1 FRINGE 2011 – SESSION SUMMARIES

This document contains the Session Summaries of the Fringe 2011 Workshop, "*Advances in the Science and Applications of SAR Interferometry and Sentinel-1 Preparatory Workshop*" that was organised between 19.9 and 23.9.2011 in ESA-ESRIN, Frascati, Italy.

1.1 List of Acronyms

APS	Atmospheric Phase Screen
ASI	Italian Space Agency
CSA	Canadian Space Agency
DS	Distributed Scatterer
ECMWF	European Centre for Medium-Range Weather Forecasts
EWS	Interferometric Wide Swath
EQ	Earthquake
GNSS	Global Navigation Satellite System
IWS	Interferometric Wide Swath
LOS	Line-Of-Sight
MAI	Multi-Aperture Interferometry
NEST	Next ESA SAR Toolbox
NWP	Numerical Weather Prediction
PIG	Pine Island Glacier
PS	Persistent Scatterer
PSI	Persistent Scatterer Interferometry
RCM	Radarsat Constellation Mission
SBAS	Small Baseline Subset
SM	StripMap
S-1	Sentinel-1
TOPS	Terrain Observation by Progressive Scans
TDX	TanDEM-X
TSX	TerraSAR-X
VHR	Very High Resolution

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1.3 Sentinel-1 Session

Chairs: P.Potin & B. Rosich

1.3.1 Seed Questions and Discussion/ESA Comments

1. What recommendations does the community have for Sentinel-1 observation scenarios over InSAR areas of interest, in terms of revisit frequency and pass (ascending / descending)?

2. What recommendations does the community have for Sentinel-1 data acquisition, in terms of instrument mode and polarization? Can the community confirm that the IWS is the most appropriate mode for most InSAR applications and related areas? In which cases dual polarization data would bring real added-value (knowing that single polarisation may allow to extent coverage / frequency of observations)?
   - Over critical areas requiring frequent observations (tectonic / subsidence / landslides / volcanoes), the capability of short repeat cycle of Sentinel-1 should be fully exploited, and acquisitions in both ascending and descending orbits should regularly be performed. The details need to be analysed based on the available mission and system resources – more information in the recommendations of the thematic sessions
   - The IWS mode is the default mode of Sentinel-1 over land and the suitability of this mode is confirmed by the InSAR community to a large extent (some exceptions…)
   - See specific recommendations from thematic sessions regarding the polarisation. On the single / dual polarisation issue: if a choice has to be made due to mission/system resources limitations, the mapping extent in single polarisation should be privileged vs. the use of dual polarisation.

3. What recommendations does the user community have for the systematic processing of Sentinel-1 data acquired over InSAR areas of interest? e.g. in terms of timeliness ? Any InSAR processing steps that could be performed within the ground segment to support the community? Potential hosted processing?

4. What recommendations does the community have for easing the access to the huge Sentinel-1 data volume for the InSAR community? What potential collaborative interfaces to facilitate data access within the InSAR user community would be recommended?

5. Is the community ready to handle the huge volume of Sentinel-1 data products, from download to processing?   Are the 250 km swath IWS products opening new InSAR applications for which specific access mechanisms should be foreseen?
   - The ESA plans are to basically process systematically within 1 day all data in SLC for some InSAR relevant areas (details / areas are to be defined based on available system resources and performance).

- Considering the huge volume of Sentinel-1 generated data, redistribution of standard Sentinel-1 products by international partners could ease the data access worldwide
- The amount of Sentinel-1 data to be dealt with of course depends on the application. Use of Sentinel-1 based InSAR for large scale mapping (e.g. Antarctica) or for very frequent monitoring of areas requires the set up of adequate infrastructure on the user side.

6. What recommendations does the community have regarding the cooperation between Sentinel-1 and RCM (Radarsat Constellation Mission from Canada), in particular regarding the complementarity of the respective observation scenarios ?
    - Cooperation between ESA and CSA on the Sentinel-1 / RCM aims at increasing the benefit for users and synergies should be exploited
    - Even if it will not be possible to perform InSAR across the 2 missions, detailed discussions on complementary S-1 / RCM observations will take place in the coming months / years between ESA and CSA
    - RCM could be used e.g. in complement of Sentinel-1 for applications requiring data of higher resolution or with the same geometry as Sentinel-1 (e.g. for landslides)
    - Cooperation across SAR missions on international activities (e.g. IPY) shall be continued in the S-1 / RCM era.

1.4 Earthquakes & Tectonics Session

Chairs: E. Fielding & S. Jonsson and Y. Fukushima & M. Furuya

1.4.1 Session Overview

- Large session with 5 oral sub-sections during two days.
- 30 oral presentations and 42 posters in total.
- Many topics presented, inter- and co-seismic deformation, fault creep etc.
- Several presentations on recent important earthquakes in Japan, New Zealand and Haiti.
- Data were presented primarily from Envisat, ERS-1/2 and ALOS. Some studies used TerraSAR-X data, but almost no results reported based on Radarsat-2 or Cosmo-Skymed

1.4.2 Topics - Interseismic Deformation

- Several studies demonstrated the usefulness of InSAR to measure interseismic deformation and thus for Earthquake Hazard Assessment.
- Almost all presentations used the ERS/Envisat archives.
- Improvements were presented in dealing with atmospheric signals.
- Techniques were presented for combining InSAR and GPS to generate strain-rate maps.
- Most presentations focused on Tibet, the Middle East, and the western US.
- Deformation across Himalayas shown!

1.4.3 Topics - Earthquake Studies

- The incredible complexity of earthquake faulting was demonstrated
- TerraSAR-X data was used to measure absolute ground displacements.
- Multi-sensor L-,C-,X-band studies demonstrated redundancy and complementarities.
- Improvements in EQ damage mapping were hown.
- EQ inversion techniques were discussed.
- Tohoku, Christchurch, and Haiti earthquakes, but also in Mexico, Africa, Tibet, Middle East and many more (in poster session)

1.4.4 Topics - Creep and Fault Offset Studies

- The strength of InSAR was once again demonstrated in measuring mm-scale fault movements.
- Number of studies presented, California, Taiwan, Africa and other places.
- Spatio-temporal variations of creep were presented.
- Details of fault motion and fault interaction were shown in Afar in a couple of presentations.

1.4.5 *Topics - Other Studies*

- Complex rift zone deformation was presented in Afar and in Iceland.
- Only one presentation focused on post-seismic deformation (Haiti), but analysis of post-seismic deformation was a part of several talks

1.4.6 *Seed Questions and Discussion*

1) What recommendations does this thematic community have for Sentinel-1 observation scenarios over InSAR areas of interest, in terms of revisit frequency and pass (ascending/descending).
   - A "Simple and boring" observation scenario is recommended.
   - High revisit frequency (every pass) is desired over active areas.
   - Regular acquisitions in other areas
   - Two look directions are important
   - Same mode and small baselines are desired
   - Concerns about the fine azimuth co-registration and possible ramps on S-1 TOPS data, which might look like interseismic deformation. Long data-takes are important.

2) What are the new InSAR findings in earthquakes and tectonics studies since FRINGE 2009?
   - Many examples of time-series analyses, to study spatiotemporal variations of fault creeps and transients, in addition to better estimating interseismic deformation.
   - DLR showed absolute displacement measurements using TSX sub-pixel cross-correlation (pixel offset tracking).
   - X-, C-, L-band sensor data were used, which provided redundancy and complementary information.
   - Constellations such as COSMO-SkyMed provide much more rapid repeat times, although presently they have very limited access, few acquisitions and small archives.
   - GEO Event Supersites have provided much more access to data for several recent earthquakes, greatly increasing the number of people who have studied those events.

3) Operations of ALOS and ERS-2 have been terminated and InSAR usage of ENVISAT data is limited. In this period of time, what further actions can we make to facilitate access to other satellite radar data?
   - The E&T community understands that ESA has limited influence on other SAR data providers, but hopes ESA can help to encourage methods to get better access to SAR data from TerraSAR-X, COSMO-SkyMed and Radarsat-2 for scientific research.

4) What can ESA do more to help scientists to further exploit the existing 20-year SAR data archive of ERS-1, ERS-2, ENVISAT?

- The E&T community would like to thank ESA for acquiring this unique archive of SAR data and making it available for scientific research.
- When possible, providing online access to large parts of the SAR archive data would be a huge help for scientists to further exploit the existing data.
- It would be helpful if the Eoli catalog were cleaned up.
- It would be extremely helpful for earthquake response if ESA could provide rapid preliminary orbit data.
- We also encourage ESA to continue to acquire as much Envisat data over high strain tectonic zones as possible to ensure that data are available for future earthquakes.

5) The Supersite initiative has shown the potential of fast and free satellite data distribution following major earthquakes. Should we try to extend these efforts to moderate earthquakes? If so, what would be the best way of doing so?
   - Not discussed in our session, deferred to Supersite session.

6) How can we prepare to analyze the volume of data that will be acquired with the Sentinel mission?
   - It would be good to have all the existing data online, easily accessible. This will help to prepare for large data volumes.
   - Some virtual data that simulate Sentinel-1 products or actual TOPS SAR acquisitions from TerraSAR-X or Radarsat-2 are necessary for the users to prepare.
   - ESA might consider providing geocoded interferograms, perhaps using a “process on demand” method.
   - Not only image data but also auxillary products may be useful. For example releasing raw GPS data from the satellite would motivate new methods of determination of precise orbits, and ESA can get feedback for improvements.

7) Has there been recent developments in methodology that are useful for studying earthquake and tectonic studies? If so, how can we promote using such techniques?
   - ESA is developing NEST-DORIS toolbox; more tools need to be included, e.g. offset-tracking and time-series analysis. Making source code fully open (e.g. NEST SAR processor) would help advancing methods.
   - It would also be great to have an open source package or packages for doing earthquake source inversions. Some source code for InSAR data resampling is available at http://roipac.org

8) What are the options currently available to correct InSAR data from tropospheric errors? And how could this be improved in the future? Are any future ESA sensors going to help?
   - The situation has improved a lot in the last two years, we now have a few options for the correction.
   - OSCAR service will start soon at http://oscar.jpl.nasa.gov (temp. available now at http://oscarproject.jpl.nasa.gov). Initial service is MODIS near-infrared water vapor zenith path delay, to be followed soon by ECMWF operational weather

forecast model estimates of zenith path delay (dry and wet) and combined products interpolated spatially and vertically to high resolution using a DEM.

- ESA might consider providing atmospheric phase screens as standard products, if information is available to estimate this from other future sensors.

1.4.7 Recommendations

1. The observation strategy for Sentinel-1 should consist of one main mode, with as frequent acquisitions over tectonically active areas as possible (along with regular acquisitions in other areas), with a priority on two look directions, with small baselines, single polarization, and long data-takes.
2. ESA should make available some virtual data that simulate Sentinel-1 products or actual TOPS SAR acquisitions from TerraSAR-X or Radarsat-2 for the user community to prepare
3. ESA should provide estimates of fine offset between TOPS SAR scenes to avoid phase ramp from small mis-registration of interferograms
4. Consider using higher resolution modes over active tectonic regions to enable along-track deformation measurements with multiple-aperture interferometry or sub-pixel correlation
5. ESA should make raw auxiliary data for Sentinel-1 available once the mission starts, e.g. raw GPS data for orbit determination
6. More ERS/Envisat data should become freely available online, to facilitate further exploitation of these huge archives and for scientists to get better prepared for Sentinel-1 data volumes
7. ESA should acquire as much Envisat SAR data around 38°N as possible, also in areas that are not tectonically very active
8. ESA should provide rapid preliminary orbit data for Envisat to help rapid response to earthquakes

1.5 Ice & Snow Session

Chairs: J. Mouginot & N. Gourmelen

1.5.1 Session Overview

- 12 talks and 10 posters
- Antarctic ice motion, grounding-line detection and monitoring, dynamics ice-fluctuations in Antarctica and Greenland, small ice-caps (Iceland, Patagonia), mountainous glaciers, periglacial landforms and glacial rebound
- Reviews of ERS-2 2011 3-days campaign and ERS2-ASAR cross-interferometry

1.5.2 Seed Questions

- What recommendations does this thematic community have for Sentinel-1 observation scenarios over InSAR areas of interest (global/supersite), in terms of revisit frequency and pass (ascending / descending)? Data delivery?
- What major challenges remain for glaciology, and how can satellite observations (InSAR in particular) assist?
- What are the relative advantages and disadvantages of InSAR observations of ice at C-band and L-band?
- What are the advantages of a short-repeat InSAR mission for glaciology? In terms of providing new understanding of physical processes, how short do we need?
- What are the advantages of acquiring simultaneous range and azimuth displacements for glaciology?
- What are the observables that glaciology wants from SAR and InSAR datasets?
- With three InSAR missions phased out in 2011, the community is facing a potential data gap until new missions like Sentinel-1 are online. What are the most important regions for the cryosphere community that the remaining InSAR missions should provide data for (at minimum)?

1.5.3 Recommendations

1. Sentinel-1: Ideally to operate at HH-polarization, with interferometric wide swath (IWS) mode, with ascending/descending passes for full coverage of ice every cycle:
   - IWS is better suited than Strip Map (SM) for calibration and mosaicking of data;
   - EWS degrades the spatial resolution too much.
   - Ascending/descending passes required for 3d vector mapping, layover in mountains glaciers and velocity field referencing.

2. Sentinel-1: Frequent visit (every cycle) is desirable to:
   - Capture rapid events and their time sequence (ice-shelf collapse, glacier speed up, calving, drawdown, seasonal variation, etc.) --> new science.
   - Enables data stacking to map ice motion in the interior (< 1 m/yr)
   - Enables retrieval of ice shelves motion (tidal contamination).

- Optimal revisit time is unknown as events can take place on a time scale of hours to days. Can we envision even shorter repeat time with sensors configuration such as Sentinel1 a&b for study of ultra-rapid deformation (e.g. stick slip on the scale of 1 hour)?

3. Selection of "supersites" for systematic acquisitions - maybe following the Tandem-X supersites definition (5 main outlet glaciers in Greenland; PIG, Thwaites Totten and the Peninsula in Antarctica + Mountain glaciers in Himalaya, Patagonia, Alaska).
    - Careful about assuming too much a priori which area matters and which does not --> focus on all coastal regions as a threshold mission with a set of predefined tracks
    - For ice sheet wide mapping, once a year is probably sufficient because large changes in the interior regions are not expected. Yet you need sufficient data stacking to tackle motion of less than 1 m/yr (e.g. a couple of months of data).
    - Do not forget the smaller glaciated areas: Sentinel-1 systematic mapping of ALL ice sheets and glaciers (Patagonia, Alaska, Himalaya, Alps, Svalbard, Canadian ice caps, etc.) decided a-priori, every cycle if possible, at the minimum by series of 4 consecutive cycles (3 for grounding line mapping, 4 in case of gaps), with coast-to-coast tracks.

4. New challenges with Sentinel-1:
    - We will be able to handle distribution of all data in RAW/SLC format and produce velocity maps.
    - Coarser resolution IWS data compared to stripmap --> Additional studies needed with 6+ days temporal baselines (e.g. ERS-2 2011)
    - TOPS azimuth co-registration?

5. Sentinel-1 Coordination with other Space Agencies:
    - Coordinate with RADARSAT-2 and constellation for coverage of the South Pole.
    - Coordinate with other satellites (TSX-TDX, Cosmo, Radarsat) for continuity measurements on specific "supersites" (rapidly changing areas), now that three InSAR missions are being phased out in 2011.

6. Maintain the ERS-1/2 and Envisat ASAR data archive.

1.5.4 Other Comments

Advantages and disadvantages of C-band and L-band: L-band procures higher coherence but also higher contamination from the ionosphere. Would S-Band be a good compromise?

1.6 Terrain Subsidence and Landslides Session

Chairs: M. Crosetto & P. Pasquali

1.6.1 Session Overview

The session included seven oral presentations:
- A country-wide product (PSI + levelling + GPS): ERS & Envisat
- Subsidence study using L-band ALOS
- Subsidence induced by deep tunnels: ERS & Envisat
- Landslide monitoring using the 20 year SAR archives: ERS & Envisat
- Slope instability in periglacial environment: TSX (preliminary results)
- Coal mining (Gardanne test site!)
- Urban subsidence due to groundwater: ERS & Envisat & TSX

The poster session included more than 40 posters related to terrain subsidence and landslides, showing that many groups are working on these topics.

1.6.2 Seed Questions and Discussion

1. What recommendations does this thematic community have for Sentinel-1 observation scenarios over InSAR areas of interest, in terms of revisit frequency and pass (ascending / descending)?
   - Systematic acquisition, with shortest revisiting time
   - In addition, for priority areas: Can ESA set a web-based system to collect, in a transparent way, the priorities of the potential users of Sentinel?
   - Dual mode (asc/desc) particularly useful for landslide monitoring in mountainous areas.
   - About the continuity Radarsat-Sentinel: Is it possible to define a set of areas where Sentinel acquisitions are guaranteed to get the Radarsat-Sentinel continuity?

2. What are the achievements obtained using the VHR SAR imagery?
   - Encouraging results have been shown. High resolution is promising for different applications, e.g. monitoring small-area landslides. However, out of 42 posters, 5 were based on TSX, and 0 (zero) on Cosmo-SkyMed.

3. Is the average displacement rate enough, or are there other (and which) synthetic descriptors more suitable for providing a condensed overview of the phenomena that can be discriminated in a certain area, in particular in the case of long observation intervals and/or strong non-linear displacements?
   - In addition to the average displacement rate, other synthetic descriptors could provide an overview of the monitored phenomena. However, for the moment there is not much research activity on this.

4. How far can nowadays the models for landslide and subsidence take advantage in a quantitative way of the measurements obtained from DInSAR, and in particular from time series analysis, and what should be developed more on the data and / or on the modeling side?
    - In addition to the InSAR research, more emphasis should be put on using quantitatively the InSAR results, e.g. for modelling the sources of deformation, risk assessment, forecasting, etc.

1.7 Volcanoes Session

Chairs: Y. Fukushima & G. Puglisi

1.7.1 Session Overview

We had presentations on volcanoes all over the world, more than the last FRINGE workshops: Etna, Campi Flegrei, Ethiopian rift, Kilauea, Galapagos, Miyakejima, North-Central-South America, Sunda arc (Indonesia), Eyjafjallajokull, Piton de la Fournaise, Saudi Arabia.

Many studies investigated the internal process and proposed models for the physics of volcanoes. These studies benefited from large amount of data of good quality. Examples: behaviour of deep magma body (Fialko), regional characteristics (Biggs, Chaussard, Ebmeier), very high resolution in time and space (many presentations) New science!

1.7.2 Seed Questions and Discussion

1. What recommendations does this thematic community have for Sentinel-1 observation scenarios over InSAR areas of interest, in terms of revisit frequency and pass (ascending / descending)?
   - Basically as simple as possible, ascending & descending on every pass on volcanic “regions”. Volcanoes often have steep slopes, and ascending & descending would be important.
   - If any anomaly such as seismic swarms is identified and a future eruption is anticipated, high priority should be put in acquiring as much data as possible.
   - The characteristics of the TOPS acquisition should be investigated, in particular on the possible phase ramp due to mis-coregistration. Experiments with real TOPS data and simulation studies are highly desirable.

2. How are we moving toward an effective global monitoring of volcanoes using InSAR?
   - Systematic investigation along entire arcs has been shown to be possible (note: L-band data have been used)
   - We are technically ready for this monitoring, so we can perhaps start to think about operational monitoring (who and how (individual countries/international organization, data transfer, result communication)).

3. What are the advances in mitigation of atmospheric noise since 2009 and what are the promising ways to proceed?
   - Things are improving, climate models work well in many cases (of course there are exceptions; local anomalies).
   - So far there is no definitive version of the method.

4. What about the integration between SAR and in-situ (geodetic) datasets?

   - GPS data are effectively used to compare with InSAR time-series results, and it has been shown that InSAR and GPS displacements can be integrated to get 3D displacement field (getting in-situ data is closely related to Supersites).

5. Since 2009 the SAR systems with high spatial or temporal resolution (X-band missions, high revisit time) have been improved (i.e. launch of TanDEM-X, during 2010, completion of Cosmo-SkyMed constellation, mid 2010). Which are the effects of this improvements on the study and monitoring of volcanic (and tectonic?) areas, according the experiences of the scientific community? And what are the expected effects?
   - Access to X,C,L band data has a large impact. Some volcanoes such as those included as Supersites benefit from this situation. However, there are many other volcanoes that cannot benefit from these data. It is nice if the space agencies can program background missions for science on those active volcanoes. This requires negotiation with space agencies (ASI).

6. What are the new InSAR findings in volcanological studies since FRINGE 2009?
   - Much more comprehensive studies have been done using more data from more sensors, on much wider area of the Earth.

1.7.3 Recommendations

Sentinel-1 data acquisition:

- We want high revisit frequency on volcanic regions, homogeneous acquisitions over such regions (e.g. the whole volcanic arc) is desirable.
- Priority is in two look directions, ascending and descending. This is because of steep slopes (layover etc) and the nature of volcanic deformation (unknown source type, geometry…)
- Make sure that the acquisitions are not missed in case some signs of possible future eruption, such as increase in seismicity, are found (users are partly responsible for this). Acquisitions in addition to background mission are desired if there is no conflict.
- Characteristics of interferograms from TOPS mode data should be investigated as this could be a major error source.

Toward global monitoring:

- Timeliness of data availability and ease of data downloading are highly desirable.
- This may be sufficient as ESA's responsibility. Do we expect more?

1.8 Methods General Session

Chairs: U. Wegmuller & A. Monti-Guarnieri

1.8.1 Session Overview

Session with four oral presentations:

- **"*Effect of Unmodelled Reference Frame Motion on InSAR Deformation Estimates*".** Due to secular tectonic motion the reference frame used for orbit data undergoes a motion with respect to the Earth surface. Such motion causes displacement rate estimation to be biased. Such error can be corrected by accounting for plate velocities, which are available through plate kinematic models.
- **"*Revising vegetation scattering theories: Adding a rotated dihedral double bounce scattering to explain cross-polarimetric SAR observations over wetlands*".** In this paper it is observed that not only co-polarization, but also cross-polarization signals provide information about water level mapping, revealing double bounce contributions occur for all polarizations. The presence of rotated dihedral components is suggested to provide physical support to this phenomenon.
- **"Recent advances on InSAR temporal decorrelation: theory and observations using UAVSAR".** It is shown in this paper that uniform Brownian motion is not sufficient to discuss temporal decorrelation in forested areas, as it does not explain the dependency w.r.t. polarization nor the arising of complex valued terms. A more proper treatment is provided by allowing temporal decorrelation to depend on the vegetation structure. As a result, a model is provided to retrieve forest height from temporal decorrelation measurements.
- **"Mining Very High Resolution InSAR Data based on Complex-GMRF Cues and Relevance Feedback".** This paper proposes an Image Information Mining system which uses InSAR data to recognize the structure and the objects with a Relevance Feedback Support Vector Machine active learning. Results show phase information can provide added information for Image Information Mining.

1.8.2 Seed Questions

1. Are there any recommendations for the future coming out of this research?
2. Relevance of these methods for Sentinel-1
3. Do these new methods result in new applications?

1.8.3 Recommendations

1. The community expresses the need to be well prepared to processing interferometric TOPS data from Sentinel-1 as soon as they will be made available. To this aim it is recommended to:
   - Disseminate detailed information about the TOPS mode of Sentinel-1

- Push for the availability of TOPS interferometric pairs from TerraSAR-X or RadarSAT-2 to be used to better understand the actual capabilities of TOPS Interferometry

2. For Sentinel 1 operations it is recommended to collect large baselines by periodically shifting platform trajectory. This modality would allow collecting packs of small baselines for DInSAR while allowing few larger baselines for InSAR and Tomography.

1.9 Methods Unwrapping Session

Chairs: M. Crosetto & M. Costantini

1.9.1 Session Overview

The session included four presentations:

- A 3D (spatio-temporal) approach: extended minimum cost flow
- A model-based unwrapping, where the importance of the thermal expansion component of X-band phases was highlighted
- A redundant 3D phase unwrapping approach
- A 2D unwrapping on homogeneous image segments

1.9.2 Seed Questions & Round Table Discussion

1. Is phase unwrapping still a key problem in SAR interferometry?
   - Yes, it is: the ambiguous nature of the phases is a key intrinsic limitation of the technique, with an important impact on many InSAR/DInSAR/PSI applications.

2. Are the methods able to provide a quality index associated with the unwrapped phases, e.g. three classes: highly reliable, reliable and problematic phases?
   - This would be useful to help a correct exploitation of the results, but for the moment there is not much research activity on this.

3. 2D vs. 3D unwrapping methods – what is the state-of-the-art and what is the most convenient trade-off with present computers and more powerful future ones.
   - 3D methods require significant computational efforts. However, this is not seen as a major limitation, given the expected development of computational tools. 3D methods offer the advantage of automatically analysing large datasets; which is in particular useful in difficult areas.

4. Model-based techniques are often necessary; at least as a preliminary step to obtain estimates (such as mean velocity and elevation) useful to help phase unwrapping. What is the state-of-the-art in this field?
   - Model-based techniques can help phase unwrapping. This is usually done by estimating, from the wrapped phases, deformation velocity and the residual topography, removing them these components before phase unwrapping. For VHR X-band data it is suggested to extend the model to include the contribution of thermal expansion.

1.10 Pol-InSAR and Tomography Session

Chairs: S. Tebaldini & C. Lopez-Martinez

1.10.1 Session Overview

The session included five oral presentations:

- **"*Diff-Tomo Opening of the Urban SAR Pixel: Single-look 4D and Non-uniform Motion "5D" Extensions*".** The availability of multi-baseline and multi-temporal data makes it possible to open the SAR pixel by retrieving height, Line-Of-Sight (LOS) velocity and LOS acceleration of multiple targets. Spatio-temporal interpolation of the baseline set to a uniform grid is shown to greatly help the imaging and hence estimation performance.
- **"*Polarimetric SAR Tomography with TerraSAR-X by means of Distributed Compressed Sensing*".** Compressed Sensing (CS) is an established technique to provide super-resolution tomographic imaging of sparse targets. Distributed CS exploits further constraints by imposing continuity of the solution for neighbouring pixels and/or different polarizations, resulting in improved imaging capabilities.
- **"*3D SAR Tomography of the Paracou Forest: Methods and Results*".** This paper provides a tomographic analysis of the Paracou forest in French Guyana based on the P-Band data collected during the TROPISAR campaign. The analysis resulted in 4 independent Single Look Complex Fully Polarimetric SAR images of the forest, each of which associated with a certain height above the ground (0,15,30,45 m). Double bounce scattering from ground-trunk interactions is revealed in the ground layer image.
- **"*Underlying Topography Estimation and Separation of Scattering Contributions over Forests Based on Pol-InSAR Data*".** This paper considers the estimation of ground topography beneath the vegetation layer based on fully polarimetric single baseline data. The estimation is shown to be feasible given a model for the polarimetric signature of volume scattering. The feasibility of this approach is fully confirmed by results from real data.
- **"*Sub-Canopy Topography Estimation with Multibaseline Pol-InSAR Data: A RELAX-Based Solution*".** This paper presents an approach to the estimation of ground topography beneath the vegetation layer based on multi-baseline data. The estimation proceeds in an iterative fashion based on the data spectral features. The validity of the method is confirmed by experimental results.

1.10.2 Seed Questions and Discussion

1. What recommendations does this thematic community have for Sentinel-1 observation scenarios over InSAR areas if interest, in terms of revisit frequency and pass (ascending/descending) ?
   - A priori, Sentinel-1 is not a system designed to perform tomography. Its main objective is deformation monitoring. Currently, the system configuration is designed in such a way that small baselines are preferred with the focus on

deformation monitoring. An increase of the baseline to allow tomography will conflict with the application of subsidence monitoring.
- In case of urban tomography, X-band systems are more suitable.
- For forest tomography, Sentinel-1 may present penetration problems due to the working frequency (C-band)
- Non uniform motions:

2. Tomography allows separation of targets within the same range-azimuth cell based on their elevation and/or LOS velocity. Yet, ambiguities may arise concerning target location and velocity, not to mention more sophisticated motion patterns.
   a. How do we characterize the ambiguity between target position and motions? Can we provide inputs for the optimal design of spatial/temporal baseline sets?
   b. What is the relevance of polarization diversity (solve ambiguity and/or reduce the number of passes)? Considering the future Sentinel-1 SAR system, are fully-polarimetric data necessary? Which is the best dual-pol configuration (HH/VV, HH/HV, HV/VV, RR/RL…)
      - (for 2a) For Differential Tomography, theoretical studies need to be addressed in order to discuss the ambiguity and performance associated with the estimation of non-uniform motions of multiple targets. These studies should consider not only theoretical bounds but also performance achievable in practical cases.
      - (2b) The low impact of Faraday rotation at C-band suggests the possibility to exploit dual-pol data(HH-HV) to help target separation in urban areas.

3. Retrieval of ground topography beneath the vegetation layer:: In recent years the problem of retrieving ground topography beneath the vegetation layer has been addressed by different research groups. To this aim, what is the relevance of polarization diversity or the use of coherent scattering models?
   - When addressing the problem of underlying topography estimation, two alternatives are possible. When the number of baselines is large, tomographic approaches give a good estimate of the ground topography, provided that electromagnetic waves penetrate enough to be sensitive to the ground. When the number of bases is small, Pol-InSAR approaches supported by coherent scattering models are a better option. All in all, both approaches are complementary.
   - It is recognized that collecting multiple baseline is the most valuable asset for spaceborne missions. Though, temporal decorrelation in multi-temporal stacks is recognized as the main limiting factors for the estimation of ground topography beneath the vegetation layer.

4. Vertical structures of distributed media: Tomography provides access to the vertical structure of distributed media, therefore providing a new tool for large scale forestry studies. Yet, radiometric accuracy is of the uttermost importance to the aim of providing useful inputs to scientists outside the field of SAR processing.

a) Super-resolution techniques are appealing as they allow minimizing the number of baselines. Yet, to what extent radiometric accuracy is preserved?
b) Would it be necessary to consider the development of coherent scattering models to retrieve quantitative information?
c) How do we cope with temporal decorrelation (e.g.: proper selection of interferometric pairs; temporal decorrelation model; other….)? Would it be necessary to introduce temporal decorrelation models for urban scenarios?
   - It is recognized the need for further studies addressing the radiometric accuracy of super-resolution algorithms.
   - Urban tomography provides way to access the ground layer by removing lay-over components. To this aim, however, temporal stability is required. This appears to be a serious limit to the study of flooded areas, for example.

1.11 Atmosphere Session

Chairs: R. Hanssen & F. Rocca and D. Perissin & D. Small

1.11.1 Session Overview

- **Paul Von Allmen** presented an *Online Service for Correcting Atmosphere in Radar* (OSCAR) by merging ECMWF and MODIS with quality control, and agreement with GPS. This seems to be a good step forward towards an operational approach for correcting atmospheric signal. (Particularly long wavelength signal and vertical stratification). There is a need for quantitative evaluation of the approach.
- **Rosella Ferretti** talked about possibilities for InSAR IWV variational assimilation in MM5: a step for improving the model initial conditions at high resolution. She demonstrated positive steps towards assimilation, and it may become possible when InSAR data become more frequently available.
- **Xiaoying Cong** discussed the ERA-Interim reanalysis of ECMWF and GNSS atmospheric correction with EUREF. She also demonstrated centimeter-Level SAR geolocation after correcting atmospheric delay using ECMWF Weather Data. GPS-ECMWF between 8 and 13mm (seasonality). Absolute NWP correction up to 3cm accuracy. Positive for earthquake analysis
- **Zhenhong Li** showed very good agreement between GNSS data and InSAR time series, over wide regions, demonstrated over various test sites. (*InSAR Time Series with Atmospheric Estimation Model for Regional Deformation Mapping*)
- **Wenyu Gong** presented mitigation strategies with a Numerical Weather Model to assist Time Series InSAR Processing. She used the WRF model and demonstrated good agreement for the long wavelength features, but not for small turbulent effects. She discussed the stochastic atmospheric variability and noted that the variability of WRF is always smaller than the observed APS in InSAR.
- **Franz Meye**r talked about the stochastic properties of the Ionosphere, presenting “IP-STATS - A System for Deriving Statistical Models of Ionospheric Signals in Low-Frequency SAR”. Using ionospheric observations he was able to simulate ionospheric phase statistics simulator quite realistically, including anisotropy. Excellent correspondence between simulated variability and observed variability, enabling a priori assessment of ionospheric error signal.
- **Daniele Perissin** showed that MM5 can help in reducing the stratification part of the APS. However, features smaller than 25 km decorrelate within one hour and it is not possible to model them with MM5. Different start times of the MM5 model give significant differences in the realization. MERIS was not available for 40% of the occasions, due to clouds. InSAR and GPS show good correlation. APS estimation from the SAR data is optimal.
- **Romain Jolivet** showed that ECMWF works for stratification with a relatively simple model in Tibet, in a talk called *“Systematic InSAR tropospheric phase delay corrections from global meteorological reanalysis data”*
- **Rana Charara** corrected DInSAR ALOS data using APS estimated by GPS to constrain the surface deformation in Taiwan.

- **Bernhard Rabus** discussed a paper on CO2 sequestration monitoring, reporting on his improvements and work since Fringe 2009, pushing the accuracy limits with statistically optimal spatio-temporal removal of the atmospheric component from InSAR Networks

1.11.2 Seed Questions and Discussion

1. How good are we at predicting the tropospheric/ionospheric path delay disturbances within a single SAR scene before touching the SAR data itself? What is the experience within local high density GPS networks and away from them (globally)?
   - Positive experiments with GPS correction within local high density GPS networks
   - On a global level, move towards Numerical Weather Prediction (NWP)

2. On MERIS/MODIS for APS correction in InSAR: if it works, you don't need it, and if you need it, it does not work. Would you agree?
   - MERIS/Modis applicability depends on the region

3. Would standard annotation of global tropospheric/ionospheric estimates be useful, e.g. within Sentinel-1?
   - Yes, standard annotation of global estimates would be useful, e.g. within S1 products.
   - Internet services are becoming available for the statistical approach of the ionosphere

4. On weather models:
   - Weather models are good for the long wavelengths (>20-25 km) and for vertical stratification. More focus on the stochastics is needed. Current accuracy is in order of cm.

5. On Atmospheric Phase Screen (APS) estimation from SAR data:
   - In Time series InSAR there may be correlation between motion and atmosphere. This may pose problems in separating them: clearly document process, do not "sweep under carpet"

1.11.3 Recommendations

1. Investigate adding global troposphere & ionosphere models routinely to SAR products to benefit geo-location & interferometry.
2. Investigate the quality of APS estimates from PSI.

1.12 DInSAR and PSI Session

Chairs: J. Mallorqui & R. Hanssen

1.12.1 Session Overview

- Several studies **combining different types of scatterers (PS, DS, temporary)**
- More **detailed analyses**, up to the level of single constructions.
- **Better error models**
- **Wider geographic areas** covered
- **TOPS preparedness**
- Optimally use of **multi-sensor data** (TSX, Cosmo-Skymed, Envisat, Radarsat)

Presentations

- **Nico Adam** presented work from the Terrafirma project, aiming for PSI products over wide spatial areas. Challenges such as atmospheric delay and low PS density were discussed. This involves the use of a NWM (WRF). He was estimating error metrics and discussing error propagation
- **Petar Marinkovic** discussed some TOPS implication for InSAR. He used ERS and TSX spotlight data to use the parts of the spectrum that would also be available in TOPS mode, and compared the characteristics. He recommended that ESA should provide some TOPS data sets to the science community to test and develop their algorithms.
- **Luca Marotti** presented TOPS characteristics. He discussed the requirement of very accurate azimuth coregistration and presented TOPS-stripmap cross-interferograms. A discussion followed on whether azimuth coregistration will work in all cases, e.g. when there are moving subparts in the image.
- **Zhong Lu** focused on estimating the 3D deformation, especially the North-South component. MAI was discussed and applied on Hawaii and on Haiti. Comparison with GPS seems very good. The error bars for SAR MAI in north direction are large, but the estimates are relatively good. He analyzed the performance for Sentinel-1 and compared an ERS-2 pair and a simulated sentinel 1 pair, combining ascending and descending. MAI allows 3D deformation mapping with cm accuracy (2-3 times better than offset based). For Sentinel-1 MAI could reach 10 cm
- **Javier Duro** talked on X-band SAR data to detect and monitor motion. He was merging information from different sensors (Cosmo-Skymed, TSX, ERS and Envisat), and discussed what are the options of cross-interferometry. He showed examples on a landslide with Cosmo-Skymed and TSX
- **Parwant Ghuman**: Bridge health monitoring: showing a good example of applications that benefit from the high resolution data.
- **Kanika Goel** presented an advanced method to combine Distributed and Persistent Scatterers (DS & PS), and an L1 norm SBAS approach. The method was demonstrated on a gas storage site.
- **Daniele Perissin** presented his processing method and how it was embedded in the Chinese situation. (i.e. different ways to connect points, such as ‘the flowering tree’). Strong need for addressing temporally coherent points.

- **Lei Zhang** presented his method to find coherent points using e.g. offset estimation and to evaluate motion of temporarily persistent scatterers
- **Alessandro Ferretti** presented TRE's SqueeSAR method: a combination of using Persistent, Distributed and Temporary coherent scatterers.
- **Piyush Agram**. Presented a noise covariance model for time series InSAR, and made a plea for using the entire covariance matrix. Better stochastics are needed.
- **Alexander Schunert** showed different ways to assess the scattering mechanism of a building, and zoomed in on extracting maximum information from window lines of a building.
- **Pooja Mahapatra** presented the use of radar transponders in cases no PS are available. She proved with a leveling experiment that for ERS-2 quality levels of 2.5 mm were obtainable. Temperature correction of the transponders was needed.

1.12.2 Recommendations

1. ESA should produce a concise note addressing the origins, the processing recommendations and the consequences of the high accuracy needs for azimuth coregistration (induced by the TOPS system).

2. ESA should distribute some sample TOPS data sets to allow the user community to prepare themselves for the new data types.

3. There is a need for an increased orbital tube to allow for better relative height estimation of scatterers. (The current 50 m tube will not allow for this, and as a result height precision is limited.) It should be investigated whether this should only be a limited period of the mission (say, at initialization) or continuous. In other words, the orbital tube needs to be revisited.

4. To facilitate the acquisition planning, ESA should make a web portal available where scientists/users can pose interest for acquisitions. The users should clearly identify the 'minimum requirements' for their proposed research (E.g. not asking for ALL available acquisitions (asc/desc/adjacent) if this not strictly necessary). Make the process transparent.

1.13 InSAR Methods Session

Chairs: M. Eineder & F. Rocca

1.13.1 Session Overview

- **Mittermeyer** showed important examples of applications of the bidirectional SAR, using TSX, TDX grating lobes as well as along track interferometry. Ship velocities could be estimated very well.
- **Sansosti** showed very accurate point target analyses and deformation histories using very high resolution X band satellites.
- **Monti Guarnieri** presented the split swath approach to estimate slow motions of the boom of a possible Ka-band InSAR system. He then presented the effects of time varying atmospheric phase screens on a geosynchronous SAR.
- **Bovenga** discussed the stack of sub band interferograms to obtain highly coherent, even if lower resolution interferograms.
- **Wright** discussed the limits of the estimate of very small (1.2 mm/100km/year) ground motion, without meteorological corrections.
- Cross interferometry between ERS and Envisat was discussed first by **Pasquali** and then by **Wegmüller** and very high quality, low altitude of ambiguity interferograms were shown, outcome of the recent campaigns.

1.13.2 Seed Questions and Discussion

1. Derivation of 3D vectors is important to land deformation analysis

2. From relative to absolute measurements: Accurate absolute positioning techniques such as Multi-chromatic analysis, delta-k and geodetic corrections are valuable for:
   - Solid Earth motion analysis
   - Atmospheric water vapour imaging
   - Phase unwrapping support

3. The joint use of the two polarimetric channels of Sentinel -1 could be helpful for target decomposition , as well as for ship detection

4. The larger swaths of Sentinel-1 will make atmospheric effects more visible.

5. Future missions involve higher resolution, wider baselines, wider swaths, shorter revisit times, polarimetry, higher penetration (lower frequencies). What is the preferred preference for these developments?
   - Multi-Parameter systems are scientifically interesting with application potential. Examples:
     - Multi-Baseline tomography for 3D point positioning and for layover resolution

    - Simultaneous Multi-frequency systems for ambiguity resolution and accuracy improvement
- But: playing with parameters will disrupt nominal imaging sequence of sites

1.13.3 Recommendations

1. Concept of squinted or split beam antenna operations and processing aspects should be investigated to support:
    - 3D vector determination for land deformation analysis
    - Ship detection and velocity estimation with multi beam systems
    - Ocean applications and analysis of 2D motion of sea currents

2. Investigate Sentinel-1 accuracy potential for absolute positioning techniques.

3. Investigate the inclusion of weather models for Sentinel-1 SAR processing.

4. Investigate possibilities of steering Sentinel-1 off the nominal 50 m orbital tube to tomographically staggered baselines during dedicated mission phases, e.g. during the Commissioning Phase.

5. ESA should issue very representative simulated data sets to allow the study of the TOPS coregistration, and the interburst and interswath variations of the azimuth offsets.

6. Investigate the possibilities of allotting part of the Sentinel – 1 time to experiment new modes.

1.14 Fringe 2011 Summary Session

1.14.1 Recommendations

1. ESA was recommended to seriously consider data-delivery in Level-0 format as this would entail enormous savings in bandwidth (factor of ~5) for both the users and ESA.
2. ESA was recommended to deliver an open source SAR processor to the community (e.g. NEST SAR Processor).
3. TOPS-coregistration study over fast moving areas is needed.

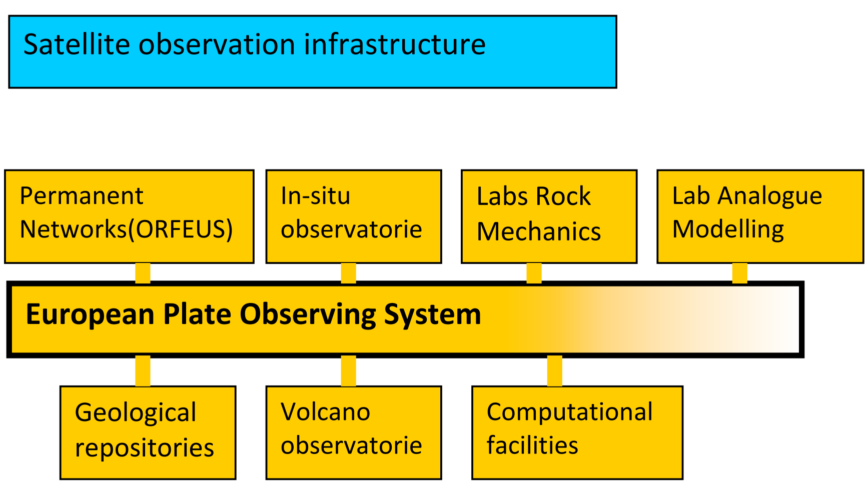
1.15 Supersites Splinter Meeting Report

Chairs: F. Amelung, C. Dobson, M. Cocco & W. Lengert

1.15.1 Progress report

- Previously identified actions have been closed (White Paper, Bylaws, Partnership instead of Consortium)
- Enlargement of on-line data repository has been done. In particular good progress has been made for the events Supersites Haiti and Japan with data from Envisat, TerraSAR-X, ALOS, Radarsat and UAV SAR
- DLR gave a presentation about procedures for accessing TS-X data to the Supersite initiative
- ESA makes very good progress in populating natural laboratories
- Space & In-situ data are joining forces:
    - Impressive presentation about in-situ assets:
    - EPOS: the "European Plate Observatory System" infrastructure project has been presented. Data assets form 18 countries are being contributed.
    - Unavco
    - Japan;
    - US- European coordination of Ground based in-situ assets are under way
    - Monitoring agencies are getting integrated into the Supersite structure

1.15.2 Supersites / EPOS infrastructure concept



1.15.3 Endorsement of White Paper

The White Paper encompasses bylaws, consortium structure, governance structure, the data policy of every contributor, time delay for volcanoes.

The CEOS survey on the Supersites resulted that:

- The White Paper looks fine.
- Reporting from the science community to the data providers is essential. The benefit for both, data provider and scientists, of openly available access needs to be shown.
- Individual data policies need to be respected

In-situ data providers are coordinated in Europe via EPOS and in the US via Earthscope. The general, beside Europe, in-situ responsibility is not clear.

1.15.4 Input for Strategic Plan (2012-2013).

- The success and usefulness need to be demonstrated
- The Strategic Plan is close to be finalized
- Draft will be posted on Supersite webpage (notification will be send). Partcipants are invited to contribute text on potential Natural Laboratories and Supersites, including information about in-situ data provider.
- (Draft of space component of strategic plan is already posted)

1.15.5 Unresolved issues

- Reporting: the usefulness of the SSNL data provision
- Different understanding of business opportunities between Space Agencies: DLR, ASI?: services (data processing and interpretation). Japan (selling of data). ESA: (1) Science; (2) innovation engine for EO
- No in-situ data provider as PoC has been identified in Japan ◊ Opportunities for CEOS data exists, but has not been exploited (e.g. no TerraSAR-X acquisitions)

1.15.6 Recommendations

1. Develop workshop to revise SSNL concept with all stake-holders on board (space and in-situ, examples: EPOS, GSI (Japan), JMA (Japan Meteorological Agency, USGS, …)
2. Make Hawaii as a **certified** – complete Supersite (e.g. some ALOS, CS, and RS1 images). Issue certificate of first Supersite at GEO Plenary to contributors and show results.

Specific needs to support the Supersite Initiative

1. To promote the link of in-situ observatories through networking initiatives (i.e., projects) at regional level (Europe, Central America, Caribbean, etc....) in order to facilitate transfer of knowledge of best practices for both tectonic and volcanic areas.
2. To support the identification of common ICT solutions as well as the implementation of modern and effective e-infrastructures standards suitable for multidisciplinary data archiving and mining.
3. To distinguish between the long-term "structured" supersites (those participating to the regional networking initiatives) and the "scientific forums" which are "virtual" platforms for sharing data, analyses and results concerning natural disasters. The latter are open immediately after a catastrophic event.
4. To encourage the collection of selected lists of supersites, candidate supersites and natural laboratories at regional level to be discussed and approved for the GEO official list. This has to be done following well-established and shared criteria.
5. To support the long-term implementation of in-situ observatories (i.e., supersites, candidate supersites and natural laboratories) in order to promote innovation for science and a better use of science for society. This might be done through regional programs and by involving funding agencies.