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Cover: Ascending ALOS-PALSAR interferogram on Reunion Island spanning 93 days from 20 February to 23 May 2007, Kyoto University

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SUMMARIES AND RECOMMENDATIONS OF THE FRINGE 2007 WORKSHOP

The Fringe 2007 summaries and recommendations have been prepared by the session chairpersons and are grouped by session.

Methodology and Techniques: General

Recommendations

- Studies for new and/or improved algorithms are necessary to fully exploit high resolution SAR data from new missions.
- Simulations can be useful to better understand the scattering mechanisms.
- Advanced techniques like SAR tomography and differential tomography, multi-aperture interferometry, Pol-InSAR, etc., will become more important with the availability of SAR data from the new missions (characterized by frequent revisit time, high resolution, wide-band, polarimetric capabilities, etc.)

Methodology and Techniques: DINSAR/PSI

Session Summary & Discussion

- People presented combinations of point-based (full-res, time behaviour) techniques and (in combination with) coherence-based (reduced res, region growing) techniques. Both seem complementary. (Marotti, Hooper, Duque, Gernhardt)
- Partially coherent targets exploited together with PS: better exploitation of the archives (pixels that would be discarded if only one of the two methods was used) (Perissin)
- Unwrapping techniques: 3D (information in time and space should be used in solving the problem) (Crosetto)
- How to optimize the selection of interferometric combinations. (Duque)
- There are still problems in producing error bars (strong dependency of data availability, distribution, signal of interest, processing parameters…etc). Quality assessment of the model (not the data). Case study dependency? What is the value of a priori knowledge?
- Unwrapping is a problem, APS too
- Riccardo Lanari: trends in estimated velocity fields (should they be removed y/n?)
- PS Quality vs. density.
- APS should be made visible, how should it be validated?
- Observation: 3 categories of ‘users’: scientists, companies, ‘end-users (non-radar experts) : different interests, different knowledge levels, different objectives.
- Should persistent scatterer (full resolution) and coherence (multilooked)-based methods be considered as independent or complementary means of extracting information from satellite SAR data?

- What are the main bottlenecks in terms of quality assessments for the various techniques?
- Is it possible to make generic statements on the quality of the estimated deformation parameters, independent of the area of interest, or are these always case-study dependent?
- How should the trade-off between point density and quality be considered?
- How can we parameterize the information content of PS time series? (to interpret time series different from linear velocity model)
- How should advanced DInSAR algorithms benefit from spatial + temporal phase unwrapping?

Recommendations

- Significantly more experiments are needed. The availability of the required data is paramount.
- ESA should make the historical SAR archive available with easy ftp access and no data charges.

Methodology and Techniques: Atmosphere

Session Summary & Discussion

- Use of Numerical Weather Models (Etna, Holley)
- APS-Analysis: Stochastic modeling (Knospe)
- APS Analysis: ERS-Envisat (Perissin)
- Ionosphere (Meyer)
- Discussion: Use of NWM for other regions (worldwide) should be evaluated
- Do we feel that the problem of atmospheric delay signal in SAR interferometric approaches is well-understood?
- We distinguish effects of (i) vertical stratification, of importance in case of strong topographic height differences, and (ii) turbulent mixing. Should both effects be tackled independently?
- Is it possible to uniquely identify a spatially correlated interferometric phase error due to ionosphere using current sensors? If yes, which empirical evidence is available?
- What is the value of Numerical Weather Models for (i) local case studies, and (ii) systematic correction of APS irrespective of location and time
- What is the value of the interferometrically derived atmospheric phase screen for operational meteorology and atmospheric research?

Recommendations

- Significantly more experiments are needed. The availability of the required data is paramount.
- ESA should make the historical SAR archive available with easy ftp access and no data charges.

Applications: Earthquakes and Tectonics

Session Summary & Discussion

- A full-day session was dedicated to Earthquakes and Tectonics.
- 14 Oral presentations and ~13 poster presentations in the session.
- Many subjects presented, including inter-seismic, co-seismic, post-seismic, rifting deformation, model parameter estimation methods, etc.
- Mostly data from the ERS/ENVISAT archives, but also ALOS, Radarsat-1.
- One presentation focused on ScanSAR InSAR.

Inter-seismic studies

- Long-term fault slip rates and locking depths were estimated from InSAR in several locations, including Tibet and California.
- High precision of interseismic velocities was achieved by careful treatment of orbital and tropospheric errors, although problems remain in areas of high topographic gradients.

Co-seismic studies

- Several presentations focused on coseismic deformation and modeling, e.g. in South America, Middle East, and Africa.
- ScanSAR interferogram of the magnitude 8.0 Peru earthquake (August 2007) was presented and showed the advantage of wide-swath for very large events
- The advantage of using multiple look directions and full data covariances in model parameter estimations was demonstrated.

Other studies

- A few studies were presented on post-seismic deformation observations and analysis, e.g. from South America, Iran, and Iceland.
- Spectacular images and analysis of the 2005 Dabbahu rifting episode were presented.
- Sub-millimetre/year surface deformation rates across the Asal rift, Djibouti, were derived from a 10-year InSAR time-series.
- Visco-elastic response of the crust, due to water level variations of lake Mead, Nevada, was constrained using a 15-year ERS/Envisat joint time-series.

Seed Questions

1. *With more than a decade of operation of C-band radar, InSAR measurements of ground deformation have improved in accuracy and its assessment has to be re-evaluated. What is the smallest ground deformation signal that can be measured with InSAR? Over what spatial and temporal scale?*

    - The precision of ground velocities has to be evaluated on case by case basis.
    - General limiting factors include data availability and time span.
    - Site-specific factors include surface coherence, topography, tropospheric conditions, and spatial scale of the deformation.
    - Examples shown with sub-millimeter/year precision in ideal cases (availability of long time series) when observing steady deformation rates.

2. *Long temporal series of radar data allows scientists to estimate rates and changes in rates of slow deformation processes using approaches such as SBAS and PS. What is the accuracy on constant rate estimates? What level of rate change can be estimated? Over what time scale?*

   ∞ Quality of deformation rate-change estimations was not discussed.

3. *With displacement and rate estimate errors we currently achieve, what are the deformation processes that we can reliably resolve? (Fault slip/creep, poro-elastic deformation, visco-elastic relaxation, dyke expansion, magma chamber inflation/deflation). Can the trade-off between competitive processes (e.g., after-slip and visco-elastic relaxation) be resolved with InSAR monitoring of post-seismic movement?*

   ∞ Important to include other information, e.g. from geology and seismology, due to non-uniqueness of models describing geophysical processes.
   ∞ Rapid response and systematic data acquisition are needed following an event to constrain processes characterized by different time constants.
   ∞ Important to combine different look directions (and azimuth offsets) to help constraining the 3D deformation field.

4. *The phase propagation delay through the troposphere has been identified as the main source of error for ground deformation measurements. What recent developments have we achieved with the use of ancillary data such as the MERIS or GPS nadir delay maps etc…? Can long temporal data series help characterize the tropospheric signal?*

   ∞ Addressed in several presentations during the session and remains one of the main limitations to achieve high precision deformation measurements.
   ∞ Methods include phase-topography correlations, atmospheric models, ground- and space-based meterological data (including MERIS), APS estimation, atmospheric error characterization.
   ∞ Half of the speakers clearly demonstrated improvement in deformation retrieval by using one or more of the methods above.

5. *How does the multi-directional observations (ascending/descending, near/far range) help constrain the source parameters (geometry of faults and slip direction)?*

   ∞ Multi-directional observations greatly improve model parameter estimates, in particular when full data covariances are accounted for in the model parameter optimization.

6. *What is the advantage of ScanSAR interferometry? What can we observe with scan-InSAR that was not accessible to conventional InSAR? Should scan-SAR become the background mode of data acquisition for surveillance purposes?*

   ∞ Advantageous for large spatial-wavelength deformation signals (large magnitude earthquakes, interseismic signals).
   ∞ Facilitates orbital corrections.

  - More frequent revisits at a any given site.
  - Some suggested ScanSAR should be part of the background mission on dedicated tracks (e.g. every 4th track), in places like Tibet, Anatolia, Iran, South America, Western North America.
  - Others suggested that we should concentrate on IS2 for the reminder of the ENVISAT mission.
  - Limited access to software for the scientific community is a concern

General Discussion

- Background mission is greatly appreciated by the community and many studies rely on these acquisitions.
- The community also appreciates the extension of the ERS-2 mission, but is concerned about gap between the Envisat and Sentinel-1 missions.
- Enormous potential research opportunities exist in further exploiting ERS/Envisat archived data using newly developed analysis methods. Important concerns include:
  - Easy and free access to archived data.
  - Required archive preservation and maintenance.

Recommendations

Primary Recommendation:
ESA should provide ERS and Envisat radar data to Cat.-1 users via FTP at no cost:
- Keep it simple, all data online in level-zero RAW format.
- If there are technical obstacles, then fund to solve them.
- If there are bandwidth issues, then introduce quotas (# of scenes/month).
- If commercial restrictions on new data exist, then only provide data older than for example 6 months.
- Make the ESA processing software for SLC generation available.

Other Recommendations:
- The important background mission should be extended to more areas, if possible, and should have a higher priority, i.e. becoming a 'foreground' mission!
- The community recommends as frequent and uniform data acquisitions as possible until the end of the Envisat mission (i.e. the IS2 mode and consistent polarization).
- However, with Envisat wide-swath InSAR being now demonstrated, some selected tracks/orbits should be dedicated to wide-swath acquisitions (but only if burst synchronization can be achieved)

Applications: Volcanoes

Session Overview

- The presentations demonstrated a significant variety of styles and scales of deformation from large deformation events on shield volcanoes to essentially no significant deformation at large strato-volcanoes. In addition, InSAR revealed rifting events.

- The importance of having in place a robust background mission that allows the detection of unforeseen events has been also demonstrated.
- In cases where there is significant decorrelation at C-band or very intense deformation, L-band data (JERS or ALOS) were particularly important.
- The atmosphere tends to be particularly problematic for volcanoes. The use of regional weather models may significantly reduce the atmospheric effects.

Summary of Discussion

1. The number of volcanoes studied has increased with respect to past Fringe workshops; the coverage is worldwide (the oral presentations or posters report the results of studies on volcanoes of all continents, except Asia).

   Is SAR Interferometry ready for an effective global monitoring of volcanic activity? If not, what improvements are desirable (e.g. new missions to reduce revisit times? Improvements in the algorithms? Improvements in the sensors?)

   - Yes, but data are often insufficient to effectively image and separate different volcanic deformation events (more frequent revisit times). In many cases this can be compensated for by acquiring data for a given volcano over multiple tracks from different incidence angles, but for detailed time series analysis this is not ideal.
   - Background missions to maximize the possibility to study unforeseen events are recommended on specific areas (e.g. East Africa Rift).

2. Several papers report studies based on the integration of multi-sensors (e.g. ERS1/2 and ENVISAT or ERS1/2, ENVISAT, RADARSAT, ALOS) or multi-swaths dataset.

   Are the current datasets satisfactory? Are multi-sensor and/or multi-swaths analyses required to improve our knowledge of the volcanoes? Is it necessary that the Agencies modify their data acquisition "policy" in order to expand the type of the images available to study/monitor the volcanoes?

   - These questions were not significantly addressed in the discussion.
   - Presentations on Piton de la Fournaise and Mt. Etna highlighted the importance of multi-swath data both in terms of achieving maximum temporal sampling and spatial resolution, and in terms of using high incidence angle data (IS4+) to reduce layover effects.
   - In the case of L-band data (ALOS) the current data acquisition strategy is often insufficient or unknown (i.e. East Africa Rift) and a robust background mission for these data is desired.

3. In recent years several techniques to process InSAR time series have been implemented.

   Is this now a standard technique that for volcano analysis? If not, what are the main limitations to these methods? And what are their requirements in terms of data acquisition strategies?

- InSAR time series (SBAS, StaMPS) are well suited for volcano deformation analyses since they allow the determination of time variable deformation. StaMPS has been applied less extensively than SBAS. L-band would still provide significant improvement in spatial coverage.
- Another key point in this discussion was the current limited use of InSAR time series in understanding the temporal evolution of volcanic sources. This is often caused by the rapid temporal evolution of the volcano source (i.e. dike intrusion) that happens on a time scale that is shorter than the InSAR repeat interval.

4. What is the current state-of-the-art in volcano modelling? Is it time to put together a "cookbook" set of software for routinely generating 3D FEM solutions for open-source software packages, such as PyLith? (i.e. input topo, structure, boundary conditions, source properties and easily generate Greens functions?). More generally, has numerical modelling definitively replaced the analytical approaches?

   - Volcano modelling is essentially data limited.
   - Spatial and temporal sensitivity of the InSAR data are often satisfied by relatively simple models.
   - In cases where very large and temporally varying deformation occur (e.g. Sierra Negra, Piton de la Fournaise; Lake Natron), the InSAR data modeling requires more complex deformation scenarios able to analyze the interaction of magmatic and volcano structures.
   - In the cases where the volcano deformation is large and rapidly evolving the InSAR data lack the temporal resolution required for a truly dynamic modeling interpretation of these events.
   - Another area where volcano modelling is limited by the data is with regard to deeper deformation sources in which the expected deformation signal is broader and weaker. The broad nature of these source means that they often extend into areas around the volcano that have higher decorrelation and therefore cannot be detected.
   - With L-band systems such as ALOS the decorrelation in the area around the volcano may be reduced, but then there is the problem of deformation resolution (i.e. 1 fringe=12cm).

5. What are the limitations for detecting small time/spatial scale events with InSAR (TerraSAR X/CosmosSkyMED)?

   Not covered due to lack of time.

6. What is the current state-of-the-art in the integration between the DInSAR measurements of deformations and the results of geodetic surveys or permanent networks?

   Not deeply discussed, mentioned briefly in terms of modelling.

Applications: Terrain Subsidence and Landslides

Session Overview

Nine papers and 23 posters were presented in the terrain subsidence and landslide session. Various applications fields, ranging from mining to ground-water induced subsidence, from peat drainage to geotechnical investigations on structures, from regional scale landslide mapping to rockglaciers activity, were considered. Methodologies and techniques varied with regard to the application field and the expertise and objectives of authors. On the evidence of this meeting the user community has evolved to cover a considerable number of countries around the world, including Argentina, Australia, Belgium, China, France, Germany, Greece, Hong Kong, Indonesia, Iran, Israel, Italy, Korea, Mexico, The Netherlands, Norway, Poland, Switzerland, Turkey. According to the papers, the posters and the plenary discussion, interferometric SAR techniques can be considered mature for terrain subsidence and landslide applications.

There is a general consensus that levelling or GPS measurements are not mandatory anymore for the validation of the SAR-derived displacement data; on the contrary, SAR-derived measurements start to be used as validation for other data. On the other hand, it is considered very important to increase the maturity of the users, via training, in terms of understanding the information content of the InSAR displacement data.

Although standardization of similar products provided by different processing chains or providers may be considered, in every other domain it is quite common that different suppliers provide measurements not necessarily consistent or homogeneous.
For many uses it is more important to minimize the number of "false alarms" instead of improving the accuracy toward smaller movements.

One very important feature of future missions shall be data continuity and consistency. A good trade-off may be obtained by paying some spatial resolutions to obtain finer temporal resolution. This will also increase the range of velocities that might be monitored.

Requests are addressed to ESA toward maintaining the ERS historical archive and possibly to open it to the science community. Some homogeneity between the data archives of different ESA and non-ESA missions would be welcome.

Applications: PSI Validation

Session Overview

Eight presentations have been made covering three main areas of validation:

- Firstly, the PSIC4 validation exercise of 2005-2007 with analysis results from BRGM and TU-DELFT.
- Secondly, the TERRAFIRMA Validation experiment over Amsterdam/Alkmaar with investigations by TU-DELFT, Institute of Geomatics (Spain) and DLR.

- Thirdly, investigations focusing on artificial corner reflectors with results from TU-DELF, University of Nottingham and the Alaska SAR Facility (ASF).

The PSIC4 validation exercise is still of value. It is now recognised that despite the test site limitations for validation purposes (rapid and large deformation), PSIC4 has stimulated further research on key issues such as:
- Phase unwrapping.
- Extension to non-linear deformation models in PSI technique, etc.

The TERRAFIRMA validation exercise delivers first results. There are now quantified results of the comparison of PSI with levelling data, e.g.:
- The standard deviation of velocity differences (PSI-levelling) in the Alkmaar test site and using ERS data ranges from 1 to 1.5mm/yr.
- Using both ERS and ASAR data a new validation method, called "validation in the parameter space" was presented by TU Delft, demonstrating that PSI measurements are equivalent to levelling for the estimation of the parameters of a geo-physical model used for monitoring gas fields.
- An extensive inter-comparison analysis of the TERRAFIRMA PSI chains has been conducted by DLR (using the DLR results as reference); 0.35mm/y is the empirical estimation of the best attainable standard deviation of velocity differences.
- With pure inter-comparison in radar space, the standard deviation of velocity differences is 0.5mm/y for all TERRAFIRMA PSI chains (ERS dataset over Alkmaar).
- The standard deviation of topographic correction differences is between 1.3 and 2.7m (i.e. 3 to 6m geocoding errors, in E-W direction).

Other noticeable results:
- The use of artificial Corner Reflectors provides valuable validation results.
- Experiments show 1.6mm standard deviation between ASAR and levelling (2.8mm concerning zero-gyro ERS-2 data).
- Current validation activities are also useful for the preparation of future EO missions (e.g. Sentinel-1)

Seed questions

1. *Can we define the "error bars" to be associated with deformation velocity; deformation time series; and PS geo-location?*

   A lot of progress is shown concerning the validation of PSI measurement (inter-comparison of chains and correlation between PSI and reference data); representative statistical results are now available (rather concerning average velocities than time series). More documented results will come with the TERRAFIRMA validation report will be issued in Q1 2008.

2. *Can we define the conditions to be fulfilled to achieve the above "error bars": number of images, deformation pattern and magnitude, deformation rates, etc?*

   Not addressed.

3. *How can we handle the spatially wide trends (tilts) in the data, which are due to residual orbit?*

   It is overall agreed that the tilt effects should be separate from the main PSI measurements. Possibly, in the case of expert users it could be relevant to provide an estimation of the trends (tilts) as a by-product.

4. *Can we characterize the PSI capability to detect deformation phenomena (e.g. in urban areas) in terms of omission and false alarms?*

   The detection capacity of the technique is linked to the PS density which has its limitations. Areas for progress in addressing this limitation include the contribution of the PSI technique using VHR SAR (e.g. TERRASAR).

5. *Can we expect significant improvements in the measurement of non-linear deformations?*

   A part of the on-going research on the PSI technique is looking at approaches not based on the linear model. In particular several research groups are active with the PSIC-4 dataset with the objective to elaborate improved PS estimation, see recommendation below.

Recommendations

ESA is recommended to support the PSI research community to get access to the Gardanne levelling data.

Airborne and Ground-Based InSAR

Papers in the Session

∞ The X-band RAMSES multi-pass interferometry campaign
∞ Monitoring of Belvedere Glacier using a wide angle GBSAR interferometer
∞ Subsidences estimation from ground based SAR: techniques and experimental results
∞ Bistatic Interferometric toolkit for campaign evaluation and DEM generation

Future research & recommendations:

∞ Availability of wide bandwidth, frequent revisit systems
∞ Integration of multiple frequencies and multiple sensors (Spaceborne, airborne, Ground Based, Ground bistatic)
∞ APS is still one of main limitation,
∞ Tomography is one of the most important themes for future researches

Interferometry and New SAR Missions

Session Summary

Presentations were made on the results of new missions recently put in orbit including ALOS (JAXA), TerraSAR-X (DLR) and COSMO-Skymed (ASI). Also ESA‘s Sentinel-1 and DLR‘s Tandem-X were presented, fully approved missions in an advanced stage of development.

For the radar interferometry community these new missions signify what is sometimes referred to as the “Golden Age of SAR”. Experimental mission commonly in a single waveband are being replaced by satellite constellations at several wavelength and a wide range of observation characteristics.

New trends include in particular:

- L-band with improved coherence over time and more canopy penetration as compared to C-Band.
- X-band/High Resolution showing higher persistent scatterer density and still with interesting polarimetric information content as compared to lower spatial resolution systems.
- C-band with largely improved revisit and conflict-free systematic data acquisition. Improved geographically synchronous SCANSAR (TOPS).

Recommendations

- For the future no detailed requirements were suggested for new systems for two reasons. First it was felt that the new missions offer excellent opportunities and that in general the right options have been chosen. Second the knowledge exists about what can be gained by adding more resources in terms of resolution, revisit, sensitivity and what this would cost. More money buys more performance.
- As an exception to the above, based on the excellent results of ALOS, it is recommended to consider for the future an operational long-term mission in L-band featuring conflict-free operations.
- In spite of the advances of interferometry applications it was agreed that further penetration into the end-user market was a key issue for the space agencies, value-added companies and the scientific community.