paired with an archive image acquired on 18 February 2005, an ERS-2 interferogram with a baseline of ~150m was generated. It exhibits a very clear set of fringes defining the co-seismic deformation in the region, which has allowed the frictional properties of the fault surface to be analysed. This interferogram was quickly made available to the community and used to focus subsequent scientific studies of the earthquake.

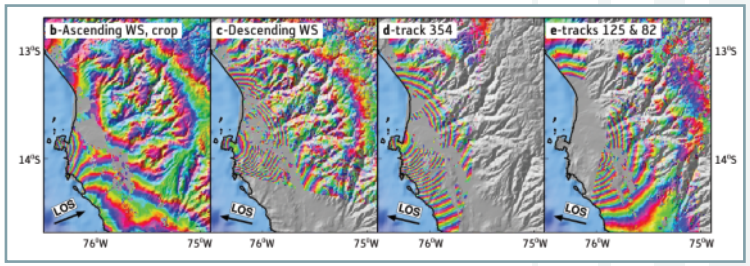


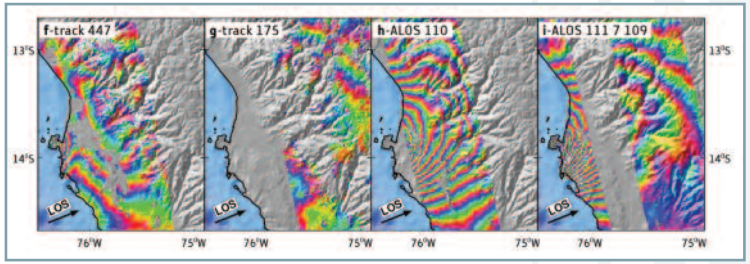
Interferogram of Pisco earthquake derived from ERS-2 data acquired on 18 February 2005 and 17 August 2007. The Doppler centroid difference was close to zero and the perpendicular baseline approximately 150m.

Integrating the ERS-2 interferogram (sub-image 'f') with those generated from other available data, a better picture of the seismic event can be built up by analysing deformation patterns over different intervals.

Interferograms from 3 satellites of the 15 August 2007 Magnitude 8.0 earthquake near Pisco, Peru. Each colour cycle corresponds to 5 cm of ground motion in the line-of-sight (LOS) of the sensor (shown as an arrow). Image 'a' shows an ascending Envisat ASAR Wide Swath interferogram of the wider region: the red box shows the extent of images 'b' to 'i'; the oceanic trench (red barbed line), focal mechanism, and hypocentre (from USGS, black star) are also shown.



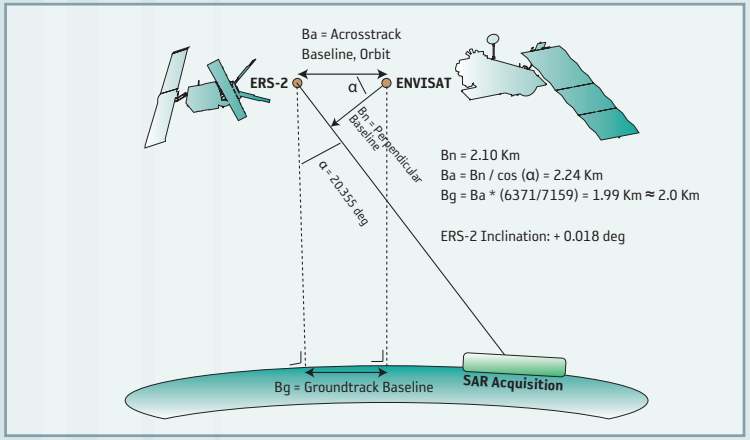




reference: ***Cornell University, CSTARS***

Notwithstanding the limitations of ZGM piloting, the continued operation of ERS-2 provides a unique opportunity to manage the platform in close cooperation with Envisat. Since its launch in 2002, Envisat has been piloted in the same orbit just 28 minutes ahead of ERS-2, providing the opportunity to exploit the synergy between the instruments on these two platforms, particularly for SAR cross interferometry with a very short temporal baseline. Such exploitation of ERS-2 data is only possible with reliable Doppler centroid information, plus a spatial baseline in the order of 2 000m.

To maximise the number of acquisitions of 28-minute SAR pairs suitable for cross interferometry, the two platforms were piloted in carefully controlled orbits during the ERS-Envisat InSAR Campaign between 27 September 2007 and 12 February 2008. During this period, perpendicular baselines of ~2km were routinely achieved, allowing the slight difference in carrier frequencies between the two instruments (31MHz) to be compensated.

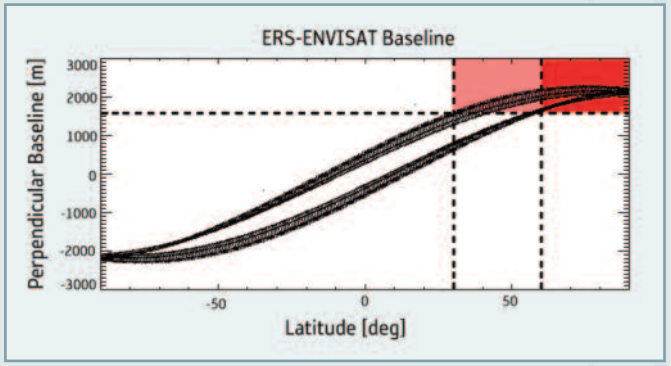


Geometry of ERS-Envisat tandem operation.

This dedicated campaign extended the ESA InSAR mission into new application domains, offering the potential to measure the velocity of fast moving glaciers (>200m per year, i.e. a shift of 1cm between acquisitions) and generate very accurate low-relief Digital Elevation Models (DEMs, e.g. in river deltas). The results are also helping to improve general understanding of interferometry and coherence.

Owing to the necessary configuration of the orbits of ERS-2 and Envisat, the InSAR Campaign favoured northern hemisphere mid and high-latitude areas by acquiring suitable data between 60°N on the ascending limb and 30°N on the descending limb (see plot), thus providing opportunities for ERS-Envisat cross interferometry over Arctic Polar regions and Europe, North America and most of Asia.

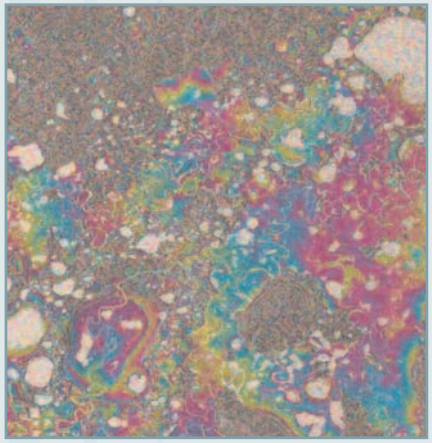
With the technique for handling the carrier frequency difference between ERS-2 and Envisat established, it can be assumed that, when ESA's next SAR mission, Sentinel 1, begins, a similar approach could be adopted to integrate the new data, acquired at 5.405GHz, into long time series.



Baseline evolution during the ERS-Envisat InSAR Campaign.

The short temporal baseline and unique viewing geometry of data from the ERS-Envisat InSAR Campaign provide opportunities to generate high quality interferograms from which precise DEMs can be derived over relatively flat areas that may not have been well represented with other interferometric techniques. The results can be an improvement on Shuttle Radar Topography Mission (SRTM) DEM products in terms of vertical resolution and noise, and, indeed, beyond 60°N, may represent the only source of recent satellite-derived elevation data.

The high phase-to-height sensitivity of interferograms with ~2 000m baselines gives an altitude ambiguity of around 5m, resulting in many fringes on even relatively gentle slopes. Where the relief becomes too great, the range reflectivity spectra become non-overlapping and the technique breaks down. Unlike classical ERS Tandem InSAR (with typically very short spatial baselines), in which the coherence of urban areas is very good, urban and forested areas in ERS-Envisat Cross InSAR decorrelate because the very long spatial baseline results in dramatically different volume scattering responses from different viewing angles.

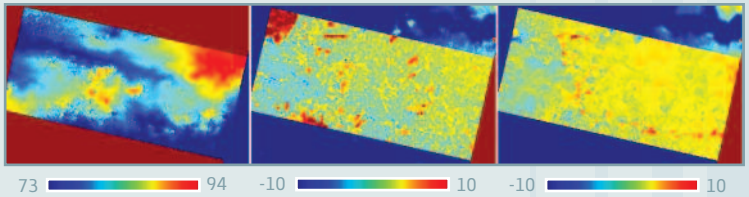


ERS-Envisat interferogram of wetland region of Siberia.

Yamalo Nenetsky in Northern Siberia, at 70°N, is beyond the coverage of the SRTM DEM. An ERS-Envisat Cross InSAR pair covering this flat wetland area was acquired in October 2007 and processed to evaluate the potential for DEM generation. Because of the small altitude ambiguity in the interferogram (5.3m, due to the long baseline of 1 740m), strong phase variations are seen in the hilly areas around the wetland, whilst even small hills exhibit many fringes. In the flatter central area, phase changes are more gentle, indicating height variations of less than 10m. For these areas, it would be easily possible to derive a DEM, which could be of high value for wetland studies in this remote region.

The lakes in the image have high backscatter but low coherence due to the roughness of their frozen surfaces, which causes significant differences in the backscatter from different viewing angles.

For a relatively flat area around Moissy-Cramayel in Île-de-France, southeast of Paris, the DEM derived from an ERS-Envisat Cross InSAR pair acquired in December 2007, with an effective resolution of 25m, compares favourably with equivalent products from the SRTM (90m resolution) and Institut Géographique National (IGN) of France (25m resolution). As elevation difference maps show, standard deviations of 2.56m and 1.58m were achieved respectively.



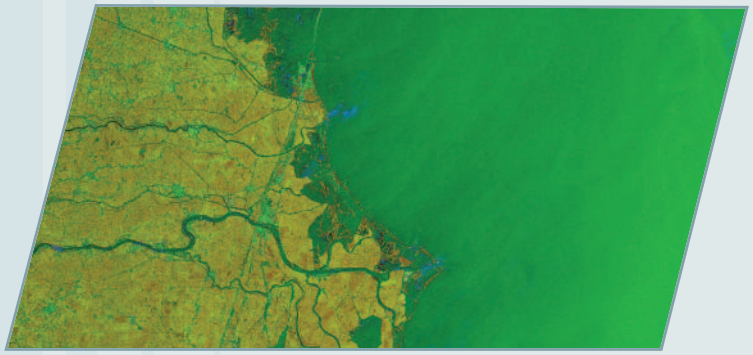
(left) DEM of an area near Paris derived from ERS-Envisat Cross InSAR; elevation difference maps comparing Cross InSAR data with products from (centre) SRTM and (right) IGN.

ERS-ENVISAT CROSS INSAR EXAMPLE: COASTAL DEM

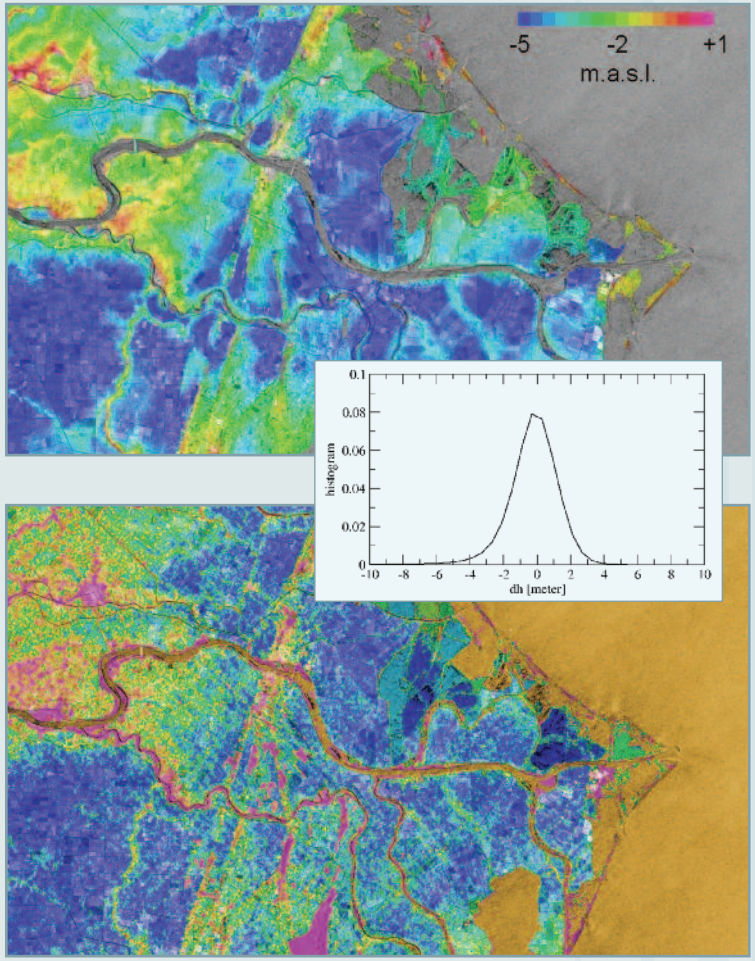
Low-lying coastal areas are especially vulnerable to sea level rise, and a difference in elevation of tens of centimetres could mean the difference between catastrophic flooding and comparative safety. There is therefore growing demand for precise maps of such regions, for flood defence planning and disaster mitigation. ERS-Envisat cross interferometry works very well in flat areas because of its high phase-to-height sensitivity, so Cross InSAR products are well suited to the generation of extremely precise DEMs in coastal areas.

A DEM of the Po Delta, Italy was generated from an image pair acquired during the ERS-Envisat InSAR Campaign in November 2007. A zoom of the unwrapped output shows the fine spatial resolution and sensitivity to slight variations in elevation. Comparison with the equivalent SRTM DEM (90m resolution) shows very good height correspondence, with a standard deviation of ~1m (see plot), and less noise.

As with classical ERS Tandem InSAR, coherence information from ERS-Envisat Cross InSAR can be used to make a colour composite that gives information about land cover (Interferometric Land Use product - ILU).



Coherence product for the Po Delta showing coherence, backscatter and backscatter ratio (RGB).



DEM of the Po Delta, Italy, from ERS-Envisat Cross InSAR (above) and the SRTM product (below); area covered 50x30km; colour scale the same for both images, magenta areas in the SRTM DEM represent urban/forested areas whose surface exceeds 1m.a.s.l. (decorrelated in ERS-Envisat DEM).

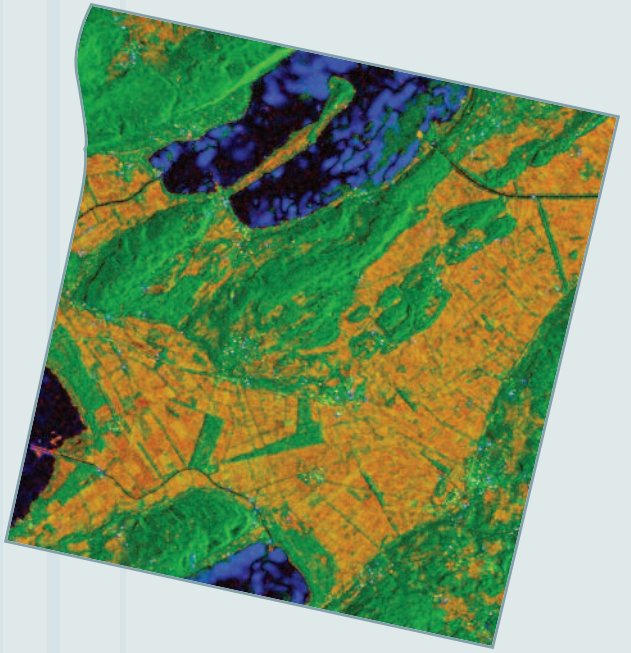
reference: **GAMMA REMOTE SENSING**

Coherence in ERS-Envisat Cross InSAR using very long baselines behaves differently from that computed from conventional InSAR. Due to the large difference in viewing angles, geometric decorrelation occurs more readily over volumetric scatterers. Therefore, in areas of low relief where the range spectra overlap, Cross InSAR coherence can be used as an indicator of land cover structure and, in combination with other SAR image derivatives, contribute to land use or biomass classifications.

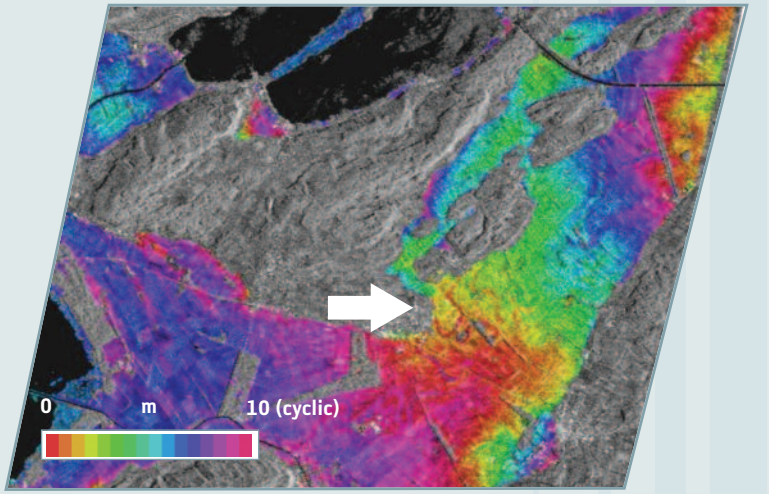
Seeland is a relatively flat region of Switzerland characterised by fertile soils and intensive agriculture. The coherence for an image pair acquired during the ERS-Envisat InSAR Campaign in October 2007 was studied to identify any correlation with land cover. Coherence was high (>0.8) over flat fields and almost completely decorrelated over 20m tall forests. A set of fields with intermediate coherence values (~0.5) was identified and these were found to correspond with crops of maize, which would be unharvested and about 2.5m tall at the time of the image acquisitions.

A false-colour composite of coherence, backscatter and backscatter ratio (RGB) further highlights differences in land cover characteristics.

Analysis of the interferogram derived from this image pair revealed some interesting linear depression features. Further investigation suggests that these correspond to ancient river beds. Indeed, several water courses were redirected to reduce the problem of inundation in the 18th Century, although floods still occur after unusually heavy rainfall. The high level of detail available in ERS-Envisat Cross InSAR DEMs could make a valuable contribution to flood risk assessment in this flat region, and to planning for disaster mitigation.



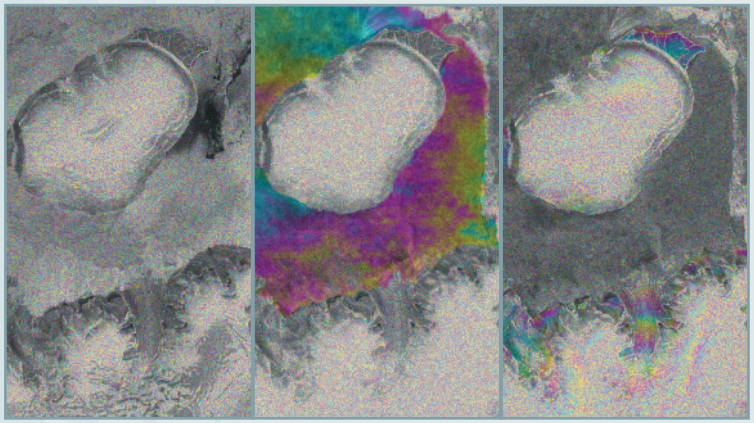
Coherence product, showing coherence, backscatter and backscatter ratio (RGB), for Seeland, Switzerland.



ERS-Envisat interferogram showing linear features associated with ancient river beds (white arrow).

InSAR and Tandem InSAR have been used to measure glacier motion in the past, but the ERS-Envisat InSAR Campaign offers the first opportunity to monitor very fast flowing glaciers from space, with the potential to quantify displacements of around 1cm during the 28-minute interval between passes. Using techniques to separate the deformation and topographic components of phase, it should be possible to map the velocity fields of rapid Arctic glaciers and derive the height of their moving surfaces.

In an example from Franz Joseph Land, Russia, two ERS-Envisat Cross InSAR pairs were available for processing. Comparison of the separate results show the growth of sea ice from September 2007 (day 2 of the InSAR Campaign), when small, isolated patches of coherent ice can be discerned (with fringes indicating motion), until December 2007, when most of the sea is covered by rather stable ice (smooth, flat phase).

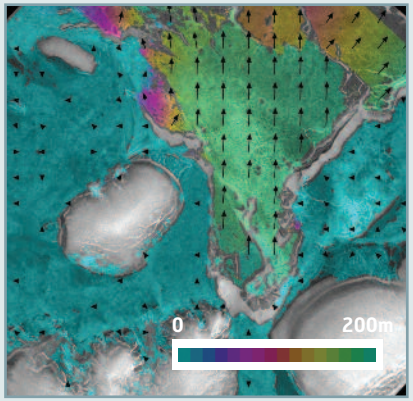


ERS-Envisat interferograms of Franz Joseph Land: September 2007 (left); December 2007 (right); combined interferogram (December minus September), showing topography in areas of low relief.

In the absence of a suitable DEM, topography can be extracted from the two interferograms by differencing them, thereby cancelling temporal phase shifts (assuming constant deformation rates) and leaving only the topographic phase associated with an 'effective' spatial baseline (equal to the difference between the two original baselines). The resultant combined interferogram can be unwrapped, scaled to match the original baselines and used as a model to remove the effect of topography from the original interferograms, leaving the phase due to motion alone. It can also be used to measure the height of moving surfaces (e.g. glaciers) without the complication of the temporal phase component.

In this example, the effective baseline is less than 50m, resulting in a fringe density that is too low to be effectively scaled up. Nevertheless, the flat areas of terrain close to the shores and the surfaces of the glaciers do exhibit fringes, and these could be unwrapped and used to derive height values.

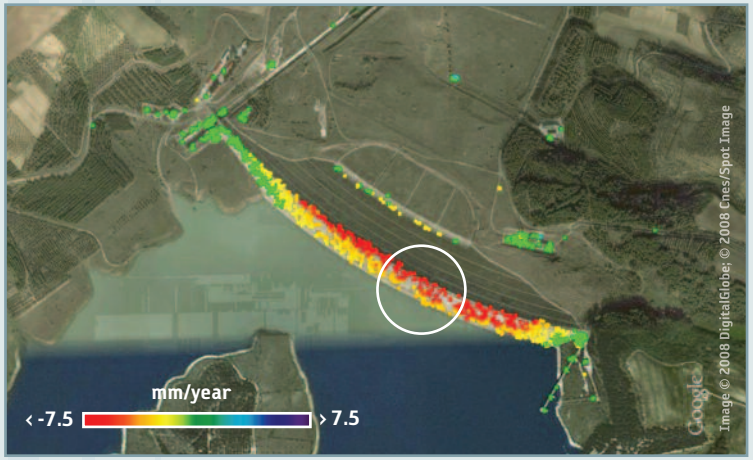
Using offset tracking techniques that do not rely on specific baseline or Doppler centroid parameters, it was possible to exploit the very short temporal interval between the images acquired in December to generate a sea ice displacement map. This shows a maximum shift of 160m during the 28-minute period in an area to the North-east that decorrelated in the interferograms.



Geocoded sea ice displacement map; the green areas correspond to an observed displacement of about 160m in 28 minutes; the image brightness corresponds to the backscattering of the Envisat image.

The Persistent Scatterer Interferometry (PSI) methods are a group of innovative technologies that enable the relative position of (usually) bright targets to be measured in the direction of the satellite line-of-sight with millimetric accuracy. These Persistent Scatterers retain their phase and amplitude stability over a period of months or years, and the information they provide can be exploited even with long temporal baselines that would cause decorrelation in conventional interferometry. PSI analysis, based on long time series of data, is reliant upon good quality ERS data as well as the integration of Envisat data for its continuation into the future.

ERS-2 ZGM data with strongly deviating Doppler centroids cannot normally be included in PSI time series; however, acquisitions with Doppler centroids similar to the rest of the time series can be integrated into the analysis, once these are identified.



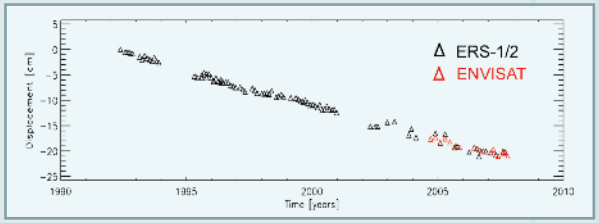
Mean deformation velocity map of the Lake Locone Dam, showing movement away from the satellite at at least 7.5mm per year; the deformation history of a single point derived from ERS and Envisat SAR data is shown in the plot.

Any data that can be used to populate datasets beyond 2001 will improve the robustness and reliability of the PSI approach, particularly for intermediate and high-rate deformation phenomena (i.e. >1cm per year), and help to complete otherwise sporadic time series.

In combination with Envisat data, ERS-2 may also improve the temporal sampling of time series, or help to resolve user conflicts where a commitment to acquire time series (i.e. image the same scene on every repeat cycle) would mean restricting the potential for acquiring data in other operational modes or using different viewing angles.

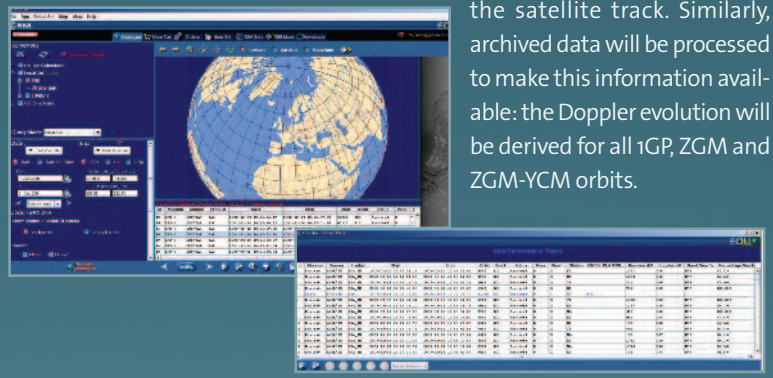
In an example from southern Italy, PSI analysis incorporating 94 ERS and 16 Envisat images of Lake Locone acquired between 1992 and 2007 was used to map mean deformation of a dam towards and away from the satellite. The results, achieved in collaboration with the Italian Civil Protection, clearly show that part of the dam is subsiding; time series for individual points show that the deformation has been quite constant over the last decade and a half. The ability to accurately and efficiently monitor dam structures is of enormous benefit where catastrophic failure would cause human disaster. As dam construction becomes increasingly ambitious, this application is likely to grow in importance.

Close inspection of the time series confirms that, using the Small BAseline Subset (SBAS) technique, ERS-2 ZGM data and Envisat products can be seamlessly incorporated into PSI analysis and exhibit comparable variability, thus enabling the deformation to be monitored over the whole period of interest and into the future.



To support the user community, ESA has taken a number of initiatives to facilitate the exploitation of ERS-2 ZGM data and ERS-Envisat synergy.

To assist users in the identification of ERS-2 data still suitable for InSAR, the Doppler information must be readily available for interrogation during data searching. To this end, newly acquired ERS-2 SAR data are now routinely processed into IMM products (now available from the new PGS processor), so that the Doppler evolution around the orbit can be extracted: Doppler centroid values are sampled every nine seconds along the satellite track. Similarly, archived data will be processed to make this information available: the Doppler evolution will be derived for all 1GP, ZGM and ZGM-YCM orbits.



Doppler frequency values are visible in the ESA multi-mission catalogue, EOLI-SA and in an interactive Doppler frequency query tool available online. Thus, the attitude uncertainty of ZGM data ordering is being reduced.

Doppler screening of the ERS-2 archive is a time-intensive process: work began in September 2007 and is expected to last 18 months, but to ensure that users are served as efficiently as possible, a prioritisation exercise was instigated to determine key applications and geographic areas in which to target data reprocessing.

In addition, EOLI-SA now fully supports ERS-Envisat cross interferometry, including a baseline query tool.

To view Doppler Frequency Values enter in EOLI-SA at:
http://earth.esa.int/resources/catalogues

- *For information or support contact:*

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> *ESA acknowledges the contributions to this brochure from these leading organisations, all of whom are committed to future exploitation of the ERS-2 InSAR mission, now that it has been restored to life.*