FRINGE 2015 – SESSION SUMMARIES

This document contains the Session Summaries of the Fringe 2015 Workshop, "*Advances in the Science and Applications of SAR Interferometry and Sentinel-1 InSAR Workshop*" that was organised on 23-27.3.2015 in ESA-ESRIN, Frascati, Italy.

1 LIST OF ACRONYMS

APC	Antenna Phase Centre
CEOS	Committee on Earth Observation Satellites
CoM	Centre of Mass
DEM	Digital Elevation Model
DRM	Disaster Risk Management
EC	European Commission
EW/EWS	Extended Wide Swath
GRD	Ground Range Detected
DEM	Digital Elevation Model
DInSAR	Differential InSAR
HR	High Resolution
ITRF	International Terrestrial Reference Frame
IW/IWS	Interferometric Wide Swath
MAI	Multi-Aperture Interferometry
NRT	Near Real Time
NWP	Numerical Weather Prediction
PDGS	Payload Data Ground Segment
PS	Persistent Scatterer
PSI	Persistent Scatterer Interferometry
RIP	Rest In Peace

SLC	Single Look Complex
SPC	Scattering Phase Centre
S-1	Sentinel-1
TEC	Total Electron Content
TOPS	Terrain Observation by Progressive Scans
TDX	TanDEM-X

1.1 Table of Contents

2 INSAR WITH SENTINEL-1 SESSION

Chairs: F. De Zan and Y. Larsen

2.1 Session Summary

- The Sentinel-1 InSAR results of the different contributions presented in the session confirm the excellent interferometric capabilities of the Sentinel-1 sensor.
- In spite of the high coregistration requirements for TOPS imaging, different presenters showed InSAR and time series results, hence demonstrating the Sentinel-1 capability for deformation monitoring in slow-rate deformation (i.e., PSI) scenarios.
- There is an agreement in the way to process TOPS Sentinel-1 data interferometrically based on a geometric coregistration plus a global offset estimation, where the latter is done by exploiting the overlap areas between bursts/sub-swaths. Instead of a global offset the model can be extended to include the first derivative of the baseline error. Owing to the small orbital tube, low resolution DEMs still give a very good coregistration performance.
- The global offset between two acquisitions seems to be consistent for different slices, a fact that can be exploited to properly calibrate the geometry in complicated areas.
- In non-stationary scenarios with strong azimuthal displacements (e.g., earthquakes, glaciers) phase jumps will appear between bursts, which might complicate the phase unwrapping. There are few references in the literature addressing this problem, hence the processing and analysis of more Sentinel-1 data is required in order to properly understand the problem and to be able to provide recommendations.
- More data are required in order to be able to evaluate the potential exploitation of the overlap areas in PSI processing in long time series, e.g., in order to refine the azimuth coregistration for long temporal baselines using persistent scatterers.
- The COMET initiative will systematically exploit the Sentinel-1 data in order to monitor, better understand, and model earthquakes, volcanoes and tectonic areas for the whole solid Earth.

2.2 Session Recommendations

- Having Sentinel-1A and Sentinel-1B, the implementation of special acquisition geometries (large baselines, 2-looks TOPS, staggered TOPS,…) for limited phases or selected target areas could provide opportunities to add value to the interferometric products, at the expense of deviating from a simple, regular acquisition plan. The actual impact on the operational requirements of the Copernicus services should be assessed.

- ESA is increasing the ground segment capabilities to distribute to the science users the SLCs of all acquired images (the baseline of the mission was only 25%) and to provide access to historical data (i.e., no rolling archive in practical terms). The scientific community strongly supports and recommends this initiative.

- The accuracy of the precise orbits seems to be similar to the accuracy of the restituted orbits. It is recommended to perform a systematic analysis of the two in order to confirm the better accuracy of the precise orbit product. In case of similar performances, it is recommended to investigate why the accuracy of the precise orbit product is not better (as it would be expected).

- The distribution of S-1 coregistered data products is considered a valuable service especially for the non-expert users. Two approaches have been identified:

    - To exploit the available S-1 PDGS stack co-registration post-processing feature;

    - To add to the non-coregistered products auxiliary co-registration information (accurate azimuth shifts) with respect to a reference orbit;

    - ESA could assess the possibility to support one of the two approaches.

3 COHERENCE EXPLOITATION SESSION

Chairs: M. Foumelis and U. Wegmüller

3.1 Responses to Seed Questions and Recommendations

1. Are there open issues in the coherence definition and estimation?
    - Discussion: Coherence is already well defined characterizing InSAR phase quality. Assumptions are necessary for its "estimation" from SAR data, which underline the need to understand what it is really measured.
    - Recommendations: The ceiling for coherence estimation has been reached with already available algorithms. Coherence should be estimated from original InSAR data. No need to optimize the estimation through filtering or pixel selection procedures within the estimation windows as this might result in altering of true properties of the land surface.
2. The understanding of temporal coherence? (e.g. on/off versus gradual temporal decorrelation; the role of the time interval)
    - Discussion: Diverse approaches for temporal coherence estimation are followed especially in PS-like processing.
    - Recommendations: Might be of interest to homogenize the temporal coherence estimation approaches. Less effects are expected for deformation related studies compared to analysis of land cover/use temporal behaviour.
3. S1 IWS coherence compared to ERS and ENVISAT coherence (role of spatial resolution? time interval? TOPS mode? baseline?)
    - Discussion: Comparisons between ERS/ENVISAT and Sentinel-1 coherence estimates should be performed to understand what is potentially gained using S1.
    - Recommendations: ?
4. What is the information content of single pass (e.g. TDX) coherence?
    - Discussion: Contains thematic information, however, the exploitation of low coherence values should be handled with care.
    - Recommendations: S1A 12-days coherence is less suited to discriminating between short vegetation and forest. Optimal configuration having 1-3 days repeat cycle, but maybe we can do better with S1B in orbit (6-days revisit).

5. Analysis of coherence time series? (temporal behaviour of land use/cover classes, advance classification schemes)

    - Discussion: Sentinel-1 will allow systematic monitoring of coherence providing additional temporal information. Observed variations might be linked to random changes (e.g. agricultural lands)

    - Recommendations: ?

6. Operational use of coherence products from Sentinel-1? (e.g. multi-temporal change detection algorithms)

    - Discussion: No anomalies identified in S-1 coherence estimation. IW TOPS mode coherence is suited for operational concepts (temporal sampling and spatial coverage).

    - Recommendations: Operational processing chains should/shall be developed. Sentinel-1 data wherever/whenever possible, taking advantage of the large swath and the dual polarization capability.

4 INSAR THEORY SESSION

Chairs: R. Bamler, M. Eineder, A. Monti Guarnieri and F. Rocca

4.1 Seed Questions and Feedback

1. The millipixel challenge: What do we do about azimuth shift corrections in TOPS? What are the accepted and validated solutions and what are the remaining problems?
    - Consensus: is solved for many scenarios such as stationary and high coherent situations and probably PSI. Further experience needed for long-term low-coherence situations. The global solution of this problem would be an along-track accuracy of the orbit of 1 cm. Then, coherence-dependent signal-based methods are no longer necessary.
    - Recommendation 1: ESA to provide 1cm precision orbits, ensure SAR processor geometric accuracy (e.g. no assumptions like the start-stop-approximation should be used in the focusing algorithm) and provide auxiliary information (e.g. antenna phase center) to achieve "blind" co-registration systematically and consistently.
2. What is the state-of-the-art in tropospheric correction (stratified & turbulent atmosphere) by use of external NWP data?
3. What is the state-of-the-art in ionospheric correction by estimation from the data themselves of by use of external data?
    - Weather models are able to reduce large scale path delay variations and stratification (topography-dependent) effects in many cases.
    - Short scale variations are rarely resolved; other data such as radiometers are needed which are rarely available/useable
    - Ionospheric delays are considered non-critical in C-band but very relevant in current and future L-Band missions. Good progress demonstrated using split-band-approaches by G. Gomba (poster). Proposal by F. Meyer to establish supersites for further studies. Effect of ionospheric TEC trends in azimuth on the azimuth-coregistration accuracy of S-1 TOPS should be investigated.
    - Available meteo/iono data should be provided with SAR products (see Recommendation 3)
4. RIP reference point: The new "SAR imaging geodesy" approaches allow for an absolute geolocation of SAR images to about 1-2 cm in range and azimuth (after correction of ionosphere, troposphere, solid earth tides, atmospheric pressure loading etc.). Together with radargrammetry also 3D localization of individual scatterers in the cm regime is possible. How can InSAR benefit from these developments? Will we need reference points any longer?

5. What is your experience with Compact Active Transponders ?
    - Consensus: co-registration of stationary scenes becomes straightforward, after the effective use of all the previously mentioned metadata.
    - For deformation estimation, reference points are still necessary. Ideal reference points such as corner reflectors are difficult to establish and to maintain.
    - Compact Active Transponders might be a solution but currently only prototypes exist. Webinar on active transponders will be organized by R. Hanssen on May, 21st.
    - Recommendation 2: Study use of cheap reference point transponders for S-1 application projects.
6. Are there applications calling for a new type of geodetic SAR product and are we prepared to produce it?
    - Agreed (see individual points before), that auxiliary information should be added to S1-SAR products to perform state of the art geometric corrections such as: Sensor parameters (SAR antenna phase center position), coordinate systems harmonization (ITRF, solid earth tides …), meteo-information, ionosphere.
    - Recommendation 3: Study the design and information content (e.g. meteorological, ionospheric, earth tides) of an auxiliary product layer to S1 products for geodetic applications. This recommendation could be combined with Recommendation 1.
7. Recently it has been shown (e.g. by De Zan et al.) that the phase closure (1-2)-(2-3)-(3-1) =/ 0 in general in interferograms. What can we do with the closure phases that are indicators of an asymmetry of volumetric profiles?
    - Recommend to further investigate and consider this effect in InSAR analysis and to possibly exploit it.
8. What is the desired revisit interval? Is that of Sentinel 1 A/B enough ? And why?
9. Should the TOPS lattice of S-1B be the same of that of S1A to get 6 days coherence or should it be at least partially staggered to achieve a better MAI or a better azimuth resolution?
    - Slight majority of the attendees showed preference for a Sentinel 1B mission identical to that of Sentinel 1A. **Consensus** on the following
    - Recommendation 4: Identify possible options to be proposed and then to be evaluated by ESA, for the experiments in a dedicated 6 month science/exploitation phase of S-1B.
        - Azimuth shifts sensitivity increase using either double TOPS or staggered TOPS.
        - Height sensitivity increase positioning S1B with a say 300m (TBC) baseline with respect to S-1A for TBC cycles.
        - Improving the azimuth resolution, doubling the Doppler spectrum.
10. ESA's Answer: The today's baseline is to stick to the mission operations concept of allowing InSAR every 6 days on priority areas, which will be particularly relevant for some applications (e.g. ice velocity). The matter may be revisited in the course of the mission, with the 2 satellites in orbit.

5 PSI AND DINSAR SESSION

Chairs: N. Adam, F. Casu, M. Crosetto, R. Hanssen, P. Marinkovic, D. Perissin

5.1 Feedback and Recommendations

1. On common data format
   - Recommendation: ESA should investigate the options to come to a common/shared data format for Time Series InSAR results, including metadata.
     - This will help in the exchange and evaluation of results.
     - Open data standards should be adhered to.
2. Reliability of Sentinel-1 interferometric results
   - Similar to previous experience with ERS/Envisat, there is a risk that one specific satellite dataset, processed to interferometric Level-2 products by different groups, will result in significantly different results. When these differences are greater than reasonable tolerances, this may jeopardize trust in the technique/mission/data.
   - Recommendation: ESA should initiate and coordinate a **benchmark study** to compare processing results of various groups, over various landscapes (arid, cryosphere, urban, vegetated, rugged, flat, …). Level-2 products, such as deformation maps, should be analysed, evaluated, and made publicly available for future reference.
3. On the use of Near Real Time data
   - NRT (<30') is available for the ocean community only now. However, it is foreseen that new applications will develop quickly that need a faster turn-around type between data acquisition and information product availability (volcanoes, infrastructure, …). Geo-synchronous system plans underline this need. Silicon valley developments…
   - Recommendation: ESA should investigate ways that lead to an acceleration of the turn-around time from data reception, via focusing to delivering SLC products and metadata.
4. 'On-demand' SLC processing
   - There may be limitations in ESA's availability to process all radar date takes into SLC products. Therefore, areas of special interest have been predefined for guaranteed SLC processing.
   - However, there may be 'ad hoc needs' to process a 'new' area (including the previous acquisitions over that area).
   - Recommendation: If 100% SLC processing is not possible, ESA should facilitate dealing with requests for on-demand SLC processing.

5. On generating wide-area InSAR products for Sentinel-1
    - No clear agreement: there are two visions:
        - Yes, it is valuable to create wide-area (worldwide) 'standardized' InSAR products.
            - Data are available, let's process them, it doesn't harm, and will be used any way.
        - No, there is no 'standard way' to process radar data.
            - The particular processing method and final product depends on the user needs, and there are many different users. A generic product may only be a 'nice-to-have', but will not be optimal for specific cases.
    - Recommendation: ESA should investigate the 'business case' of a potential wide-area product, who is the 'user'?
6. Data accessibility
    - During Fringe'15 it became clear that, from a user's perspective, there will be no major difference between the 'rolling-archive' and the 'long-term archive' ('just another ftp-site').
        - This takes away all concerns on data accessibility
    - Recommendation: ESA should communicate the data access implementation clearly online, and reveal how data from the long term archive can be retrieved.
7. Absolute Positioning
    - Recommendation: ESA should improve the quality of the S1 orbits with one order of magnitude (to the cm-level).
        - To allow high-precision positioning and to aid phase unwrapping
    - Recommendation: ESA should provide the (time-dependent) vector between the CoM of the satellite to the Antenna Phase Center (APC) of the radar and make this NRT available.
8. Localized acquisition scenario
    - Recommendation: ESA should produce and reveal a map showing how each point on earth (e.g. a 10x10 km grid) will be interferometrically imaged in the default long-term baseline mode:
        - Ascending repeat interval, and or
        - Descending repeat interval, and or
        - from various tracks (adjacent overlapping)
        - Both for the S1a and the S1a/b configuration.
        - Including time window
        - (A trainee could implement this to make e.g. a color map, or a query tool based on coordinates)
9. Orbital Tube
    - The orbital tube is set to have a radius of 50 m. This may be insufficient for 3D PS positioning.
    - Recommendation: A larger orbital tube will be beneficial for some applications, however, this should not jeopardise the main applications, particularly in geophysics. After more experience is being built up over the coming year, ESA should re-evaluate whether further improvements are possible.

10. Geodetic support products
    - "New" applications were demonstrated during Fringe, such as Phase inconsistencies technique for water effects in the ground (De Zan), Tectonic mapping (e.g. University of Leeds), Wide Area PSI (e.g. PPO, ALTAMIRA, TRE, DLR), or Absolute maps of atmospheric water vapour (Karlsruhe Institute of Technology)
    - Recommendation: ESA should develop a geodetic support product (for correction of all systematic effects: tropospheric/ionospheric delays, earth tides, Antenna Phase Center position, orbits, etc)
        - Define and specify.
        - Demonstrate.
        - Validate.

6 CRYOSPHERE SESSION

Chairs: N. Gourmelen, T. Nagler, E. Rignot, A. Shepherd

6.1 Session Summary

- 11 Exciting Cryosphere presentations were given!
- Presentations covered Antarctica (3), Greenland (4), Arctic (4).
- Several presentations showed first results of Sentinel-1 data.
    - First Greenland Ice Surface Velocity map from Sentinel-1 generated (from ~700 Sentinel-1 SLC scenes).
    - Ice velocity measurements from Sentinel-1 of Greenland outlet glaciers were validated and can be reliably used to extend long time series of velocity change.
    - Analysis of Sentinel-1 in rapidly changing Antarctic Peninsula and West Antarctica produced good results..
    - North East coast of Greenland shows rapid ice velocity increase, further speed-up of changes are expected in the near future
    - The seasonal variability of ice speed was shown for various glaciers in different regions and was recommended to be studied in more detail in the future .
- Dynamic activation of a tide water arctic glacier has been observed on Austfonna. Swath mode CryoSat SARIn data allows fine spatial resolution surface elevation change measurements to be made.
- The short repeat period of Cosmo-SkyMed data was used to assess grounding lines on the Rutford ice stream.

6.2 **Recommendations**

1. What is the preferred Sentinel-1 data product for monitoring ice sheets and glaciers (SLC or GRD; or RAW data+SAR Focussing Module provided by ESA) ?
    - Methods for parameter retrieval make use of both the interferometric amplitude and phase. Therefore,
        - SLC product is definitely the primary product of choice required by the community.
        - RAW data is just as useful as SLC's with the added benefit of lower data volume for downloading and archiving, however a SAR Focussing Module accessible to the community would be needed.
        - GRD products yield lower performance levels and are less useful for land ice applications due to lack of phase information.
2. Which Acquisition Mode?
    - IW is the primary mode for ice sheet and glacier monitoring, and the large spatial coverage and frequent repeat measurement capability will revolutionise our understanding of seasonal and annual ice velocity variations.
    - High spatial resolution StripMap mode data should be tested over fast flowing outlet glaciers.
    - Many EWS data are available for Ocean Services, however first results show that the EWS GRD data ice velocity results have much larger data gaps than IWS mode. ESA could provide a set of test EWS SLC's to assess EWS performance in more detail.
    - Gaps in current IWS provision over glaciers and ice caps (e.g. Russian Arctic) should be filled. We recommend to put in place a coordination forum together with the Sea Ice operational community.
    - Coordination with other space missions, via the Polar Space Task Group, is critical to fill in gaps in S1a observations.
    - Are we getting enough coverage of the Cryosphere from Sentinel-1a at present? Is there a need for Sentinel-1 acquisition planning for main ice sheets and ice caps (e.g. currently 3 – 4 repeat acquisitions), would the community support the concept of more frequent, systematic, year round acquisitions on the ice sheets and glaciers?
    - We recommend that data should be acquired over the full Ice Sheet area as critical gaps remain:
        - For full ice sheet coverage, at least 4 IWS consecutive acquisitions (12 day repeat) should be acquired to form 2 independent pairs as our experience in Greenland showed that with 3 passes, gaps in the velocity map still remain due to surface weathering. 4 passes would also enable grounding line mapping.
        - The ice sheet margin is the highest priority target. Continuous acquisition of selected tracks covering the periphery of ice sheets is critical to monitor seasonal and inter-annual variability of glaciers and to detect rapid transitions. We recommend to implement this along the entire coast of Greenland, and select parts of the Antarctic margins at a minimum. We would however prefer the entire monitoring of the Antarctic coast in order to detect new changes.

3. Is there a need for an archive of all Sentinel-1 A/B data of the main ice sheets and ice caps accessible to the community; if yes where / who ?
    - Sentinel-1a contributes to the long term archive of ice sheet and glacier observations. This archive is critical to document changes on the long term (decadal scale to multi decadal). It is therefore essential for the community to maintain access to this archive and keep its processing standard up to date. Access to a S-1 global data archive is sufficient.
4. Training
    - We recommend to put in place a training course targeted for a new generation of EO students in Cryosphere applications and services. Tentative date for the first training course would be early September 2016.
5. What are the observations that Sentinels cannot provide.
    - Grounding lines over fast glaciers outlets with 12-days repeat TOPS mode has not yet been demonstrated but needs to be evaluated further provided than series of 12-day repeat are scheduled and acquired around ice sheet margins more systematically. We expect the 6-day repeat period of S-1a/b will provide much better results.
    - High resolution surface elevation and elevation change (e.g. as provided by swath products from CryoSat SARIn mode) cannot be generated at this time.
    - Ice motion mapping in 3D (e.g. requires at least 3 looks: ascending, descending on two independent tracks).
    - Repeat observations of high resolution DEMs for measuring surface elevation changes (volume change), for example, single pass interferometry

7 MAPPING SESSION

Chairs: O. Antropov, S. Solberg

7.1 Session Overview

- Session with five oral presentations
    - Forest storm damage mapping with InSAR;
    - TanDEM-X InSAR time series data in forest cover mapping in boreal zone;
    - Temporal tracking of rice paddy heights with TanDEM-X;
    - Bathymetric survey of small reservoirs based on InSAR technique and TanDEM-X data;
    - Extraction of subsurface features from InSAR-derived DEMs.
- Primary focus was on exploitation and use of interferometric coherency or derived DEMs
    - Applications: forestry, agriculture, bathymetry, topographic features.
    - Bitemporal (change detection) or multitemporal (change monitoring and interpretation) approaches.
    - DEM differencing, analysis of SPC location in the “random volume layer”, single and dual-pol InSAR, multi-sensor and multi-frequency data use

7.2 Seed Questions

1. What are the main spaceborne remote sensing methods for mapping applications, and how could SAR and InSAR improve current mapping methods?
    - Depending on the context of mapping application, either optical or lidar data is routinely used, while SAR data are increasingly used yet often still has a complementary role, and InSAR is still at methodology development stage.
    - For the use of InSAR in forestry temporal decorrelation limits the use to bi-static acquisitions. Decorrelation models should be critically examined with respect to different frequency bands and revisit times or correlation lengths to give full picture.
    - At shorter wavelength only single-pass InSAR seems feasible for inversion - TanDEM-X, what about L-band (SAOCOM, TanDEM-L) and C-band?
    - Multi-pol InSAR could potentially help with lack of training data.
    - Multi-sensor approaches should be investigated, multi-band data fusion, SAR and optical data fusion, both interoperability and complementarity.

2. What are the most valuable InSAR derived variables for forest and land cover mapping?
    - Interferometric phase relative height (relative location of scattering phase centre, vertical structure proxy), so missions with single-pass (bi-static) acquisition are particularly valuable
    - Interferometric coherency magnitude.
    - Extracted DEMs.
    - Combination of them (hybrid approaches utilizing coherence magnitude and coherence phase using model-based interpretation).
    - Multitemporal combination (improve stability or analyse seasonality).
    - Also incorporating SAR backscatter might prove useful.
3. Coherence varies with across-track baseline and weather conditions, what is the best way to standardize coherence in order to make mosaics and to do change detection?
    - Accounting for vertical wavenumber, local incidence angle.
    - Reference data helps.
    - Look-up-tables, filtering of InSAR pairs (rainy/dry season, summer/winter acquisitions).
    - One way is to rely exclusively on DEMs.
4. What accuracy levels should be aimed at in different applications, e.g., forest cover mapping and land cover mapping?
    - Depends on application and target use groups – ask users (thematic exploitation platforms), ask downstream service providers or ask ESA,
    - Depends on what is measured (e.g., above ground biomass or just biomass change),
    - Satellite based measurements can't aim to beat accuracies of reference data collection or that of airborne campaigns
    - Sampling design is an issue, especially in change detection

8 EARTHQUAKES AND TECTONICS SESSION

Chairs: J. Elliott, Y. Fialko, E. Fielding, S. Jonsson, B. Parsons, G. Peltzer, J. Sun, T. Wright

8.1 Seed Questions

1. How can we prepare to analyse the volume of data that is starting to be acquired with the Sentinel-1 mission?
    - We are happy that data will be provided in SLC format everywhere.
    - Registered SLC's to a single master per track would simplify the processing.
    - Keep the acquisition mode consistent for interferometry.
    - We support the creation and expansion of the ESA Geohazard Exploitation Platform.
2. What are the unique challenges for interferometric measurements with the TOPS mode?
    - Basic processing of TOPS mode data is solved.
    - Processing and modelling issues remain for large azimuth displacement (large earthquakes).
    - For very large events, each burst may need to be analysed separately
3. What are our priority areas for Sentinel-1 data acquisition?
    - Support ESA decision to obtain global background acquisitions at the rate of ~4 per year (per satellite) to cover events not included in the current masks.
    - Increase frequency of acquisitions after significant events (scientific, humanitarian).
    - Establish a mechanism for deciding on when increased acquisitions for the events should be triggered (maybe Supersites or CEOS DRM Seismic Pilot?).
    - Once we have experience with short-interval C-band, we should identify areas where a reduced repeat interval would lead to better coherence.
    - We recommend that ESA set up a review in 6-12 months to add potential areas to existing priority masks (areas poorly defined near masks borders, large historical earthquakes…).
4. Does the Community require SLC production from Sentinel-1?
    - ESA said that it is the plan. We welcome this decision.
5. What can ESA do more to help scientists to further exploit the existing 20-year SAR data archive of ERS1, ERS2, ENVISAT?
    - We recommend the legacy data (ERS, ENVISAT) to be placed on an open server for free access.
    - This could be done through Exploitation Platforms offering processing capabilities.
    - Some old ERS scenes that were previously processed cannot be processed to new L0 products due to missing lines. We recommend finding a work-around to save this historical data.
6. What are the new InSAR findings in earthquakes and tectonics studies since FRINGE 2011?
    - In 2015, there were five sessions on Earthquakes and Tectonics…
    - Time series analysis is becoming the standard mode of data analysis. This is a step towards the way Sentinel-1 data will be analysed.

7. Have there been recent developments in methodology that are useful for studying earthquakes and tectonics? If so, how can we promote using such techniques?
    - Systematic processing of stacks of data and time series analysis.
    - New software developed by users should be made available to a wider community through the exploitation platforms.
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?
    - Use of Numerical Weather Models.
    - Empirical corrections in time series.
    - Auxiliary data from other sensors (MERIS, MODIS).
    - Would be good to include correction facility in the Exploitation Platforms.
9. Overall recommendations:
    - Keep the acquisition mode consistent and optimal for interferometric analysis.
    - Keep the orbital tube to 120m or smaller if possible.
    - Place Sentinel-1B in same small tube as Sentinel-1A.
    - We are happy about the tectonic zone coverage being acquired already by Sentinel-1A and look forward to the future expansion.

9 VOLCANOES SESSION

Chairs: G. Puglisi, N. D'Oreye, P. Lundgren, Z. Lu

9.1 Volcano Community Recommendations

- Data acquisitions should be boringly consistent:
  - Small orbital tube to reduce DEM sensitivity and maintain coherence as best possible.
  - Same mode of acquisition in both ascending and descending tracks.
  - Full polarization if possible.
- Community driven prioritization of data acquisition plan:
  - Regional priorities (i.e. faster ramp-up and more frequent acquisitions in areas of highly dynamic behaviour or vegetation such as SE Asia volcanoes).
  - StripMap data for volcanoes? Is this possible and what are the space-time conflicts and trade-offs?
  - Can ESA coordinate with other agencies to get data complementary to S1A for volcanoes (i.e. StripMap or spotlight modes)? Is CEOS the only vehicle for this?
  - Procedure for adding new targets that have been overlooked in current acquisition plan.
- Need for high resolution DEMs
  - Repeat DEMs for volcano topographic change.
- Are there ways to activate the Int. Charter or a "charter-like" procedure in cases where there is not a national emergency or disaster?
  - This provoked much discussion with a resounding "no" from ESA.
  - Can "we" (including ESA) stimulate other agencies to develop a comprehensive background mission for volcanoes that would provide baseline and response data?
- Ultimately volcanoes span a wide range of spatiotemporal scales, thus requiring sensors with different space-time resolutions (and different wavelengths).
- Recommendations for future ESA missions:
  - Higher resolution than current TOPS data at least on specific volcano targets – study other modes such as SweepSAR?

10 SUBSIDENCE AND LANDSLIDES SESSION

Chairs: J. Catalao, A. Hooper, T. R. Lauknes, F. Novali, P. Pasquali, Z. Perski, T. Strozzi

10.1 Session Summary

- 22 oral presentations + 72 posters of worldwide coverage
- Contributions by theme: 48 – subsidence, 16 - infrastructure, 30 landslides
- Contributions from countries than have not yet (?) been present on Fringe: Albania, Estonia, India, Mexico, Romania
- 19 Seed Questions!

10.2 Thematic Areas

- First S1 interferograms were presented and analysed.
- Subsidence due to gas extraction (more contributions), new solutions towards to slow movement detection.
- Multi sensor studies, infrastructure monitoring with HR data.
- Speckle tracking for fast landslide movement detection.
- Landslides – complex analysis and 3D modelling.
- Challenges/problems for InSAR time series analysis in snow covered areas.

10.3 **Recommendations**

1. Increase S1 coverage:
    - Data for arctic permafrost studies –extend S1 IW VV acquisitions from South to North Alaska.
    - Svalbard – manage continues acquisition of one selected track covering the Svalbard IW mode.
    - Subsidence phenomena in Australia should be considered.
    - Large parts of US and Africa are not covered.
    - Landslide & subsidence are going on all over the world.
    - Better temporal coverage over the world is required (asc and dsc!).
2. New validation campaign is needed:
    - Study like psic4/terrafirma.
    - After more S1 data is available.
    - ESA should start the discussion what should be validated: processing chain? Products? Data?
    - Test case proposed - Mexico City (disadvantage: lack of in-situ data).
    - Validation should be performed in Europe.
3. WAP – Wide Area Products continental/country-wide scale?
    - Initiative proposed as a new operational service.
    - ESA should support this initiative when proposed to EC level
4. ESA should better promote the exploitation of 'geohazard-tep' for subsidence and landslide community to be more involved.

- Comment: Examples from IW interferometry were presented. What is applicability of EWS for interferometry – any further exploitation of this subject is required? ESA could provide a set of test EWS SLC's to assess EWS performance in more detail.