Summaries and Recommendations of the POLinSAR 2009 Workshop (26-30 January 2009, ESRIN)

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These summaries and recommendations have been prepared by the session chairpersons and are grouped by session.

1 Pol-InSAR Missions Session (prepared by A. Coletta, D. De Lisle, A. Moreira and E. Attema)

1.1 Summary

Representatives of a large number of Space Agencies gave a comprehensive presentation of the results of the current SAR missions in orbit carrying radar sensors with polarisation capabilities, as well as of the capabilities of SAR missions under development and under review. These included: in P-band: BIOMASS (ESA); in L-band: ALOS/PALSAR and ALOS-2 (JAXA), Tandem-L (DLR), DESDynI: (JPL/NASA); in C-band: RADARSAT-2 (CSA/MDA), Sentinel-1 (ESA); in X-band: TerraSAR-X (DLR), COSMO-SkyMed (ASI), Tandem-X (DLR); in X+K-band: COREH2O (ESA).

Commercial/operational end-user driven missions focus on the long-term provision of data to support proven applications with higher revisit frequencies, better coverage and avoiding operational conflicts arising from a multitude of mutually exclusive operational modes. Science driven missions focus on specific Earth science issues commonly associated with climate change and natural resources. Technology development missions provide the maximum performance and flexibility to serve as a test bed for application development.

Many missions have mixed objectives and optimise resources to satisfy as many requirements as possible. The new missions apply advanced technologies such as efficient coding and/or digital beam forming to reduce constraints imposed by data rate limitations and to avoid conflicts between coverage, spatial resolution and polarisation requirements.

1.2 Seed questions discussion

In preparation of the discussion a table of relevant SAR missions had been prepared.

Mission	Status	Launch	Band & Polarisation
ERS-2	In-orbit	1995	C, VV
Envisat/ASAR	In-orbit	2002	C, VV/HH/HV/VH, alternating dual pol
Sentinel-1a & 1b (2)	Under development	2011 (1a)	C, VV+VH/HH+HV
Biomass	Proposed	-	P, quad pol
CoreH2O	Proposed	-	X+Ku, VV+VH
Cosmo-Skymed (4)	In-orbit (3 of 4)	2007 – 2009	X, dual pol
TerraSAR-X	In-orbit	2007	X, dual (quad pol, experimental)

TanDEM-X	Under development	2009	X, interf. (dual pol, quad pol experimental)
Radarsat-2	In-orbit	2007	C, quad pol
Radarsat-2	In-orbit	2007	C, quad pol
Radarsat Constel. (3)	Phase B	??	C, dual pol
ALOS/PalSAR	In-orbit	2006	L, quad pol.
ALOS Follow-on (2)	Under development	??	L, quad pol.
Kompsat-5	Under development	2010	X, dual pol.
SAOCOM (2)	Under development	??	X, dual pol.
DESDynI &Tandem-L (2)	Study Phase	-	L, quad pol. Idem, interferometric
RISAT	Under development	2009	C, quad pol
HJ-1C (2)	Under development	2010	S, ??

The following seed questions were tabled.

1) Requirements for Future Missions

Having seen the objectives and performance of the missions in orbit, under development and being evaluated, is there still a need for planning additional missions? If so where are the gaps? Different wavelengths, more frequent revisits, better resolution, wider swaths, other.......? Which scientific problem and/or operational application would be the driver for this?

This question resulted in a lot of discussion. First it was agreed that the proposed P-band mission would be an essential tool for future SAR polarimetry research and Earth science, notably in the framework of international initiatives such as the International Polar Year. Secondly it was suggested that all future missions should have polarimetric capabilities such as full, hybrid or compact polarimetry. Polarimetric systems should also have the appropriate performance - notably sensitivity and calibration - to facilitate full exploitation of polarimetric features. It was noted that operational & commercial mission would only follow such recommendations if a robust data product and an application & market would be proven. The Pol-InSAR community accepted this challenge.

2) Requirements for Current Missions

Having seen the objectives and performance of the missions in orbit are there requirements for new algorithm developments for calibration and/or (level-2++) retrieval? Which scientific problem and/or operational application would be the driver for this? Are data access facilities and data policies currently satisfactory? What changes would be required (if any)?

3) From Research to Service Provision

Which Polinsar data product(s) are sufficiently robust to form the basis for operational services? Which Polinsar data product(s) promise to become sufficiently robust to form the basis for operational services? Which recommendations emerge from the lessons learned about a roadmap from research to service provision?

Due to time pressure questions 2 and 3 were not treated as exhaustively as question 1. However the results presented in other sessions appear to indicate that current missions have definite potential already to support a range of operational services.

1.3 Recommendations

1) Based on the results presented at the workshop and on the high potential to be expected in the near future as more analysis of polarimetric data becomes available, the workshop recommended that all future SAR missions should include polarimetric operational modes.

2) Analysis of the polarimetric data sets was recommended with a view to identify robust applications that could support reliable service provision. As an example in C-band RADARSAT-2 fully polarimetric data and airborne data could provide a test bed for future operational modes for Sentinel-1 and the RADARSAT Constellation Mission.

3) It was recommended to study the feasibility of fully or hybrid/compact polarimetric operational modes for systems currently designed for single or dual polarisation (e.g. Sentinel-1 and RADARSAT Constellation Mission). These efforts would be justified by the proven potential for this in application areas such as ice, forest and vegetation monitoring.

2 Calibration/Validation Session (prepared by A. Freeman and M. Shimada)

2.1 Seed questions discussion

1. What are the recommended calibration test sites, observation conditions, and hardware condition for gaining the most accurate distortion matrix for the polarimetric SAR? (i.e., under the existence of the constant ionosphere, under the unstable ionosphere)

   - *Amazon test sites (where Faraday Rotation (FR) ~ 0) are useful for longer wavelengths*
   - *Since estimated FR is not zero in PalSAR data over Amazon, may be a residual channel imbalance to correct for [Freeman, 1991]*

2. What is the recommend method, if possible, to correct the amplitude or phase streaks caused by the scintillation?

   - *Potential to use FR estimates from polarimetric data to generate a phase screen to correct repeat-pass interferometry at L- and P-Band.*
   - *Dr. Shimada noted that scintillation had affected only 0.5% of PalSAR data acquisitions up until last year, but that the frequency of occurrence was increasing*

3. Recently, the use of polarimetric SAR has increased. Which research area is not satisfied with which calibration accuracy of SAR? In order to increase the frequency of use of the polarimetric mode in the regular SAR operation, which parameter(s) should be improved? (Background of this question is that PALSAR-POL has only 7% of the total resources due by the imaging swath is half of regular mode)

   - *Frequency of orders for polarimetric PalSAR data products (PLR) is most probably limited by user preference for wider swaths, a larger range of incidence angles, and contiguous coverage, which is featured in other PalSAR modes, but not PLR.*
   - *Thanks to the excellent performance of PalSAR and Radarsat-II in polarimetric mode, there is evidence to suggest that calibration performance (amplitude and phase imbalances, cross-talk, etc.) are actually well in excess of requirements. Applications have yet to catch up to fully exploit this realized capability.*
   - *Evidence to suggest that the Touzi extension of the Freeman/van Zyl approach offers improved performance in low HV conditions.*

4. Dual-pol data acquisition is currently much more common than quad-pol. Is this due to calibration performance (see Q3), incidence angle restrictions or swath width/data volume constraints? Do we have the right strategies for calibrating dual-pol data? Can we do more with external targets of opportunity or distributed targets to calibrate dual-pol (including Compact Polarimetry) data?

   - *Calibration of dual-pol data appears no harder than calibration of quad-pol data did initially. Similar classes of solutions exist: 3 known targets, 2 known targets + a distributed target with given properties, etc. Minimizing cross-talk gives a huge advantage.*
   - *Some evidence that preference for dual-pol data may be best choice for high-entropy targets as shown in Cloude's paper on Thursday morning*

5. At longer wavelengths, do we need corner reflectors or transponders any more to complete the quad-pol data calibration by balancing the HH and VV measurements?

   - *Need for some target with well-characterized RCS and scattering properties to verify calibration will never entirely go away*
   - *Polarimetric calibration in preference of FR without corner reflectors appears feasible*
   - *Persistent scatterers also offer a way to measure stability (relative calibration)*

6. Should Faraday rotation corrections to polarimetric SAR be applied to the raw data or to the fully processed image data?

   - *Depends on the temporal and spatial correlation lengths of the TEC columns along the radar line of sight.*

7. For quad-pol operation, there are distinct advantages to switching from the conventional linear to a hybrid polarity (see Raney-Freeman paper on Wed). Can we achieve the same excellent cross-talk isolation (-30 to -40 dB) with a circular transmit antenna?

   - *Remains to be determined through analysis and measurements of real antennas*
   - *Concern expressed by Keith Raney that offset-fed reflectors may have degraded cross-pol isolation, especially in circular pol*
   - *For compact pol systems using circular pol on transmit, the cross-pol isolation of the transmit antenna is very critical*

3 Forestry Session (prepared by T. Ainsworth and K. Papathanassiou)

3.1 Seed questions

- Even at low frequencies, forests are in general high entropy scattering environments. What is the importance / benefit of using (quad-) polarimetric information (in terms of amplitude and phase) for the characterisation / classification of forest environments?

- Is there enough evidence about the advantage of quad-polarimetric acquisitions vs. compact- and dual-polarimetric acquisitions for forest applications?

- Is the association of polarimetric classes to certain forest characteristics/attributes established (unique)? How does structural and seasonal variation (Leaf-on / leaf-off, mixed deciduous / conifer forests,…) affect the characterisation of forest environments by means of PolSAR? What kind of external information is required in order to establish this relation?

- What is interferometry (and polarimetric interferometry) expected to bring compared to conventional polarimetry?

- How does SAR frequency affect forest parameter estimations by means of Pol-InSAR?

- Is there a benefit / synergy of incorporating Lidar measurements in PolSAR and/or Pol-InSAR inversion/classification techniques?

3.2 PolSAR Forestry: summary, seed questions discussions and recommendations

3.2.1 Summary and seed questions discussion

4 Papers: L-band (ALOS-PalSAR Quad-, Dual-Pol, Time Series), C-band (ASAR, Pol Ratios) about 10 Papers at POLinSAR 2009:

- Importance of quad- compact- dual-polarimetric information for forest applications:
    - Limited due to the high (polarimetric) entropy but still significant:
        - Forest-Non Forest classification in the presence of slopes;
        - BIOMASS Mission based on Quad-Polarimetry;
        - Biomass map of Scotland by means of Quad-Pol ALOS-PalSAR data;
    - Polarimetry becomes more important at lower frequencies.

- Polarimetric Time Series: Important (for example for the interpretation of polarimetric classes) but not available today.
- Topography Impact: Compensation required: Not established methodology.
- Compact-Pol: Compromises HV measurements, problematic on Slopes.
- Dual/Compact Pol cover the polarimetric information content for some forest conditions.

3.2.2 Recommendations

Note 1: PolSAR Conclusions are not Pol-InSAR Conclusions.

- Recommendation 1: Exploration of Time-Series Quad- Dual-Pol data.

- Recommendation 2: Revisit the impact of frequency on the information content of (polarimetric) SAR data.
    - Establishment of super-test sites for all existing sensors;
    - The implementation of <u>experimental</u> Quad-/Compact-Pol Modes in future SAR missions;

3.3 Pol-InSAR Forestry: summary, seed questions discussions and recommendations

3.3.1 Summary and seed questions discussion

2 Presentations using airborne L-band / X-band and ~12 presentations in POLinSAR 2009:

- SAR Interferometry: Provides sensitivity to vertical (forest) structure. Multi-Baseline Pol-InSAR (MB-Pol-InSAR) is one of the best options (if not only the only one) we have to get vertical forest structure in high resolution global coverage.

- FH Product has reached a mature level in terms of validation and understanding;
    - Better than 10% accuracy possible (using optimised configurations: Short time repeat pass MB Pol-InSAR or Single-Baseline Single-Pass).
    - Essential component of future SAR mission proposals (BIOMASS, Tandem-L)
- Vertical Forest Structure estimation algorithms are under development by different groups in Europe; Common to all: Multi-baseline (Coherent) Acquisitions.

    → <u>We cannot do it with the sensors available today from space.</u>
- Temporal decorrelation is the main limiting factor:

- Short repeat-pass times and/or longer wavelengths and large spatial baselines (C-band constellations ESA, CSA, P-band repeat-pass BIOMASS);
- Single-pass implementations: (TD-X, TD-L).

- Underlying topography information is required for a number of approaches / products. Pol-InSAR techniques have the potential to remove the vegetation bias (2 presentations). (MB)-Pol-InSAR is probably the best way to get it. Confirmed by the presentations / results in the tomography session.

- Compact Pol: Compromised performance (with respect to quad-pol) especially in critical cases as:

  - in the absence of a dominant dihedral scattering component: dense vegetation, understory;

  - in the presence of terrain slopes.

- The technology to realize the required measurements is today in a large degree available. There are solutions for the remaining issues (wide-swath high resolution) that do not compromise the required observation space.

  The increased system / mission complexity and the associated costs has to be justified / traded against the scientific delta provided.

  But: Never stop exploring …

3.3.2 Recommendations

- Recommendation 1: Next key product is vertical forest structure. We are today there where we were with forest height in 2003!!!

  A new space has to be explored:
  - Addressing estimation requirements for different applications;
  - Development and validation of inversion methodology;
  - Assessment of measurment / instrument / mission requirements.
  - …

  Exploring MB-Pol-InSAR and its transition to tomography in terms of (not only) the points addressed above is strongly recommended.

- Recommendation 2: Exploring the role of Tandem-X for forest parameter estimation.

4 *Pol-InSAR Session (prepared by S. Cloude & P. Dubois-Fernandez)*

4.1 *Summary*

7 papers presented with 3 main themes

- New techniques (dual baseline, more detailed physical models, new tools)
- New Surface topography estimation results at P- & L- bands
- P Band Pol-InSAR (bandwidth effects and Faraday rotation effects)

+ related papers in other sessions..

4.2 *Seed questions*

- What are the Pol-InSAR system requirements for surface topography estimation? Are they the same as for tree height retrieval in terms of spatial and temporal baselines, multi-baseline requirements, angle of incidence, operating frequency etc?
- Do the latest ideas for Pol-InSAR parameter retrieval impact on any major system design issues such as the need for multiple baselines, quad vs compact pol modes and optimum operating frequency/bandwidth?
- Given the issues of bandwidth limits and ionospheric distortions, is repeat pass P band space Pol-InSAR forest parameter retrieval feasible and is it best to use quad , dual or compact polarisation modes?
- Based on our experience on ALOS results, what is the potential of L-Band repeat pass Pol-InSAR from space? What are the major show-stoppers?
- What are the potential applications of X-band Pol-InSAR with Tandem-X?
- Are there currently sufficient tools available for the wider community to apply and advance Pol-InSAR techniques?
- Are they sufficient Pol-InSAR datasets available to the community?

4.3 *Seed questions discussion and recommendations*

7 Main points:

- A mature Pol-InSAR product now exists, forest height (basis of Tandem-L mission). With impacts on biomass and vertical structure estimation for new product development. Need development of vertical structure estimation techniques using multi-baseline Pol-InSAR.

- Now have better quantitative understanding of temporal effects in Pol-InSAR …L band is more susceptible than P and has three levels, single pass (best for L), moderate (6-12 days), (possible compensation) and long term (bad for L)…

- Surface phase estimation is a new product of great potential importance from Pol-InSAR. From initial results the retrieval accuracy seems to be linked with seasons.

- Is winter more suitable for ground topography, summer for vegetation height? (where appropriate)…requires further experiments with (single-pass if possible) L-band/P-band S-band sensors

- Compact Pol-InSAR is shown to be feasible at P-/L- bands band although bandwidth limitations at P reduce product accuracy, FR can be overcome by careful quad or compact circular designs……..but loss of line length up to 50% of quad-pol will lead to further product degradation (in tropical and high topographic environments)…

- High Frequency X-band Pol-InSAR for open canopy forest shows good initial results……need further investigation in light of Tandem-X potential for new forest products of high accuracy from X band single pass satellite…also in agriculture.

- Low frequency Pol-InSAR for ice is promising new area…need to better understand surface/volume scattering balance…perhaps more use of ALOS/PALSAR?

- POLSARPRO has now been extended to allow Polinsar analysis instead of just Pol-InSAR training. Useful tool for wider user community….

5 Urban applications Session (Prepared by P. Lombardo and G.Trianni)

New SAR missions provide High Resolution images better suited for the analysis of the URBAN environment:

1. Is the resolution now sufficient for URBAN applications?

    - The resolution with the most recent air- and space-borne sensors is largely higher than in the past and a significant higher understanding of the urban environment is now possible based on radar images. However, due to the high level of detail involved in the URBAN environment, many applications would still benefit of a smaller scale of imaging. This is especially important to achieve the full benefit of polarimetry for urban applications, avoiding mixing together objects with different polarimetric characteristics.

2. Can polarimetry offer major improvements for high resolution SAR observations of the URBAN environment?

    a) Is compact polarimetry enough or is full polarimetry required?

    - The common feeling is that polarisation has much more potential than what has been exploited so far, and the wide availability of more high resolution datasets will increase applications soon.
    - Compact pol is largely agreed to offer in urban application much more information than Single Pol and it should be better exploited for URBAN applications in the coming years. However, the most important advantage of Compact Pol vs. Full Pol is swath width, which is not an issue in urban applications. Thus it is recommended to better exploit Full Pol techniques and sensors in the near future for urban applications.

    b) Is compact polarimetry enough or is full polarimetry required?

    - There is still much work to be done for the full exploitation of polarimetry in URBAN areas. It is premature to identify a killer application, or to quantify the advantage offered by SAR polarimetry.

3. Interferometry offered major results even with medium/low resolution SAR images in the URBAN environment (e.g. subsidence monitoring, ..). Is its effectiveness sensibly improved when operating with high-resolution SAR images?

    - A killer application of SAR for URBAN areas has been identified in the subsidence monitoring based on differential interferometry - especially Persistent Scatterer Interferometry (PSI). Despite it is very difficult to quantify its impact, high resolution allows better separation of objects for a more appropriate monitoring.

4. Can the joint use of Polarimetry and Interferometry offer a significant advantage for URBAN applications with high Resolution SAR images?

    - POLINSAR approach can be used for the mapping and monitoring of the temporal evolution of urban vegetation and sub-urban areas. This is a potential basis for future URBAN applications.
    - The use of polarimetry to improve the interferometric results in urban areas is a current research topic. The research is presently aiming at assessing the quality improvement available using high-resolution radar images with different approaches to exploit polarimetry with differential InSAR.

6 Compact/Hybrid Polarimetry Session (prepared by K. Raney and A. Minchella)

6.1 Summary: Recurring Themes

- Agreed: Compact Polarimetry (CP) is not being promoted as a substitute for quad- or full-pol, but the technique does offer value added with respect to single- or (non-phase) dual-polarization, and is compatible as a mode within a FP system

- Objective comparisons between CP and Quad-Pol (and occasionally other architectures)

- Hybrid-polarity (C transmit, H&V receive) has advantages for quad- or full-pol radars

6.2 Seed questions discussion

1. Seed question topic: **Calibration**

- Is quantitative (polarimetric) calibration of a CP radar possible in principle? –
  - *Yes*
- Issues arising:
  - *Necessity for "quasi-perfect" transmitted polarization, and in-flight verification (true for any form of CP)*
  - *Remaining calibration: amplitude & spectral balance and differential phase between the two receive channels*
  - *Potential negative system consequence (less SNR, greater quantization noise) on the cross-polarized signal constituents; needs further investigation*

2. Seed question topic: **Information content**

- *Dubious value of "reconstruction" of 2x2 cov matrix to 3x3 pseudo-scattering matrix ; may "ease" analysis, but based on what physical justification?*
- *Already substantial progress on quantitative comparisons; application-specific; more needed*
- Issues arising
  - *Essential to render CP "comparisons" wrt to mono-pol and conventional dual pol, together with quad-pol*
  - *Helpful to focus on the end (data) product, rather than the (traditional) methodology (e.g., HH or HV numbers), while keeping in mind the User's need/expectation for continuity*

3) Seed question topic: ***Processing and interpretation***

- *PolSARPro 4.0 includes a suite of tools applicable to Compact Polarimetry, including generation of the 2x2 covariance matrix (from quad-pol data) corresponding to user's choice of CP architecture*
- Issues arising
  - *Pol-InSAR (forests) canopy height OK, but biomass estimate TBD (Implied need for an integrated CP Pol-InSAR analytical model)*
  - *Applications needing further comparative study include ocean (science & vessel detection) and ice (sea ice, glaciers (continental and alpine)*

6.3 Recommendations

- Establish a unified theoretical basis for CP Pol-InSAR, in the same fashion as the founding basis for (quad-pol) Pol-InSAR

- "Require" multi-PI based objective quantitative comparisons of CP vs MP, DP, and FP for all Super Sites

- Work system-engineering level analyses of CP issues (e.g., required dynamic range, strengths and weaknesses of self-calibration, cross-talk, ambiguity levels vis-à-vis H&V quad-pol, etc.)

7 Soil Moisture Session (prepared by F. Charbonneau and L. Ferro-Famil)

7.1 Seed questions discussion

1. Robustness:

   – Can polarimetry help to avoid model adjustments on every site, with **operational** theoretical or semi-empirical retrieval schemes?

   – Are complementary sources of information needed?

   – Which kind of diversity (frequency, incidence angle ...) should be preferred?

   Discussion:

   – *Yes, complementary sources of information are needed, to:*

     • *Increase retrieval robustness*

     • *Provide a priori information to adapt the inversion scheme (types of vegetation, weather conditions, ...)*

   – *The preferred kind of diversity is not clear yet:*

     • *Frequency diversity: can provide information on overlying volumes*

     • *Angular diversity: may provide more robustness and increase polarization sensitivity (large incidence angles)*

     • *Interesting relations beetwen geophysical parameters and POLSAR indicators (e.g roughness). Sites with more diversity in geophysical characteristics are needed.*

2. Multi-temporal acquisitions:

   – Which information can be extracted?

   – Multi-sensor data combination (planning issue)

   Discussion:

   – *Multi-temporal acquisitions: particularly important for this topic:*

     • *Surface properties may vary within a few days*

        - *Integrated knowledge can be used (up to now mainly used for classification purposes)*
    - *Multi-sensor combination:*
        - *Way to reduce the revisit time over a site*
        - *Possible source of diversity (RADARSAT-2, ALOS, TerraSAR-X)*

3. Vegetation bias removal:
    - Are polarimetric decompositions sufficient? (which one should be chosen)
    - Could Pol-InSAR help ? (sensitivity & revisit time)

Discussion:

- *Polarimetric decomposition: unique tool to estimate the underlying soil properties when a* ***single*** *POLSAR data set is available*
- *Fully polarimetric data required*
- *Estimation results may depend on the chosen decomposition approach*
- *Diversity might help ! frequency for volume estimation, incidence angle to increase the observation space*
- *POL-inSAR: can be a solution for an unambiguous estimation of the overlying volume. Still under investigation using airborne data*
- *Simulations show that POL-inSAR should be applied to this problem*

7.2 Recommendations

- Extensive use of available ESA campaign data, by a larger number of research teams, is strongly encouraged
- In order to increase POLSAR retrieval efficiency, in terms of sensitivity and diversity, spaceborne POLSAR sensors should operate at larger incidence angles.
- A revisit time of 1 week should be guaranteed for efficient soil characterization
- Efforts should be made to allow a synchronization of acquisitions from different spaceborne sensors (inter-space agency coordination)

- A quantitative analysis of the influence of the POLSAR decomposition used to estimate soil properties should be conducted

- Pol-inSAR analysis for surface + volume analysis and component separation should be further carried on, in order to establish sensor/accuracy requirements

8 Cryosphere/Oceans Session (prepared by D. Floricioiu and S. Lehner)

8.1 Summary

- 2 presentations (Torbjörn Eltoft, Dana Floricioiu) on glacier facies classification with quad-pol L-band (ALOS) and multi-pol TerraSAR-X data. Statistical and backscattering modeling + meteorological parameters approaches. Both aim at application to glacier/ice sheet mass balance.

- River ice mapping in Canada with dual pol TerraSAR-X (Stéphane Mermoz): algorithms for classification of 4 river ice types + open water based on HH/VV, overall accuracy > 90%. Interesting application for ice jam formation warning. (Outlook: density, thickness of ice estimation).

- Backscattering modeling (Jayanti Sharma): 2-D maps of extinction coefficient of glacier ice by polarimetric decomposition and interferometric coherence at L- and P-band. 3-D distribution of particles in ice volume considered.

- Derivation of wind fields from X-SAR and TerraSAR-X (Thomas Koenig): geophysical model based on backscattering (VV or HH), wind speed, wind direction and incidence angle. The inverted high resolution wind fields are needed for coastal areas and cases with high spatial meteorological variability.

- Polynyas monitoring (Thomas Busche) the sensitivity of polarimetric parameters derived from dual-pol HH VV TerraSAR-X data to thin ice thickness change was investigated. Dual-pol X-band useful for thin sea ice classification. Inversion algorithms of thin ice thickness over sea surface may be possible based on polarimetric parameters. Remote sensing of sea ice thickness remains a challenging problem for SAR data analysis.

Poster presentations

- Fully polarimetric ALOS L-band and SIR-C C-band data investigated for oil slicks detection. Oil and biogenic slicks could be discriminated. Several approaches were tested based on Mueller matrix, target decomposition and Bragg scattering.

- Different imaging modes of TerraSAR-X tested for detection of natural oil seeps over Australian coastal waters.

- River ice classification with fully polarimetric data. Simulations of fully polarimetric response over river ice cover and sensitivity to roughness, ice thickness, porosity.

- Mapping of permafrost changes with L-band InSAR (subsidence) and fully polarimetric Radarsat-2 + optical (land classes classification).

8.2 Seed questions discussion

1. C-, L- and X-band multi- or fully-polarimetric spaceborne SAR systems are currently in operations.

   1. What are the capabilities/limits of theoretical models to describe backscattering from snow covered surfaces, glaciers and Open Ocean at these frequencies?

   2. How important is the availability of multi-frequency data sets to retrieve geophysical parameters of snow and ice?

There are many effects in respect to microwave scattering of ice that current models are not able to describe. Effort is needed to further develop physical scattering models of ice.

Multi frequency data give different information e.g. due to penetration depth. It is recommended to combine fully polarized Radarsat-2 data with ALOS L-band data. Also the advantages of P-band data were stressed. Lower frequencies can be used for investigations of volume scattering contributions (by InSAR) for land ice while higher frequencies for near surface contributions.

2. Which polarimetric parameters provide the highest information content over snow and ice? Which information is gained by fully polarimetric SAR in comparison to dual-pol SAR?

Near backscattering coefficients and ratios, the HHVV correlation coefficient, entropy, anisotropy.
Fully polarized SAR data have clear advantages over single or dual polarized for ice classification (as demonstrated by presentation) as well as ocean applications (i.e. Oil and ship detection).

3. What dual-pol (HH and VV) is preferred for your applications:

   a) The burst-like (or twin-pol) mode with full swath width and no coherence between HH and VV channels

or

   b) The reduced swath width with preservation of the HH-VV coherence?

As shown in the presentations the HH-VV coherence is a useful parameter for classifications.

4. Currently for TerraSAR-X the HV-polarization is not available in spotlight and high resolution spotlight modes. Is the HV availability at such a high spatial resolution (2.2 m and 3.4 m) desired for land snow/ice and oceanography applications or is the 6.6 m resolution in Stripmap mode sufficient?

Exploitation of experimental products e.g. from TerraSAR-X is strongly recommended. This includes the reception of HV-polarized data in spotlight mode.

5. Which are the advantages of using polarimetric SAR in detection of oil slicks and ships?

For ship detection, the use of fully polarized data leads to either lower number of undetected targets or to lower false alarm rate (or both). The exploitation of fully polarimetric information allows considerable improvement of the detection of oil slicks.

8.2.1 Further comments

- NRT availability of L-band data is invaluable for ice applications
- There is still heavy need of ground truth data over ice. It is recommended to support one or several ice supersites in coordinating multi-frequency polarimetric SAR data collection and distribution to all contributing scientists.
- It is very important to have regular multitemporal observations.
- High geometric resolution as provided by TerraSAR-X is very useful for ice and coastal ocean applications

9 *Agriculture/Wetlands Session (prepared by I. Hajnsek and R. Touzi)*

9.1 *Summary*

- **Very diverse topic/method of the session ranging from**
  - Characterization of vertical structure of short crop volumes @ X-band InSAR (I. Hajnsek)
  - Wetland characterization using at L-, C- and X-band using ALOS, Radarsat2 and TerraSAR (S. Hong)
  - Rice monitoring using time series of TerraSAR-X dual-pol (J. Lopez-Sanchez)
  - Model based decomposition of different forest layers using Pol-InSAR (M. Neumnann)
  - Frequency analysis of Coastal wetland monitoring using multi-frequency polarimetric SAR (L-P band Airsar, ALOS, Radarsat2 and TerraSAR). S. Park.
  - Polarimetric Touzi decomposition for wetland classification and monitoring using C-band SAR. (R. Touzi)
- **General comments:**
  - New methods showed potential for the development of new application or improved estimation of environmental parameters.
  - The Touzi decomposition, which is an extension of Cloude-Pottier decomposition, introduce new parameters in particular the phase of the scattering and its helicity that should be investigated in addition to Cloude-Pottier alpha, entropy, and anisotropy for optimum extraction of polarimetric information.
  - The new parameters increased significantly the potential of polarimetric SAR for forest and vegetation species discrimination in comparison with conventional one and dual polarization SAR. This should permit a wider use of polarimetric all-weather satellite SAR for forest, park, wetland and agriculture crop monitoring.
  - The presentations given show very promising potential in agriculture and wetland application. There is an urgent need to validate these methods with the end-users using the existing polarimetric satellite for the increased (and operational) use of polarimetric and Pol-InSAR satellite to support government decision making.

- The 20-40 degree modes of RADARSAT-2 should be fully exploited for the determination of the optimum incidence angle that responds to a given application.
- Models that integrate the multi-frequency polarimetric and Pol-IN SAR parameters should be developed and validated using scatterometer, airborne and satellite data.

9.2 Recommendations

- **Data availability:**
  - Radarsat-II standard mode (24 m resolution) images are provided in 25x25 km frames to meet the severe requirement of -30 dB noise floor. This requirement is very severe, and can be relaxed to -25 dB. There is an immediate need of the 50x50 km scene for better exploitation of polarimetric information with larger cover.
  - Urgent requirement for continuous/systematic polarimetric SAR data acquisition @ X-,C-, & L-band using TerraSAR, Radarsat2 and ALOS.
  - Need for continuous/systematic polarimetric SAR data acquisition @ X-,C-, & L-and P band using airborne SARs
  - Data time series
  - Scatterometer data (?) for model validation or/and EMSL/JRC controlled laboratory data

- **Model maturity**
  - Strong need for further development in terms of
    - Local incidence angle variation
    - Combination of different wavelength
    - Polarimetry and Pol-InSAR
    - Different polarimetric decomposition
    - Vegetation structural changes in time
    - Validation of EM model

- **Needed parameters:**
  - ***Agriculture:***

        - Water plant content
        - Plant biomass
        - LAI – Plant productivity/vitality
        - Phenological state
        - Changes of the parameter in time
        - Underlying soil moisture
    - ***Wetland indicator:***
        - Hydrology & change
        - Wetland extend & change
        - Vegetation group & change
        - Water level and change
        - Tidal height & change
        - Underlying soil moisture
        - Local topography

- **Combination of different sensors (SAR+Optic's):**
    - Important for parameters that can not be only derived by polarimetric SAR
        - Vegetation species
        - ALBEDO
        - LAI
    - Potential for EM models as *a priori* parameter – need to be investigated!

- **General comments:**
    - Polarimetry should play an essential role in vegetation parameter derivation – the parameter space and accuracy cannot be reached with single/dual polarization SAR

- Demonstration of the potential of polarimetric SAR @ different frequencies on selected ‚super test sites‘ using ALOS/PALSAR, RadarSAT-2, TerraSAR-X
- Bistatic observation provide a wider observable space and new imaging characteristics – should be investigated!

10 PolSAR Session (prepared by W.- M. Boerner and E. Pottier)

10.1 Summary and seed questions discussion

11 Presentations

1. ALOS-PALSAR and RADARSAT-2 are the first fully polarimetric space-borne sensors that provide today polarimetric data in a systematic way. One of the ESA recommendations during the last POLINSAR07 symposium was to initiate, identify, coordinate and construct several international super test sites to validate the important number of applications that benefit from the availability of Multi-frequency Quad-pol data. What about the situation?

   - *Different Super Test Sites have been identified*
   - *Coordination will be shortly finalized between ESA – JAXA – CSA – DLR*
   - *Availability of Multi-frequency Quad-pol data → Announcement to the P.I*
   - *Quad-Pol, Dual-Pol, Hybrid-Pol, Compact-Pol … : validation and testing of the different modes*

ESA – JAXA project *"TEST SITES FOR ALOS POLARIMETRIC SAR APPLICATION EMONSTRATION (CAT-1 PROPOSAL ID 5780)"*

ID	TEST Site	Application	Source
1	*Traunstein (Germany)*	*Forest*	POLARIMETRIC & INTERFEROMETRIC MISSION AND APPLICATION STUDY 17893/03/I-LG FINAL REPORT (lead by DLR)
2	*Bayrischer Wald (Germany)*	*Forest*	POLARIMETRIC & INTERFEROMETRIC MISSION AND APPLICATION STUDY 17893/03/I-LG FINAL REPORT (lead by DLR)
3	*Remningstorp (Sweden)*	*Forest*	ESA Campaign BioSAR P-L band with E-SAR (2007)
4	*SCOTLAND*	*Forest*	Prof. Shane Cloude (AEL, UK)
5	*South West Australia*	*Forest*	Prof. Shane Cloude (AEL, UK)
6	*Foulum (Denmark)*	*Agriculture*	POLARIMETRIC & INTERFEROMETRIC MISSION AND APPLICATION STUDY 17893/03/I-LG FINAL REPORT (lead by DLR)
7	*Alling-DLR (Germany)*	*Agriculture*	POLARIMETRIC & INTERFEROMETRIC MISSION AND APPLICATION STUDY 17893/03/I-LG FINAL REPORT (lead by DLR)
8	*Demmin (Germany)*	*Agriculture*	ESA Campaign Agrisar 2006 with E-SAR
9	*Taian district (China)*	*Forest - Land use - Urban changes*	Prof. Eric Pottier, Dr. Exrue Chen
10	*Jungfrau Alpine glacier (Switzland)*	*Snow*	Swiss Alpine Airborne SAR Experiment (SASARE)
11	*Svalbard (Norvey)*	*Ice*	Cryovex LaRa Esa Campaigns
12	*Tapajos Forest (Brazil)*	*Forest*	Prof. Luciano Dutra (INPE)
13	*Mar Bleue - East of Ottawa (Canada)*	*Wetland mapping and monitoring*	Dr. Ridha Touzi (CCRS)
14	*Injune forest (Australia)*	*Forest*	Dr. Paul Siqueira (University of Massachusetts)
15	*Duke forest (USA)*	*Forest*	Dr. Paul Siqueira (University of Massachusetts)
16	*Harvard forest (USA)*	*Forest*	Dr. Paul Siqueira (University of Massachusetts)
17	*Kenai / Alaska (wetlands and boreal forests)*	*Wetlands and Boreal forests*	Dr. Don Atwood (ASK)

2. This POL-SAR session concerns and presents some relevant and original recent advances in Polarimetry SAR methodologies. What could be the future challenges in the following topics: Polarimetric speckle filtering, polarimetric decompositions, data fusion, Pol-InSAR or Multi-temporal PolSAR, etc....

    - *Bistatic scattering – Multistatic scattering (multi-angle)*
      Next generation of spaceborne sensors – Constellation
      New parameter inversion strategy -> HV ne VH

    - *Decomposition theorems*
      Don't provide all the information - Link with the applications

    - *Speckle filtering: Link with the applications*
      Computation efficiency

3. This POL-SAR session concerns and presents some relevant and original recent advances in Polarimetry SAR methodologies. What could be the future challenges in the following topics: Polarimetric speckle filtering, polarimetric decompositions, data fusion, Pol-InSAR or Multi-temporal PolSAR, etc....

    - *Classification / Parameter Inversion: Locally find the best model that fit with the applications*

    - *More scatterometer measurements for ground truth*
      Better modelisation of environment scattering – physical understanding

    - *Multi-temporal repeat pass*

    - *Data fusion: microwave and optical data*

4. Hitherto only P, L, C, X, K Band POL-SAR image data sets had been employed: What about implementing S-Band POL-SAR?

    - *Need improved high quality airborne test platforms: F-SAR (DLR) UAVSAR (JPL) multi-bands (P, L, C, X, Ku …) including S-Band*

5. Next to introducing the three space-borne POL-SAR systems, in a next step we need to find out whether Hybrid POL-SAR may provide improved quality imaging data takes than standard POL-SAR: What are the next steps to be taken in comparing hybrid versus standard POL-SAR approaches?

    - *Different papers analyze topology full polarimetry vs compact polarimetry for which future test sites can be used for comparative studies*

    - *Consensus on applicability (application where hybrid/compact polarimetry could make sense)*

6. How can we extend POL-SAR methodologies in slow vegetation growth assessments, and which bands apply best for which specific cases?

   - *Time acquisition is critical and methodologies further need advances for slow vegetation growth assessments, Band depending (X, L, P …)*

   - *Repeat pass which cover seasonal growth requirements*

   - *Change detection*

7. How could space-borne POL-SAR assist in mapping precipitation phenomena, which data acquisition modes apply or may have to be devised and which bands are to be chosen?

   - *Utilization of X-Band polarimetric spaceborne SAR for cloud – storm – meteorological phenomena description over land and ocean (particularly in tropical regions)*
   - *Experimental mode for the Tandem-X*

11 *Tomography Session (prepared by K. Papathanassiou and F. Rocca)*

11.1 Summary

4 Papers: 2 on the results of the Remningstorp data set (Lombardini and Pardini, Tebaldini)

- 1 on the synthesis of scattering mechanisms consistent with the multi polarization multi baseline covariance matrix (Tebaldini et al.)

- 1 on the optimal multibaseline exploitation of Tandem L (De Zan et al.)

The papers gave a consistent picture of the benefits of coherent multi baseline surveys, in term of:

- the possibility of retrieval of the vertical structure of the vegetation
- the decomposition of the scatter in multiple scattering mechanisms
- the continuity and the consistency with single baseline PolInSAR

The results of the campaign carried out in Remningstorp were comparable in that, using different methodologies,

- a very satisfying recovery of the ground and canopy topographies was obtained,
- notwithstanding the very unfavourable power ratio between the strong ground scatter and the weak canopy scatter.
- the reduction of the bandwidth to 6 MHz was not seen to be a show stopper.

An interesting attempt to synthesize scattering mechanisms from the polarimetric interferometric structure of the covariance matrix was carried out by Tebaldini et al. This approach yielded:

- a generalization to multi baseline of the PolInSAR approach and showed that, again in the case of Remningstorp,
- just two scattering mechanisms could account for more than 90% of the scattered power
- alternate candidate scattering mechanisms leading to the very same covariance matrix had very similar ground and canopy topographies, but rather different fill factors. This showed the robustness of this parameterization.

In a presentation by De Zan et al., the optimal multibaseline exploitation of Tandem L was discussed to derive, using the hybrid Cramér Rao bound, the error in the recovery of a four layered vertical structure, as a function of the baselines to be used.

- about 4 – 5 baselines was shown to be needed,
- the possibility of the correct recovery of the vertical structure was indicated,

Still to be analyzed are:

- the impact of forest changes during the acquisitions
- the effects of a limited phase calibration.

11.2 Seed questions discussion

1. Do we expect something useful out of a three Scattering Mechanisms tomography, or two (ground and canopy) could be enough?

Tebaldini observed that, besides ground and canopy, a third scattering mechanism could still be ground locked, but it was difficult to detect in the case of Remningstorp. Probably, different results could be got in L band or for the rain forest. Cloude observed that orientation anisotropy and differential extinction could also generate further scattering mechanisms and their effects are still to be analyzed.

2. Is the interpretation of vertical forest structure extracted by SAR established? If tomography is able to determine the vertical structure of forests, would this be really useful and for what?

Cloude agreed that all technologies determined the low frequency components of the vertical structure, and there would be a satisfying agreement on that, as he expected 20% accuracy.

3. What is the vertical resolution of forest structure that can be achieved realistically with the actual generation of SAR sensors? Is this achieved resolution sufficient for the actual / potential applications ?

Referring again to the vertical structure that could be recovered with PCT, Cloude observed that two baselines would be useful to recover more than three Legendre coefficients using PCT.

4. When will we be able to predict and compensate the effects of temporal decorrelation? Shouldn't we act before new P band satellites are designed, using fast revisit L band or S band satellites?

Tebaldini observed that he believes that the vertical structure could be recovered without phase calibration, necessary to recover the DEM of ground and the canopy heights. It was also observed by Redondo that the fractal nature of the forest should be parameterized and investigated in the modelling.

5. Is tomography capable of determining soil moisture or even geological structures underneath the vegetation canopy? Are we doing all we can about it?

Concerning this last point, Rocca observed that this analysis could be of very high interest for the geophysical application in the oil and gas industry. Cloude observed that this is one of the goals of polarimetric studies and that the help of tomography should be evaluated.

11.3 Recommendations

Vertical forest structure and terrain reflectivity under vegetated canopies should be studied.

1- Temporal decorrelation and temporal change are the main limiting factors:

- Short repeat-pass times and/or longer wavelengths and large spatial baselines
- (C-band constellations ESA, CSA, P-band repeat-pass BIOMASS);
- Single-pass implementations: (TD-X, TD-L).

2- Phase calibration requirements should be addressed

3- Inversion methodologies should be developed and validated

Exploring tomography and its transition to PolInSAR in terms of (not only) the points addressed above is strongly recommended.