Fringe 2005 Session Summaries

The Fringe 2005 Session Summaries have been prepared by the session chairpersons, and are grouped as follows:

- Thematic Mapping and DEMs
- Methodology: General
- Methodology: Longterm DInSAR and Terrain Motion (combined summary)
- Methodology: Advances in PSI (Persistent Scatterer Interferometry)
- Ice and Snow
- Volcanoes
- Earthquakes and Tectonics
- Landslides
- Future Missions

Thematic Mapping and DEMs Session Summary

(by Jörn Hoffmann and F.M. Seifert)

Summary based on Seed Questions

1. *Are SAR and InSAR-based damage maps reliable enough to use operationally?*
    a. *What are their fundamental limitations?*
    b. *What (possible) future missions could serve this application better (other repeat cycles, radar frequencies, resolutions, mission operations, etc.)?*

- The reliability of damage mapping using coherence has yet to be tested for a variety of cases.
- Coherence cannot be interpreted at the pixel level, but only in regions. Spatial resolution is therefore viewed as a critical factor in future missions to support this application.
- The flexibility of the data acquisitions is critical to this application.
- Short revisit times are needed!
- Using different platforms in parallel can improve response time.
- Polarimetric data might improve damage classification accuracy.

Recommendations:

- ESA should define a procedure to submit last-minute acquisition requests, e.g. after a disaster, so the necessary data are acquired.
- Make InSAR-data available under Charter context.
- Datasets should also be made available for some events not covered by Charter (who defines them?)

2. *What potential do repeated InSAR-DEM acquisitions have for monitoring surface changes over different types of terrain?*
    a. *Can they substitute repeat-pass InSAR observations where these fail due to temporal decorrelation?*
    b. *What contributions can we expect from planned missions (ALOS, TerraSAR-X)?*

- Repeated DEMs are rarely accurate enough to use as a measurement tool – SNR too low.
- Only a single-pass system can avoid atmospheric error and achieve the needed accuracy to interpret differences at a small level.

3. *What limits the positioning accuracy of Permanent Scatterers?*
    a. *What are the effects of multiple strong scatterers in a single resolution cell, "extended" point scatterers, strong sidelobes, and other difficulties?*
    b. *Can we expect new possibilities from the planned missions using different radar frequencies?*

- Larger baselines are needed to improve positioning accuracy
- However, many other applications require smaller baselines, so relaxing the baseline control is not unanimous
- Future systems should employ the largest possible bandwidths to enable both, high positioning accuracy and maintaining coherence over larger baselines

Recommendation:

- The ENVISAT baselines should be maintained at least at the level they currently are.

4. *What is the relative importance of volume and temporal effects in decorrelation over forested areas?*
   a. *How robust is biomass estimation over forests using C-band SAR?*
   b. *Which experimental setup (e.g. radar frequency, temporal baseline) would be best suited for this application?*

- Biomass estimation works for boreal forests, but must be adapted for other forest types.
- The effects of volume decorrelation are understood sufficiently to be modelled – the temporal effects are the limiting factor.
- Therefore, short revisit times are the most critical aspect to ensure that the decorrelation can be interpreted reliably.
- More recent data are needed – the ERS archive is getting old.
- Substantial experience with biomass mapping only exists for C-band, but longer frequencies may be better suited, particularly with respect to tropical forests.

General comments "Thematic Mapping and DEMs"

- ALOS data should be investigated with respect to its potential for thematic InSAR applications
- Make use of the ALOS AO (open until December 19th).

Recommendation:

- Full-resolution SAR data should be disseminated online for quicker and more convenient access.

Methodology: General Session Summary

(by R. Bamler, R. Hanssen, A. Monti Guarnieri and C. Prati)

Overview

5 papers on atmospheric modelling, measurement, and correction:

- from InSAR data itself
- auxilliary data (GPS, MODIS, MERIS)

Results on troposphere:

- Optical instruments are either non-simultaneously to SAR, or/and limited to sufficient daylight and cloud-free conditions.
- GPS is cloud-independent but limited in resolution and worldwide availability.
- A part of the non-turbulent tropospheric delay is vertical stratification, this is correlated with topography and can be compensated using a low-res atmospheric model + high-res topography.

Result on ionosphere:

- Estimation of ionospheric small-scale features should be possible with high bandwidth L-band SARs by exploiting the difference of phase and group delay.

4 papers on multi-baseline InSAR:

- 3 on high-precision 3D location incl. spectral stitching as a special case.
- 1 multi-baseline presentation on natural targets

Result:

- For a typical ERS/ENVISAT 50+ scenes configuration and +/- 1 km baseline spread the 3D location accuracy/precision is in the order 1 m3.
- Semi-permanent distributed scatterer can be exploited similarly as PSI

2 papers on ScanSAR interferometry:

- ESA is working out a procedure to maximize burst overlap for ASAR wide swath acquisitions
- The properties and processing of the new WSS complex product shown.
- Examples over Bam shown.
- WSS data are ready to be used by community

1 paper on orbit accuracy:

- Experience with dual frequency D-GPS on GRACE.
- Baseline accuracies in the order of 1-2 mm for constellations like TanDEM-X achievable

Answers to Seed Questions

1. *Accuracy of InSAR results and ability for rapid mapping requires the reduction of the number or "nuisance parameters" to be estimated/adjusted. How can the influence of these parameters (orbits, ionosphere, atmosphere) be mitigated or eliminated?*

   - Use physical models and auxiliary data as much as possible.
   - Use frequent temporal sampling for stochastic mitigation
   - ESA should perform technical study on WV corrections (radiometer solutions?)

2. *Multibaseline techniques for 3-D imaging of natural or man-made objects are becoming increasingly interesting. The boundaries between InSAR, PSI, and tomography are no longer well defined. Is our modelling of the scattering processes (1st Born approximation) sufficient for progressing in this area or do we need more complicated models?*

   For present resolution we can use Born's Approximation (except for double-bounce). For higher resolution we need better models. Complementary research in forward modelling is required in order to understand our results.

3. *Urban DEM: Which is the contribution of InSAR (standard/multibaseline/PSI)? How it compares/integrates with other techniques (Photogrammetry, Lidar etc.)? What is the best parameters combination (angles, wavelengths, baselines etc.)?*

   Low compared with LIDAR and photogrammetry. But InSAR is necessary for highly accurate geolocation of PS and for rapid change detection and emergency.

4. *Is there a way to integrate all the available multi-temporal/multi-baseline techniques to get elevation and motion measurements from the largest number of scatterers?*

   Yes, using a priori and measured models.

5. *Clutter-to-noise ratio, signal-to-noise ratio and resolution: which one is the driver for new InSAR, DEM, or PS oriented missions, be them constellations or repeat pass? What is the lower bound for the SAR antenna length/width? What are reasonable figures for these parameters?*

   Priority is short revisit time. High resolution is essential, but azimuth and range ambiguities must be under control. Long wavelengths are preferred, e.g. to mitigate Phase Unwrapping problems.

6. *Camera and SAR: can we suggest combined missions that integrate a Camera and SAR sensor? What would be the optimal (cost-effective) design of the SAR sensor in this case?*

See answer for seed question 3

Methodology: Long-Term DInSAR and Terrain Motion Session Summaries

(by A. Arnaud, R. Lanari and J. Mallorqui)

Summary based on combined Seed Questions

1. *Which is the accuracy of the deformation measurements we can obtain from a long-term DInSAR analysis? How accurately can we monitor terrain motion with DInSAR analysis?*

    - There is ***not a unique answer*** as it ***depends on so many factors.***
        - SAR Processor, interferometric chain (orbit calculations, co-registration, …), DInSAR processing (phase unwrapping, models, …).
        - All the processing parameters/thresholds that can be adjusted on the different algorithms.
        - How suited is the dataset (temporal sampling) to the deformation to monitor.
    - We have to distinguish between ***precision*** (number of relevant digits) and ***accuracy*** (how close we are to the true value) of the results.
        - ***Theoretical precisions/accuracies*** could be ***analytically estimated*** considering the different sources of errors, despite some of them (like phase unwrapping) can not be modelled on the classical way of error propagation.
        - Two products are usually delivered:
            - Linear Velocity of Deformation, possible to perform the study.
            - Times Series, too many parameters for a theoretical study.
        - ***Empirical Precisions/Accuracy*** can only be obtained with a ***significant amount of ground-truth and a very accurate validation.***
        - ***PSIC4*** is the first step but probably other test-sites would be necessary.
    - ***Final users*** really ***demand a magic number to which rely.***

2. *Which are the weak points of the DInSAR processing chain for long-term monitoring? How they can be overcome? Key points in pixel selection, interferogram selection, phase unwrapping, atmospheric artefacts estimation, etc.?*

    - Agreement that ***phase unwrapping is the most difficult part*** as it is not possible to define a *propagation error function.*
        - In addition, the unwrapping of the residual phases is much more difficult than in classical InSAR as the errors are not as evident as when generating a DEM.
    - ***Coupling between atmospheric artefacts and non-linear deformation*** is also difficult to separate.

3. *How much long-term DInSAR applications benefited from the integration of ERS and ENVISAT SAR data?*

- The continuity of the long-series of data started with ERS has been "ensured" with ENVISAT.
- The level of integration depends on the different methodologies:
    - Basic approach based on subsets.
    - Real integration using cross-interferometry.

4. *Which additional data types (non SAR) are required for increasing the effectiveness of long-term DInSAR techniques?*

- No specific type of data has been mentioned during the discussion, neither meteorological ones.
- Validation data over several test-sites will indeed help the community to detect unknown or difficult to see errors on their processing chains.

5. *What are the operational and research need for long-term monitoring via DInSAR approaches? How far from an "operational" status we are?*

6. *What would be an optimum configuration for a SAR sensor to be developed for long-term DInSAR applications? How far we are from a DInSAR dedicated mission?*

- With ENVISAT we are still "far" away.
- The "optimum" configuration has to be decided because ask for "as much as possible" is not allowed. Values of:
    - revisiting time/images per month,
    - high resolution and/or wide swath capabilities,
    - baseline and Doppler distributions (small, medium or large),
    - polarimetric capabilities, full or light polarimetry
    - bands (L, C, X), …
- There is some agreement on having L-band sensors for Long-Term DInSAR.
- Geosynchronous sensors are still "science fiction".

7. *Could a polarimetric and/or multi-incidence angle sensor improve the performance of single polarization DInSAR?*

- Trade-off problem of *what I want to gain* and *what I accept to lose.*
    - Multiple modes generate conflicts among users and a reduction on the number of archived images over a zone of interest.
    - But also means new opportunities for experimentation.
- Polarimetry can be a future requirement for its potential benefits, mostly on L-band.
    - As usual benefit/cost has to be evaluated, for instance experience from RADARSAT2 and TERRASAR-X will help.

8. *There is also some consensus on granting "free" and easy access to large amounts of data for the scientific community.*

- *Free* can be replaced with *Low-Cost.*
- Some free evaluation datasets with validation data, similar to PSIC4, can be an intermediate option.

9. *What (information) would the final users like to obtain from DInSAR data?*

- No users were present or liked to answer.
- The ***PSIC4 validation consortium can provide valuable information*** about this point.

10. *How do we see complementarities between classical DInSAR and PSI?*

- In practice both are fully integrated and PSI is a logical evolution of classical DInSAR.

11. *How non-linear movements are assessed?*

- Nothing is linear or almost linear after a long period of time.
- More sophisticated models seem to be necessary, but the adjustment of large number of parameters is not an easy task.

Methodology: Advances in PSI Session Summary

(by R. Bamler and F. Rocca)

Overview

12 Papers (incl. 1 paper as a fill-in in the Earthquakes and Tectonics session)

3 Papers on **PSI-processing** with emphasis on spatial, temporal or spatio-temporal phase unwrapping:

- Integer least square algorithm adopted from GPS
- Joint space-time approach
- Phase ambiguities is one of the major uncertainties in PSI analysis

2 papers on methods that **combine classical InSAR** (assumption: spatial continuity -> temporal-model-free) processing methods and PSI (assumption: temporal continuity/ predictability) supporting:

- Non-urban applications
- Motion-model-free reconstruction

3 papers on the **physical nature of PS**:

- Polarimetric properties of PS help to infer the physical nature of PS.
- Angular responses can be used to separate 5 classes of PS: dihedral, roofs, gratings, poles, trihedrals.
- Birth and death of PS is important information -> frequent revisits
- The baseline (angular) dependence can be used to separate single scatterers from double scatterers even from the amplitude-only data (before interferogram formation)
- Baseline can be an advantage -> precise 3D mapping (cross-range)

1 Paper on an **PSI accuracy test** using dihedral reflectors (sigma = ca. 1.3 mm, close to mechanical precision)

1 Paper on **ERS-ASAR PSI integration**

1 Paper on **web-based** sharing and **dissemination** of PSI results:

- WebGIS technology
- GoogleEarth as a new platform to exchange results
- Discussion: PSI subsidence results may be sensitive and may cause economic disadvantage, if freely and unauthorized distributed.

1 Paper on **PSIC4 validation**:

- 8 teams involved
- Differences in PS density and geo-location
- Area exhibits strong non-linear motion
- Levelling data of good quality (1-2 mm) are available
- Comment: Comparison will be difficult, must be consistent with the “rules” at the outset

Answers to Seed Questions

1. *What is next, after PS? Is it possible to achieve a scatter prediction model useable for multiplatform use, and if so, how and what?*

    - Scattering models must/can be improved, in particular scattering at buildings (cf. cell phone requirements). See methodology: General question 2.

2. *We should be able to combine also multi image optical (from infrared to visible) information for interpretation and forward modelling. Is anyone doing so? Can we combine coherent Synthetic Aperture Radar with incoherent Synthetic Aperture Photogrammetry (watching from a train a tennis match behind a fence) and if so, why?*

    - Optical images (stereo) help to model cities and scattering models. Ground-based data (e.g. from camera-equipped cars) could be an interesting additional information. Combine digital photogrammetry and radar information.

3. *In the world of cheap Teraflops and Terabytes, High Altitude Platforms, UAV's, etc. which is the long term goal for Remote Sensing and how to get there in the shortest time and with minimal costs?*

    - Stratospheric autonomous HALEs ("Stratellites") are promising platforms for remote sensing and should be studied in detail.

4. *What is the physical nature of PS's, what do we really measure?*

    - We will understand this much better with the advent of higher resolution SARs and in combination with optical 3D models. Currently: 5 scattering mechanism can be (marginally) distinguished.

5. *What is the optimum PSI SAR system (wavelength, polarization, incidence angle, resolution, and revisit time)? What issues affect the observation of PS and that of PS-fields with Scan-SAR modes?*

    - Optimum wavelength is not yet clear due to limited experience. S-band is missing completely.
    - Revisit time is essential, followed by resolution. Short revisits can be turned into improved resolution, but not vice versa. Incidence angle should be steep enough to "see" into urban canyons. Full polarization could be helpful to interpret PS.
    - Ambiguities must be well controlled due to high dynamic range of high-res urban images.
    - ScanSAR-PSI: Resolution should not be too low, burst cycle duration and burst location should be under control to choose between InSAR and bandwidth increase.

Ice and Snow Session Summary

(by D. Derauw and J. J. Mohr)

Overview

- Controlled Interferometric Modelling of Glacier Changes in Svalbard (Aleksey Sharov)
  - Combined information from many sensors: InSAR (ERS), altimetry (ICESat GLAS), historical maps, VNIR satellite imagery (ASTER), and GPS
  - Demonstrated cartographic map products
- Application of SAR Interferometry to Himalayan Glaciers (Gopalan Venkataraman)
  - Concerned two major glaciers in the Himalayans
  - Used SRTM to remove topographic signal
  - Velocity profiles were derived from Tandem data
- A comparison of remotely sensed surface velocities with balance velocities on two Svalbard ice caps (Suzanne Bevan)
  - Derived ice surface velocities using InSAR
  - Calculated balance velocities at equilibrium line altitudes
  - Concluded that tide-water glaciers to the south and east are flowing faster than balance velocities at ELAs
- The effects of basal water beneath Vatnajökull, Iceland, observed by SAR interferometry (Eyjólfur Magnússon)
  - Derived 3-D velocity fields from ascending and descending ERS Tandem pairs
  - Observed high variability in glacier velocity (up to 5-10 fold increase; attributed to basal lubrication)
  - Concluded that mass fluxes of temperate glaciers may be underestimated from short time interval InSAR
- Greenland ice velocities: Envisat vs. Radarsat-1 background missions (Eric Rignot)
  - Compared Radarsat (HH, 24 days) and ENVISAT (VV, 35-days) for mapping outlet glaciers in Greenland. Demonstrated that HH scattering is more stable
  - Summarized mass balance results from flux-gates along the entire coast of Greenland from 1996, 2000, and 2005, respectively
  - Showed increases in out-flux. Concluded that the Greenland ice sheet is presently out of balance with -215 +/- 35 km3/y
- Monitoring Alaskan snow pack with InSAR (Richard Forster)
  - Investigated relative snow water equivalent measurements by exploiting the phase delays through a differential snow layer
  - Used a time series from the 3-day phase of ERS and meteo-data
  - Concluded that snow accumulation causes a detectable signature

Presentations conclusions

- Apart from the process-oriented studies, we also now see large scale results. Answers to questions like: "what is this current state of an ice-cap/sheet" can be given
- Ice flow is an application area where InSAR provides unique measurements
- Glaciers and ice-sheet are dynamic
  - Large scale: repeated mapping is required
  - Local scale: requires high time-sampling

Discussions/recommendations – present sensors

- HH polarization reveals to be more efficient for ice flow measurements by InSAR. ESA proposed to change all background IM and WS acquisitions over Greenland and Antarctica from VV to HH. No objections to this were raised.
- Recommendation: Switch from VV to HH over polar land-ice
- Ice is dynamic
- Recommendation: Keep on measuring with ENVISAT!
- Glaciers are influenced by surface temperature and snow accumulation but also other complicated effects like changes in basal sliding due to melt or rain water
- Recommendation: True 3-D would be useful. Investigate ascending + descending + alternative angle of incidence. Investigate options for optimizing acquisition modes of different radars in orbit
- The usefulness of WS mode was discussed. Loss of resolution deteriorates speckle tracking and measurements on highly dynamic glaciers, but is expected to be extremely useful on continental scale investigations
  - Recommendation: Continue WS in the interior of Greenland and Antarctica. Encourage and support WS-WS interferometry
  - Recommendation: Allocate some resources to IM mode in Greenland and Antarctica

Discussions/recommendations – auxiliary data

- High quality DEMs are very useful
  - We would welcome: SRTM-like product of polar regions
- It was stated that ECMWF data are useful.
  - Recommendation: Investigate options for easy ENVISAT-user access to ECMWF data and derived products
- It was discussed if magnetometer data could be used to quality-flag radar data
  - We would welcome: A mechanism for easy ENVISAT-user access to magnetometer data
- It occurred to the chairmen that we didn't discuss ice thickness data despite the fact that they constitutes a critical input to mass balance studies
  - Request for discussion: Should we recommend encouraging ice thickness measurement campaigns and data sharing

Discussions/recommendations – future

- The use of full polarimetry was touched upon. Quad-pol data should reveal to be interesting for future ice and snow type applications. PolInSAR is still at an experimental stage
  - Recommendation: Further studies and PolInSAR campaigns
- For glacier motion studies, HH appear to be the most wanted polarization scheme
  - Recommendation: For ice motion applications more channels should not be traded for spatial or temporal resolution
- The presentations showed that the most important data set still is the ERS Tandem one. It was clear that short revisit time improves reliability and probability of displacement measurements
  - Recommendation: Another Tandem like (1- or 3-days) configuration or a constellation is most wanted by the community
  - Recommendation: Future missions should keep (or enhance) spatial resolution. Enhanced temporal sampling is recommended

Volcanoes Session Summary

(by P. Lundgren and G. Wadge)

Summary

- On the evidence of this meeting, volcano InSAR has evolved since 2003 – but no revolution.
- Etna and Piton de la Fournaise remain the main European testbeds, the latter study shows how a multi-angle strategy can benefit the operational response.
- There were a few more persistent scatterer studies but no wide-swath work.
- The list of deformation mechanisms in volcanic terrains continues to grow: fissures (dykes), magma reservoirs, sills, gravity slide decollements, lava loading, collapse unloading, shallow crystallisation induced pressurisation, post-emplacement lava/deposit subsidence, geothermal de/pressurisation, viscoelastic relaxation, various tectonic interactions including stress transfer.
- This bewildering list (not usually all at the same volcano!) is nearly matched by the growing sophistication of models that use multi-source inversions InSAR and other data in analytical and numerical schemes sometimes using finite element/boundaries and voxels.
- We now have an excellent example of how well we can use C-band InSAR for operational monitoring of volcano deformation – courtesy of the effort at Piton de la Fournaise. Very frequent eruptions, excellent coherence, multi-angle data series giving 4-day effective time resolution, all possible acquisitions, fast data access and good modelling make this possible. ESA should use this as an exemplar of how well C-band for volcano observatories can do under near optimum circumstances. Not all of this is transferable, but we should explore how this approach might be applied to other volcanoes in crisis.
- The need for L-band data was illustrated obliquely by several studies at the meeting in New Zealand, Alaska, Kamchatka and Congo. Even the Piton de la Fournaise monitoring people accepted they would like L-band …..Having L-band availability will expand the volcano monitoring community who feel they can make regular use of InSAR.
- Topographic water vapour-induced artefacts are common on many volcanoes and mitigation of their effects is particularly required for volcanoes with very poor archives. The use of MERIS/MODIS/GPS and atmospheric modelling techniques show promise. No volcano InSAR study should be without an explicit atmospheric error analysis.
- The variability of volcanic InSAR signals continues to surprise. Some volcanoes show no signal during eruption, others show continuous complex motions. Basaltic volcanoes with calderas often show detectable signals, conical volcanoes rarely do. From a hazard/operational perspective this is not what we want because the conical volcanoes are generally more dangerous. It is not clear whether this is mostly caused by strain-neutral behaviour or by our inability to measure the deformation. We need to focus more effort on these volcanoes with potential signals on steep, vegetated surfaces (e.g. Pinatubo (1991)). L-band, frequent (~10 day interval) acquisitions and perhaps the wider adoption of permanent scatterer analysis will help here.

Recommendations

- The Background Mission acquisitions are generally useful but there is no oversight effort to learn general lessons (e.g. 4 above). Also the volcano community should/does have the aspiration to monitor all the world's volcanoes and InSAR should play a key role in this. Two things need to happen to move this forward:
  - A concerted community effort to pool volcano InSAR monitoring results by existing research groups at the regional level would be undertaken.
  - A Global Observing System umbrella would be sought to provide an international conduit for results.
    - ESA support for this via Background Mission -type support would be necessary.

Earthquakes and Tectonics Session Summary

(by S. Jonsson, P. Lundgren and B. Parsons)

Overview

There were 13 papers presented in this session focusing on co-seismic, inter-seismic, and post-seismic deformation in the various parts of the world.

Of the co-seismic studies there were two papers on recent earthquakes in Morocco (Biggs et al. and Akoglu et al.). These presentations demonstrated that shallow moderate sized earthquakes can be much better located using InSAR than tele-seismic methods. These studies also discussed the ambiguity of determining which of the two nodal planes ruptured in small to moderate sized strike-slip earthquakes. A presentation on the 1997 Manyi, Tibet earthquake (Funning et al.) demonstrated the importance of InSAR in constraining finite fault rupture models and reflected on limitations of traditional tele-seismic methods. This study also showed that the Akeike Bayesian Information Criterion (ABIC) method is effective in combining geodetic and seismic data. Early results of the October 2005 Kashmir earthquake were presented (Pathier et al.) showing that conventional C-band interferometry failed due to conjunction of high topography and large baseline, while significant deformation parameters could still be retrieved using range offsets due to the large coseismic displacements in this earthquake.

A paper on North Chile (de Chabalier et al.) demonstrated the use of InSAR to observe inter- and intra plate earthquakes, post-seismic deformation, and inter-seismic deformation in the subduction zone in an optimal InSAR environment. Other presentations on post-seismic deformation included a study (Fielding et al.) on InSAR time-series analysis from Bam, Iran following the 2003 earthquake. They showed an example of resolving non-linear deformation-rates in series of interferograms, but also discussed (like many other presentations in this session) the difficulties in separating weak deformation rates in the presence of strong atmospheric effects. A study (Gourmelen et al.) on deriving deformation rates in central Nevada from stacks of interferograms identified a large-scale deformation feature that has not been previously recognized. They associate this feature with post-seismic relaxation following a series of large earthquakes in the past century.

Several presentations focused on tectonic/inter-seismic deformation in Tibet, Turkey and the Bay Area. Two teams presented studies using series of interferograms to derive long-term slip-rates on major fault systems in Tibet (Wright et al., and Lasserre et al.). Both teams demonstrated the capability of using InSAR for this task, but were confronted significant topography correlated atmospheric signals, which appears to be the main limiting factor in determining long-term slip rates, at least in northern Tibet. Two teams employed PS methods on the North Anatolian fault system to determine long-term slip and seismic potential. While one study (Pathier et al.) discussed difficulties of using this technique in rural areas of eastern Turkey, another study (Motagh et al.) demonstrated significant success in the western part of Turkey. And finally, a paper (Burgmann et al.) on using PS in the San Francisco Bay Area showed examples of separating vertical and horizontal tectonic motion considering other sources of deformation.

General Discussion

The general discussion after the presentations in the earthquakes and tectonics session was lively taking on a variety of subjects.

There was a discussion on the ERS archive and that it is far from being extensively exploited by research community. Many potential research opportunities exist in using large amount of data from the archive and members of the scientific community raised the importance of opening access to older data at no cost for large scale deformation analysis. Others stated the importance of cost by means of contain data flow at a level of ESA's production capability.

The issue of processing larger amounts of data was raised and that maybe the research community should organize a limited number of large processing facilities.

Question was raised why wide-swath products are not being used in current studies. It was stated that it is too early for these data to be of general use and for the necessary processing tools to be developed. Results expected on Fringe '07

Answers to Seed Questions

1. *Can measurements of atmospheric water-vapour variations, such as by MERIS, accurately correct for the path delay in interferograms of areas with great topographic relief?*

    - MERIS offers a potential solution, but a problem is that clouds are often associated with mountains. It was stated that even though MERIS has limitations it can be very useful in estimating elevation dependent atmospheric components. No recommendation other than that more research is needed in this domain to assess the potential of MERIS for this task.

2. *Interseismic and postseismic processes are recognized as subjects where geodetic measurements play a key role toward understanding fault mechanics and the response of the crust and lithosphere following large earthquakes. The spatial and temporal scales of these processes continue to challenge InSAR observations. How can we resolve these processes both within the current SAR missions and in future missions?*

    - Discussion here referred back to atmospheric modeling and issues related to acquisition strategy. There was not a clear consensus on current acquisition strategy or future missions because different deformation processes have different spatial and temporal signatures. However, ESA's background mission is clearly highly appreciated.

3. *Large earthquakes produce a wealth of seismic and geodetic data, e.g. strong-motion and tele-seismic recordings, ground-based geodetic data (GPS) and InSAR data. How can we best combine these different sets of data for a meaningful estimation of finite earthquake source models?*

4. *Finite-fault rupture models of large earthquakes can provide reliable information on ground-shaking intensity and can therefore be used for improved damage estimations (when combined with surface effects and building stock). What is needed for an operational rapid finite-source determination of large earthquakes using InSAR (in combination with other data)? Is this operationally feasible?*

    - Not properly discussed due to time constraints

Recommendations

- Data from the ERS archives should become freely available and easily accessible
- Envisat wide-swath data acquisitions should be continued to build up archives
- The Envisat background mission is highly appreciated and very important and should definitely be continued (extended?)

Recommendations on Future Missions from Fringe 2003

- For reliable tectonic deformation measurement, a dedicated mission is desirable, with a long time-series of regular and identical acquisitions during several years, both in ascending and descending. Archive build-up on sensitive sites insuring incidence continuity. A minimum number (~30) of acquisitions is required for monitoring small deformation rates in order to remove atmospheric biases
- L-band would allow longer-term monitor of inter-seismic deformation and strain accumulation on regions of poor coherence in C-band.
- Very precise orbit knowledge required to increase measurement reliability. More precise orbit control in future will help to increase number of possible interferograms for stacking and measuring small signals.

Landslides Session Summary

(by H. Rott and U. Wegmuller)

Overview

4 oral presentations and some additional 5 posters.

- Results of experiments carried out over various test areas (Italy, Switzerland, Austria and Czech Republic), located in different geomorphologic environments were presented.
- InSAR was applied to retrieve deformation data, exploiting a variety of approaches, including classical DInSAR, SBAS, IPTA, PS… Fixed target reflectors were also deployed, to increase the number of targets over vegetated areas. In close cooperation with the end-users, deformations values have been used as input to landslide hazard maps
- C-band InSAR is very useful for monitoring slope deformations if stable targets are available, but reveals limitations (vegetation, snow and atmospheric artefacts, rough and steep topography, orientation of slopes, speed and acceleration of movements). Studies with J-ERS suggest improvements for vegetated areas and faster deformations with L-band.

Answers to Seed Questions

1. *Maturity of techniques and required improvements: What is the maturity of the InSAR retrieval techniques for landslide monitoring and which methodological developments would help to improve the InSAR products?*

    - Mature if available advanced tools are properly applied; for C-band with 35-days repeat cycle “still challenging”
    - Main outcomes: spatial distribution/temporal evolution of displacements
    - Case-specific processing and interpretation is needed
    - There is a clear need to improve the capability of identifying and following time-variable motion

2. *Artificial targets: Is the use of artificial targets for InSAR landslide monitoring in densely vegetated areas useful, and which type of targets (active, passive) is preferable?*

    - Some potential in specific cases
    - Cost issues to be addressed (conventional ground-based monitoring techniques might be cheaper and provide more complete information such as 3D measurements). The user decides

3. *Qualification and presentation of results: How do we best qualify results (e.g. average deformation rates or unique values of a deformation history, but also positional accuracies; where do we get information and what is the role of*

missing information)? Which complementary information (satellite-based, GIS etc.) would help to improve the presentation and applicability of InSAR products?

- More interaction between the 2-communities “FRINGEs” and Engineering geologists needed
- Spatial distributed information might be of higher value than mm information
- Complementary information is important (ground data always needed for interpretation): more valuable in an integrated environment, in presence of ancillary data

4. *Status of acceptance of EO methods: What is the status of the acceptance of EO methods (in particular of SAR interferometric techniques) and of information derived using these methods in the "landslide monitoring community", and which measures can be taken to enhance the acceptance?*

- It varies, it takes time for the community to understand potential and limitations of the techniques
- Project with user involvement resulted in an high level of acceptance: a unique understanding of terminology and requirements is needed
- Rate of deformation that current C-band systems may measure, represent only a small subset of the landslide velocity scale (ranging from mm/y to m/s)

5. *Future systems: What is the preferred configuration and operation mode of a satellite constellation for operational landslide monitoring services (SAR frequency, spatial resolution, repeat cycle etc.)?*

- More frequent revisiting time (weekly or better) for C-band InSAR to avoid temporal decorrelation and phase ambiguity and to observe faster slides. Use of repeat 3-days (Ice-phase) data might be used to demonstrate it.
- Longer wavelength (L-band proved successful in some case-studies) can overcome above limitations with a longer repeat cycle, but a short repeat cycle (2-weeks or better) would be of further benefit. Easier to follow time-variable deformations. The J-ERS data archived at ESA can be used to better study L-band capabilities and prepare for ALOS
- Higher spatial resolution may improve mapping of smaller, local phenomena (many damaging landslides are small-sized). Tests can be carried out with available Radarsat data and near-future Terrasar-X before asking for dedicated missions

Recommendations

- For further developing and supporting the use of InSAR for operational landslide monitoring, long-term continuity of SAR missions is crucial
- Provide new space-borne systems (C-band or L-band) with short revisiting time (several days)
- Stimulate interaction between InSAR community and Engineering geologists community
- Stimulate research aiming at integration of processed InSAR data into user practices

- Standardisation of InSAR-derived landslide products would enhance the acceptance of the technique and products by the users
- Improve accessibility of available JERS-1 data archived at ESA for InSAR purposes

Future Missions Session Summary

(by G. Levrini)

Overview

Tandem X:

- global DEM at HRTI-3 standard,
- along-track and multibaseline across-track interferometry, spotlight and bistatic capabilities, short repeat-cycle

ALOS:

- launch date Jan 19, 2006.
- Six main observation modes.
- InSAR and D-InSAR capability

Radarsat-2:

- Launch 2006.
- Full polarimetry, right and left, spotlight and Scansar interferometry capability

Canadian SAR constellation:

- Maritime surveillance, sea-ice monitoring. InSAR coherent change detection
- 3 (or 6) satellite constellation for combined ground coverage 1000km, short repeat-cycle

SENTINEL-1:

- GMES service requirements, C-band continuity
- short revisit, Scansar interferometry as main operative mode