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DOCUMENT

# POLinSAR 2013 session summaries: seed questions discussion and recommendations

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# 1 INTRODUCTION

This document gathers the session summaries with seed questions discussion and recommendations of the POLinSAR2013 workshop (https://earth.esa.int/polinsar2013), the 6th International Workshop on Science and Applications of SAR Polarimetry and Polarimetric Interferometry, organised by the European Space Agency at ESRIN, Frascati, Italy, from 28 January to 01 February 2013.

## 1.1 Workshop objectives and themes

The main objectives of the POLinSAR2013 workshop are:

- Provide a forum for scientific exchange
- Present exploitation results from fully polarimetric airborne and spaceborne systems
- Present latest studies in the field and ESA POLSARAP results
- Report on progress/status of POLinSAR 2011 recommendations
- Demonstrate benefits of fully polarimetric systems (vs. dual or single polarization)
- Present future missions in preparation
- Present final PI results from ESA/CSA SOAR EU initiative

The workshop is focused on the theory and methods in the fields of SAR Polarimetry and Polarimetric Interferometry, around the following themes:

1. Theoretical Modeling;
2. SAR Polarimetric Interferometry (Pol-InSAR);
3. Polarimetry and Persistent Scatterer Interferometry (PSI);
4. Polarimetry and Tomography;
5. Applications of SAR Polarimetry
   - Land: Forest, Agriculture, Environment and Wetlands
   - Ocean: Pollution Monitoring, Ship detection, Ocean Parameters Retrieval, Sea Features
   - Cryosphere: Snow, Land Ice and Sea Ice Monitoring
   - Hazards: Fire Monitoring, Volcanoes, Flooding, Earthquake
   - Other applications
6. Past, Current and Future SAR Missions (e.g. RCM, SENTINEL-1, ALOS-2, NovaSAR-S, SAOCOM;
7. Airborne and Spaceborne campaigns.

## 1.2 The workshop in numbers

The workshop programme consisted of 10 (no parallel) thematic sessions complemented by one poster session on Wednesday 30 January 2013. A total of 83 oral presentations (6 keynote addresses, 67 thematic speeches and 10 summaries) were given and 67 posters were presented.

| Date | Session |
|---|---|
| Monday 28 January 2013 | Opening |
| | Methods & Theoretical Modeling |
| Tuesday 29 January 2013 | Polarimetric SAR Interferometry (Pol-InSAR) |
| | Polarimetric SAR Interferometry (Pol-InSAR): Forest |
| | Polarimetry & DInSAR, Polarimetry & PSI |
| Wednesday 30 January 2013 | Polarimetry and Tomography |
| | Applications on Ocean & Cryosphere |
| | Applications on Ocean Pollution monitoring & target detection |
| Thursday 31 January 2013 | Applications of SAR Polarimetry on Land: Agriculture, Urban, Archaeology |
| | Applications of SAR Polarimetry on Land: Soil Moisture and Wetlands |
| | Applications of SAR Polarimetry: Other |
| Friday 1 February 2013 | Sessions Summaries |
| | Closing |

**Figure 1 Workshop sessions**

The workshop's presentations are on line published at:
https://earth.esa.int/web/guest/polinsar-2013/workshop-programme

The workshop has been attended by a total of 162 participants originating from 32 countries (see figure 1 for national distribution of the participants).

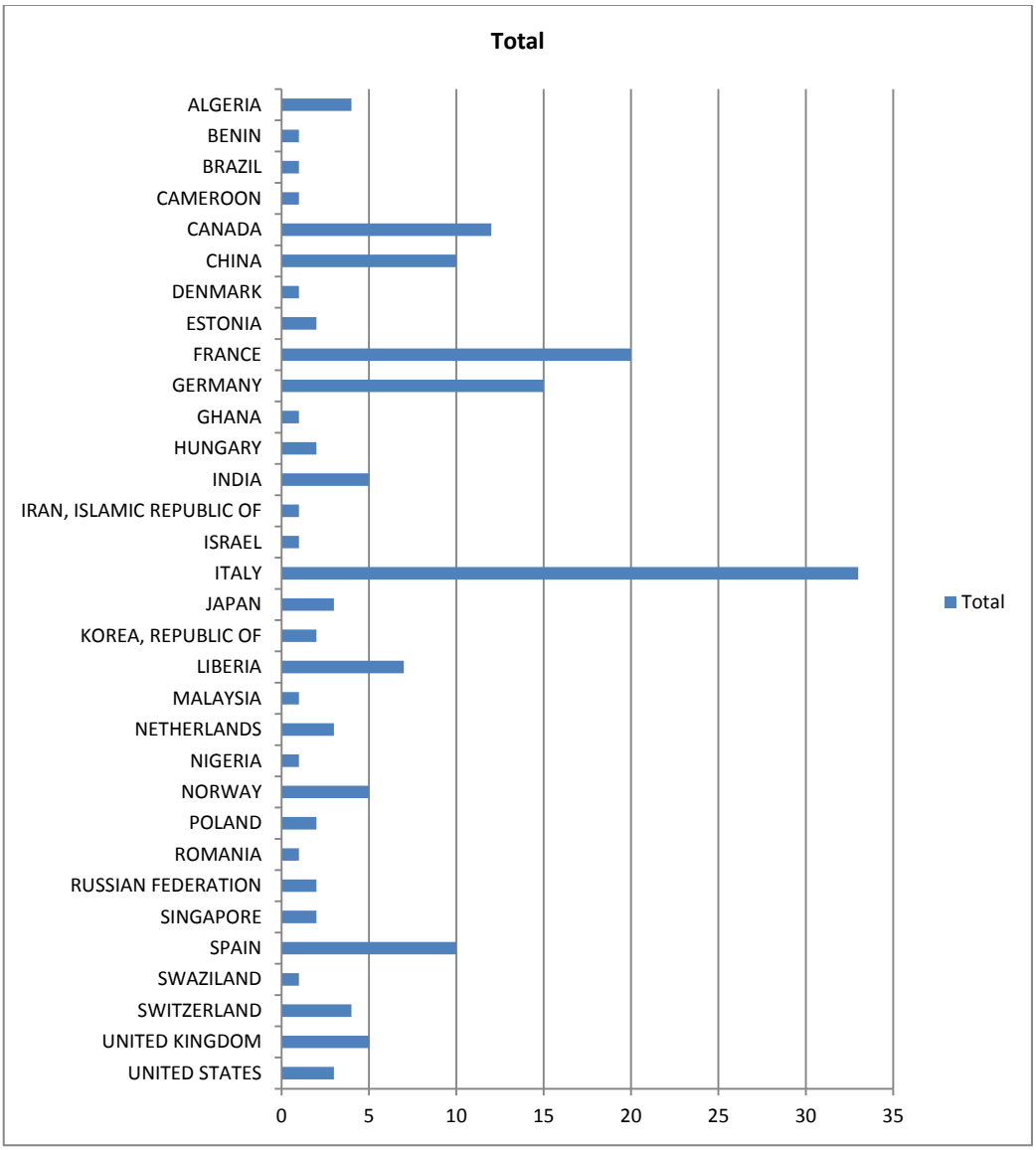


**Figure 2 National distribution of the participants**

# 2 METHODS AND THEORETICAL MODELING SESSION (PREPARED BY KEITH RANEY, IRENA HAJNSEK, CARLOS LÓPEZ-MARTINEZ)

## 2.1 Proposed Seed Questions

1) What is in the future for Compact Polarimetry?
2) What are the challenges for models & interpretive tools?
3) What extended or new models and techniques will be required to accommodate data from higher-capability systems, especially those having finer spatial resolution or bistatic geometry?
4) What are the applications with a high maturity based on PolSAR?

## 2.2 Seed question 1 discussion and recommendations

What is in the future for Compact Polarimetry*?*

Pertinent papers: (2) Raney; (5) Touzi; (7) Attwood; (10) Toutin; (11) Villa; (12) Villano.

### Discussion

- Experience with compact-pol data is spreading, with mixed results;
- Comparative analyses derived from quad-pol based emulations are encouraging;
- Flight systems have been imperfect (Mini-SAR, Mini-RF, RiSAT-1) posing challenges;
- Future systems anticipated (RCM, ALOS0-2, SAOCOM-1);
- Formal analysis basis yet to be established;
- Sensitivity to SNR and in-flight calibration issues remain.

### Recommendations

- Establish a unified theoretical basis for CP Pol-InSAR, in the same spirit as the founding basis for (quad-pol) Pol-InSAR;
- "Require" multi-PI objective quantitative comparisons of CP vs MP, DP, and FP for all Super Sites, including open availability of in situ data;
- Work system-engineering analyses of CP issues (e.g., required dynamic range, impact of imperfect transmit polarization, SNR, cross-talk, ambiguity levels vis-à-vis H&V quadpol, etc.).

## 2.3 Seed question 2 discussion and recommendations

*What are the challenges for models & interpretive tools?*

Pertinent papers: (1) Kojima; (3) López-Martinez; (4) Le; (6) Besic; (8) Alonzo-Gonzales; (9) Alvarez-Perez; (10) Toutin.

### Discussion

- The development of models and interpretative tools is still on-going and much remains to be still done.
- The understanding what polarimetry can provide is still in the beginning and need to be further developed.

### Recommendations

- Extend the texture model to the polarimetric case, which by implication means that a significantly different texture parameter should obtain for each polarimetric channel.
- Develop model-based decomposition schemes for application-specific physics (biomass + topography for example).
- Continue initiatives to make analysis and interpretive software tools validated, and integrated into user-friendly application resources.

## 2.4 Seed question 3 discussion and recommendations

*What is to be gained, and through which strategies, in pursuit of higher-order statistics, and non-Gaussian models?*

Pertinent papers:(1) Kojima; (3) López-Martinez; (6) Besic; (8) Alonzo-Gonzalez.

### Discussion

Is Eigen-value based methodology sub-optimum? If so, what are promising alternatives? It has not yet been shown that the usual suite of quad-pol analysis tools are “optimum”? If not, then there is a huge opportunity for a theoretical contribution to respond to this question.

### Recommendations

- Increase reliance on quantitative objective norms for comparing the performance of alternative analysis and decomposition paradigms
- Develop a rigorous theoretical construct for the optimal backscattering information extraction from quad- (full-) pol data ensembles.

## 2.5 Seed question 4 discussion and recommendations

***What are the applications with a high maturity based on PolSAR?***

The following table extracted from the on-going ESA PolSARAP[1] study animated the discussion.

| Domain | Application / Product | Application Maturity (Polarimetry) |
|---|---|---|
| Forestry | Above Ground Biomass | Medium |
| | Stand Height | High |
| | Vertical Structure | Medium |
| | Thematic Maps | High |
| | Change Detection | High |
| Agriculture | Crop Type Mapping | Medium |
| | Soil Moisture | High |
| | Phenology Determination | Medium |
| | Wetland Delineation | Medium |
| | Flooding Mapping | Medium |
| Cryosphere | Snow Volume | Medium |
| | Land Ice Extinction | Low |
| | Sea Ice Surface Char. | Low |
| Urban | Mapping / Classification | Medium |
| | 3D Rendering | Medium |
| | Subsidence | Medium |
| Ocean | Oil Slick Detection | Medium |
| | Metallic Targets | Medium |

**Figure 3 Applications and application maturity using Polarimetry (form ESA PolSAPAp study)**

[1] PolSARAp: Exploitation of Fully Polarimetric SAR Data for Application Demonstration (Ref: EOEP-DTEX-EOPS-SW-11-0001)

# 3 POLARIMETRIC SAR INTERFEROMETRY (POL-INSAR) SESSION (PREPARED BY SCOTT HENSLEY, ANDREAS REIGBER)

## 3.1 Proposed Seed Questions

1) Temporal decorrelation remains a challenging issue for PolinSAR studies and some proposed missions. Recent work has help to characterize and mitigate its effects particularly at L-band and P-band. Is there still the need for additional controlled experiments? If yes, what would these be?

2) Forest structure/elevation measurements still remains a key focus of polarimetric interferometry. Is the robustness of these techniques fully characterized between full polarizations and compact polarization modes of operation? If not what remains to complete this characterizations so that this trade space can be dealt with in quantitative fashion?

3) Community tools like POLSARPRO have played an integral role in helping new and old researchers develop facility with polarimetric interferometry. What major enhancements would most benefit the community both from a data processing and modeling perspective (answers should encompass tomography and multibaseline interferometry)?

4) What are the major gaps in data, airborne and spaceborne, that are limiting continued progress?

## 3.2 Seed question 1 discussion and recommendations

*Temporal decorrelation remains a challenging issue for PolinSAR studies and some proposed missions. Recent work has help to characterize and mitigate its effects particularly at L-band and P-band. Is there still the need for additional controlled experiments? If yes, what would these be?*

- The consensus was that scatterometer experiments like the P-band TropiSCAT experiments coupled with modeling are answering many of the issues needed to understand and characterize temporal decorrelation. **It was suggested that a similar experiment at L-band would be desired.**

- Recent work in mitigating temporal decorrelation is interesting, however the community felt that this work is still in its nascent stages and **much work still be remains in this area.**

- Consequently, controlled experiments are desirable, but there seems to be no immediate consensus what these could be.

## 3.3 Seed question 2 discussion and recommendations

*Forest structure/elevation measurements still remains a key focus of polarimetric-interferometry. Is the robustness of these techniques fully characterized between full polarizations and compact polarization modes of operation? If not what remains to complete this characterizations so that this trade space can be dealt with in quantitative fashion?*

- For single baseline PolInSAR there exists a rigorous performance model for quantifying the compact versus full polarization modes.
    - Multi-baseline studies exist but further refinements are possible.
- Applications, like biomass estimation, still require additional studies to determine when compact pol can be effectively substituted for full polarization measurements.
    - Should consider compact pol observables in their own right without a priori biasing with respect to full polarimetric analog measurements.

## 3.4 Seed question 3 discussion and recommendations

*Community tools like POLSARPRO have played an integral role in helping new and experienced researchers develop facility with polarimetric interferometry. What major enhancements would most benefit the community both from a data processing and modeling perspective (answers should encompass tomography and multi-baseline interferometry)?*

- One tool the community thought would be very useful is a tool that will automatically co-register stacks of data either in the radar slant plane or data that has been geo-coded.
- This tool needs to work at a fraction of pixel and should be not sensor specific.

## 3.5 Seed question 4 discussion and recommendations

*What are the major gaps in data, airborne and spaceborne, that are limiting continued progress?*

- The idea of supersites with commensurate ground truth, airborne and spaceborne data was suggested. Examples included Marc Simard' website and ESA data sets for campaigns like TropiSAR.
- Specifics and how this could be realized in a more uniform and systematic fashion need to be developed if this is ever to come to fruition.

- Another (similar) idea mentioned is to establish one or few standard data sets for comparing the performance of competing algorithms on a common base. Such data could serve as a long-term reference for evaluating new approaches (compare: “Lena” image in image processing)

# 4 POLARIMETRIC SAR INTERFEROMETRY (POL-INSAR): FOREST SESSION (PREPARED BY KOSTAS PAPATHANASSIOU, PASCALE DUBOIS-FERNANDEZ)

## 4.1 Proposed Seed Questions

1) What comes after forest height / DTM? What is the next generation of Pol-InSAR products:

   - Vertical Structure: Do we understand what we 'see' ? Do we have the required validation approaches / data bases for the new products?

   - Forest gaps and gap dynamics;

   - Biomass ??? Height is not enough ... what else.

2) What is the robustness of the forest parameter techniques with respect to spatial variation of the forest characteristics ? (resolution – spatial variation). What are the available tools for an accuracy estimation?

3) Pol-InSAR acquisition design:

   - How many baselines are needed: 1, 2, 3 or more?

   - Optimisation of geometry: Vertical vs Horizontal baselines?

## 4.2 Seed question 1 discussion and recommendations

*What comes after forest height / DTM? What is the next generation of Pol-InSAR products:*

*- Vertical Structure: Do we understand what we 'see' ? Do we have the required validation approaches / data bases for the new products?*

*- Forest gaps and gap dynamics;*

*- Biomass ??? Height is not enough ... what else.*

- Temporal decorrelation the key limitation factor in the implementation of traditional tomographic techniques: We need to understand better the mechanisms behind.

- Coherence Tomography (based on Single-pass interferograms) is a very promising way to avoid temporal / propagation disturbances;

- The interpretation of SAR tomograms is not established:

- Structure Validation Protocol > 3D ground measurements is required for future tomographic experiments;

- Is there a requirement of EM Modeling improvement (Thuy)?

**Time Series of PolSAR / Pol-InSAR Data:**

- There is no established way today how to process time series of Pol-InSAR Data;
- **Strong recommendation for the realisation of Quad-pol Temporal data sets with the appropriate reference measurements**.
  - Third party mission(s) & campaigns: Requirement on temporal series?
- What is the optimum way to process a reduced set (~3) of Pol-InSAR baselines?

## 4.3 Seed question 2 discussion and recommendations

*What is the robustness of the forest parameter techniques with respect to spatial variation of the forest characteristics ? (resolution – spatial variation). What are the available tools for an accuracy estimation?*

- Statistical analysis may be helpful for assessing validity.
- Data fusion (in terms of Frequency (Optical), Statistical Parameters as texture, Radiometry) may increase stability / performance of Pol-InSAR Algorithms.

## 4.4 Seed question 3 discussion and recommendations

*Pol-InSAR acquisition design:*

*- How many baselines are needed: 1, 2, 3 or more?*

*- Optimisation of geometry: Vertical vs Horizontal baselines?*

- *How many baselines are needed: 1, 2, 3 or more?*

  Depends on:

  ✓ Forest height range to be covered;

  ✓ The variation of kz in the swath;

  ✓ Level of Temporal Decorrelation in the Data;

- *Optimisation of geometry: Vertical vs Horizontal baselines?*

  Depends on:

  ✓ the total number of baselines to be realised;

- ✓ the objective of the experiment;
- ✓ Large(r) vertical baselines may limited by flight regulations (i.e. may require operation at multiple flight levels).

**→ Fact: There is a need of an ESA Pol-InSAR mission !**

# 5 POLARIMETRY & DINSAR, POLARIMETRY & PSI SESSION (PREPARED BY ANDREA MONTI-GUARNIERI, CARLOS LÓPEZ-MARTÍNEZ)

Papers presented in the session:

1. Assimilation of Distributed Targets and PS Information for a Scene-Based Monitoring of the Polarimetric Data Distortion *(Iannini, L.; Monti Guarnieri, A.; Tebaldini, S.)*

- Use of PS as alternative to traditional polarimetric calibration

2. Performance Comparison between Dual Polarimetric and Fully Polarimetric Data for DInSAR Subsidence Monitoring *(Monells, D.; Iglesias, R.; Mallorqui, J. J.)*

- Higher density of PS obtained with fully polarimetric data compared with dual pol data

3. Polarimetric adaptive Speckle Filtering driven by temporal Statistics for PSI Applications *(Navarro-Sanchez, V. D.; Lopez-Sanchez, J. M.)*

- Selection and combination of PS and distributed targets based on polarimetric criteria

4. Phase Quality Optimization Techniques and Limitations in Polarimetric Differential SAR Interferometry *(Iglesias, R.; Monells, D.; Fabregas, X.; Mallorquí, J. J.; Aguasca, A.; López-Martínez, Carlos)*

- Polarimetric optimization allows to improve de density of PS

## 5.1 Proposed Seed Questions

1) About the use of distributed targets

   - Subsidence monitoring has been classically considered in terms of point targets, either selected from amplitude or coherence information. Which is the role of distributed targets in subsidence monitoring ?

   - Does dual-/full-polarimetry improve accuracy, and in case of a positive answer, how much ?

   - Does coherence provide a suitable measure to qualify distributed targets for subsidence monitoring ?

2) About the use of polarimetric data

   Are there statistics on the stability of scattering matrix for PSI ?

   Which polarization is mostly stable or less affected by noise ?

   It is demonstrated that optimization techniques improve phase quality. Should these optimization approaches be adapted specifically to the DinSAR&PSI problem?

Would it be necessary set-up a campaign, with collection of ground-truth data, to assess the benefit of polarimetry?

3) About the use/comparison of single-, dual- and full-pol data.

- Could it be possible to compare quantitatively the gain of full-pol data in front of single- and dual-pol data?

- Is it expected an improvement in the use of Sentinel1 dual-polarization scheme with respect to single polarization ? Which combination do we recommend?

4) About temporal homogeneity

- Nowadays, do we have a clear understanding of the temporal behaviour, the statistical characterization and indeed about the concept of homogeneity of temporal polarimetric data for their use in DInSA&PSI applications?

## 5.2 Seed question 1 discussion and recommendation

***About the use of distributed targets***

*- Subsidence monitoring has been classically considered in terms of point targets, either selected from amplitude or coherence information. Which is the role of distributed targets in subsidence monitoring ?*

*- Does dual-/full-polarimetry improve accuracy, and in case of a positive answer, how much ?*

*- Does coherence provide a suitable measure to qualify distributed targets for subsidence monitoring ?*

- Distributed targets play an important role in DInSAR & PSI as they help to improve the estimation accuracy of subsidence phenomena.
- The capability of polarimetry to discriminate targets could get a great gain in DInSAR if properly used.
- Coherence may be not the figure-of-merit to be maximized. More research is needed.

## 5.3 Seed question 2 discussion and recommendation

***About the use of polarimetric data***

*- Are there statistics on the stability of scattering matrix for PSI ? Which polarization is mostly stable or less affected by noise ?*

*- It is demonstrated that optimization techniques improve phase quality. Should these optimization approaches be adapted specifically to the DinSAR&PSI problem?*

*- Would it be necessary set-up a campaign, with collection of ground-truth data, to assess the benefit of polarimetry?*

- Polarimetry is useful as it allows to increase the density of PS, separate targets and resolve confusions and better retrieval of orbital errors.
- A careful separation of interferometric and polarimetric aspects in the signal needs to be considered.
- Polarimetric optimization plays an important role on increasing the density of PS with high coherence and lower phase std. dev., but it must be demonstrated that it is not obtained at the expense of introducing biases.
- There is a clear lack of a PolSAR dataset dedicated to DInSAR&PSI with simultaneous ground-truth. A possible solution is to have proper simulation tools and strategies.

## 5.4 Seed question 3 discussion and recommendation

***About the use/comparison of single-, dual- and full-pol data.***

*- Could it be possible to compare quantitatively the gain of full-pol data in front of single- and dual-pol data?*

*- Is it expected an improvement in the use of Sentinel1 dual-polarization scheme with respect to single polarization ? Which combination do we recommend?*

- Additional criteria should be defined specially regarding the accuracy of the quantitative estimation of the subsidence phenomena.
- In case of Sentinel 1, dual-polarization data is better than single polarization data as the former achieve larger PS density. HV or VH channels are important in urban environments as they contain multiple scattering information. Nevertheless, attention must be paid to the scattered power in HV or VH with respect to the noise floor. This should be low to make possible the use of HV or VH.

## 5.5 Seed question 4 discussion and recommendation

***About temporal homogeneity***

*- Nowadays, do we have a clear understanding of the temporal behaviour, the statistical characterization and indeed about the concept of homogeneity of temporal polarimetric data for their use in DInSA&PSI applications?*

- Temporal studies are important to be able to study and to characterize the dynamics of the scene.

# 6 POLARIMETRY AND TOMOGRAPHY SESSION (PREPARED BY LAURENT FERRO-FAMIL, STEFANO TEBALDINI)

6 presentations about polarimetric tomography of forested areas:

- **Pardini**: TomSAR with simultaneous tandem-X pairs proposed as a tool to bypass temporal decorrelation. Results from TDX data.
- **Ho Tong**: P-Band TomSAR at 6 MHz proved feasible on tropical forests using 6 MHz data derived from the TropiSAR data-set.
- **Ferro-Famil**: theoretical advancements about multi-baseline estimation theory and applications to real data (TropiSAR).
- **Aguilera**: accurate TomSAR reconstruction with few sparse baselines using compressive sensing wavelet-based estimation. Results from E-SAR data.
- **Schwaebisch:** dual baseline airborne TomSAR proved effective for topography and vegetation height estimation. Results from real data by Intermap.
- **Lombardini:** Differential TomSAR as a tool to model and understand temporal decorrelation. Results from BIOSAR 1 data.

## 6.1 Proposed Seed Questions

1) Estimation performance

   The forest vertical structure can be imaged using several baselines or estimated using a few, with all intermediate possibilities in between.

   To what extent the performance of current estimation algorithms operating with few baselines can be compared to multibaseline imaging (for example, forest height estimation is OK with 1 or two baselines, but what about radiometric accuracy, robustness to temporal decorrelation, other....) ?

2) Temporal decorrelation

   Temporal decorrelation is crucial in repeat-pass scenarios (spaceborne). Multiple baselines and physical modeling can be employed to counteract its effects for the retrieval of physical parameters.

   In terms of theoretical developments, validation from real data, info about volume statistics, campaign requirements, etc. etc. what is now needed to make these methods established tools in forest analysis ?

3) Polarimetric modeling

   For estimation purposes, a lot of physical modeling has been done about forest vertical structure, whereas ground and volume polarimetric signatures are not so well considered. To what extent would forest structure estimation be improved if we pushed on polarimetric modeling?

4) General methodological applications of polarimetric SAR tomography

**Various** polarimetric techniques (applicable to air/spaceborne data sets) have been developed to separate volume/non volume contributions based on arbitrary, and often hardly verifiable hypothesis. Estimation of important features (underlying ground characteristics, types of trees, ... ) is generally conditioned by the choice of a decomposition method.

On the other hand PolTomSAR offers unique **3-D polarimetric imaging** possibilities, requires specific campaigns, and could be used to validate working hypothesis for large scale POLSAR applications.

Should we favour this type of cross-validation? Should we define a working group, specific sites and campaigns?

## 6.2 Recommendations

LIDAR measurements help interpretation of the results, but they should not be taken as the reference against which to compare TomSAR, since LIDAR and Radar vertical profiles are intrinsically different objects.

It is then recognized that:

- TomSAR products should be discussed based on the added-value associated with the applications
- TomSAR algorithms operating in practical conditions (few baselines, lower resolution, temporal decorrelation) should be tested against high resolution TomSAR products obtained in optimal conditions (many baselines flown on the same day), rather than against LIDAR.

Accordingly, the audience expresses the **need for dedicated airborne or ground based TomSAR campaigns,** aimed at producing high resolution 3D reconstructions of forest scattering in selected areas where accurate in-situ measurements are available.

This would result in a fundamental tool to:

- improve our understanding of the connection between TomSAR and relevant forest parameters (not only height, but also structure, biomass, dynamics);
- increase collaboration with scientists from forestry and ecology
- develop estimation methods tailored to specific forest parameters
- develop and validate PolSAR and PolInSAR models
- validate the accuracy of TomSAR algorithms able to operate in spaceborne-like conditions and/or with data from few baseline airborne campaign.

It is also recommended to further study theoretical modeling and performance bounds

# 7 APPLICATIONS ON OCEAN & CRYOSPHERE SESSION (PREPARED BY TORBJØRN. ELTOFT, MAURIZIO MIGLIACCIO)

The following presentations were given during the session:

- Polarimetric Decomposition Analysis of Sea Ice Data
- On the Interpretation of L- and P-Band PolSAR Signatures of Polithermal Glaciers
- Snow Property Extraction based on Polarimetry and Differential SAR Interferometry
- On Dual-Polarized SAR Measurements of the Ocean Surface
- Marine Bacteria Monitoring via Polarimetric SAR

## 7.1 Proposed Seed Questions:

1) What applications within the fields of ocean and cryosphere justify polarimetry compared to less complex systems? What benefits can be obtained using polSAR data (scattering mechanisms, estimation of multiple parameters, ....)

2) How can cooperative missions benefit PolSAR applications (multiple sensors, multiple frequencies)? For which applications is combining of data beneficial? What are the strategies for data fusion?

3) Are there any major inadequacies with respect to e.g. frequency, polarisation, and repeat cycle that can be identified with the present and near future satellite SAR systems for operational applications within the fields of ocean and cryosphere?

4) Are the tools available today, i.e. decompositions methods, classification methods, filtering methods, etc. sufficient, or are there serious deficiencies for the applications within the fields of ocean and cryosphere?

5) Are there any operational benefits of polarimetry? How much has been done? How much is still to do?

6) How can data availability can match the requirements of real time services?

## 7.2 Seed questions discussion and recommendations

### Summary

The benefit of polarimetric SARs with respect to single-pol SARs is clear for its unique capability to extract, by proper modeling, relevant geophysical parameters.

In some cases, such as wind field estimation, tropical cyclone tracking, ice monitoring, oil slick monitoring, coastal monitoring, the benefit of polSAR has been proved by scientific results.

In order to have full benefit of full polarimetric SAR measurements it is mandatory that sensors ensure a good SNR, especially for HV measurements and for some applications. For example this is particularly true for oil slick monitoring and wind field estimation.

Sea Ice and continental ice classification is greatly enhanced by polarimetric SAR measurements as witnessed by several scientific papers and by the COREH20 EE7 mission proposal. This is for example witnessed by Ice Service in Canada which is one of the primary users of polarimetric RADARSAT-2 data.

**Recommendations:**

- Although in the long term, it is desirable to have more polarimetric SAR missions, at the present state-of-art the scientific community agrees that virtual constellation combining different frequency and polarimetric modes can be of scientific and operational interest.

- The scientific community agrees that full polarimetric SAR measurements contain more information to be extracted and are suitable to several applications.

- The scientific community welcomes the forthcoming polarimetric SAR missions, and their application to ocean and cryosphere, such as CosmoSkyMed second generation, TerraSAR second generation, ALOS-Palsar 2, RCM constellation, RISAT-1 and the Chinese SAR constellation.

- Moving to operational outcomes it is desirable to enhance the swath coverage, i.e. revisit time (particularly critical when dynamic physical processes must be monitored) by using the most appropriate technology.

# 8 APPLICATIONS ON OCEAN POLLUTION MONITORING & TARGET DETECTION SESSION (PREPARED BY CAMILA BREKKE AND FERDINANDO NUNZIATA)

During the session there were 5 oral presentations, as follows:

- 2 relevant to oil slick monitoring
- 3 relevant to ship observation

**Oil slick monitoring:**

The presentations clearly showed the unique benefits of polSAR data to both observe oil slicks and obtaining rough information on the surfactants properties. Moreover, the capability of polSAR to observe oil in ice infested areas was also addressed.

**Ship observation:**

The presentations showed different approaches to process polSAR data for ship observation purposes:

a) a combined use of different polarimetric channels was proposed and extensively verified against actual data;

b) a TF technique was presented to deal with ship observation in etherogeneous environments;

c) an approach that exploits the different symmetry properties of man-made targets and sea surface was applied on TerraSAR-X data.

## 8.1 Proposed Seed Questions for Ship Target detection:

1) What are the unique benefits of polarimetric SAR data vs singlepol for ship observation?

2) What are the best polSAR (quad-, dual-, compact/hybrid) configurations for ship observation ?

3) Is the theoretical framework behind polSAR ship observation mature? What are future trends (ship classification?)?

4) An operational full-pol SAR system to observe oil/ships at sea is significantly affected by the low spatial/temporal coverage: What is the current status of new technologies (e.g. compact/hybrid pol, digital beam forming) ?

## 8.2 Ship detection discussion and recommendations

There is a general consensus that polSAR measurements offer unique benefits for ship observation, providing:

a) better detection, even of small targets;

b) discrimination between targets and false alarms;

c) Quad-pol SAR systems allows observing both oil slicks and ships.

However, wide area coverage is a fundamental aspect to make polSAR ship observation effective operationally.

- ✓ This application will benefit of the forthcoming CP SAR missions that allow combining polarimetric capabilities with wide area coverage.
- ✓ Ship classification is an important issue which can be addressed via polarimetric SAR.
- ✓ Scientific community pointed out that it is important to take advantage of key archival papers published in early days making an extensive literature review that includes some recommendations for the future.

## 8.3 Proposed Seed Questions for Oil pollution

- What is the current status on new techniques based on multipolarisation SAR/PolSAR/compact polarimetry for oil spill versus look-alike discrimination?
- What is the current status on new techniques based on multipolarisation SAR/PolSAR for characterization (thickness, oil volume fraction etc) of oil spills?
- There is an increasing interest in remote sensing of oil in sea ice infested waters. How far can we get with current SAR/PolSAR techniques? What types of sensors do we need?
- An operational full-pol SAR system to observe oil at sea is significantly affected by the low spatial/temporal coverage:

  What is the current status of new technologies (e.g. compact/hybrid pol, digital beam forming) ? Can the polarimetric measurements be exploited to enhance the value of single-pol ones?

## 8.4 Oil pollution discussion and recommendations

There is a general consensus that polSAR measurements offer unique benefits for oil slick observation. They allow both distinguishing oil from weak-damping look-alikes and providing rough information on the surfactant properties.

Further developments are devoted to:

a) developments of algorithms/models for oil detection in ice infested areas;
b) finer characterization of oil properties.

- Scientific community underlines the importance for oil slick observation to ensure an high SNR even for the cross-pol channel.
- PolSAR missions are needed to make the oil spill observation scientific idea operational. The most important drawback is the lack of spatial/time coverage. A

technological solution that combines the advantages of polSAR and enhances the spatial/temporal coverage is provided by the forthcoming SAR missions operating the CP mode.

- The integration of single-pol measurements and polSAR ones is important operationally.

# 9 APPLICATIONS OF SAR POLARIMETRY ON LAND: AGRICULTURE, URBAN, ARCHAEOLOGY SESSION (PREPARED BY JUAN MANUEL LOPEZ-SANCHEZ, ELISE COLIN-KOENIGUER)

## 9.1 Agriculture

During this session 3 presentations were given regarding the Agriculture, as follows:

- Time series with compact-pol data
- Phenology retrieval at C-band for for rice
- Incidence angle influence on polarimetric response of wheat and bare surfaces

### *9.1.1 Agriculture: proposed Seed Questions*

1) Considering the experience accumulated so far, which are the key products for end-users and which ones can be successfully retrieved?

2) Which polarimetric configuration meets better the requirements from the end-users? Is compact-pol enough?

3) Benefits from time series vs benefits from polarimetry?

4) Is there any potential contribution from interferometry and PolInSAR? If so, which would be the required configuration?

5) Do current techniques (decompositions and algorithms) satisfy the required accuracy for agriculture products?

6) Do we need new developments in theory, e.m. modeling or data processing for agriculture applications?

### *9.1.2 Agriculture: discussion and recommendations*

The following comments were discussed during the Agriculture - round table:

- There is no competition between time series and polarimetry, but complementariness. One can serve to solve the ambiguities of the others.
- **Recommendation**: to continue on this line (time+polarimetry) for agriculture applications.
- Rice monitoring: tests with ScanSAR dual-pol data (wide swath) of Radarsat-2 are convenient. It is an important application, attending to food security reasons.

## 9.2 Urban

During this session 3 presentations were given regarding the Urban, as follows:

- Comparison of many different methods for urban classification
- Use of polarimetry at X-band for both classification and 3D rendering
- Hybrid PolInSAR for urban studies

### *9.2.1 Urban: proposed Seed Questions*

1) What are the key applications in urban context and what are their maturity?
2) Which resolution is required for them? At which frequency band? Is there a compromise to find between resolution and frequency?
3) Benefits from resolution vs benefits from polarimetry?
4) Do we need new developments in e.m. modeling for understanding and satisfying applications?
5) Do we well understand HV in urban ?

### *9.2.2 Urban: discussion and recommendations*

The following comments were made and discussed during the Urban - round table:

- Additional effort in e.m. modeling is needed to understand complex scenarios
- Polarimetry vs resolution: application dependent, but
  - ✓ POLSAR can provide wide scale maps
  - ✓ High resolution provides information on changes and small details within a city
- Fusion with other data and sensors should be studied.

## 9.3 Archaeology

During this session 2 presentations (new application domain) were given regarding the Archaeology, as follows:

- Sudan: known archaeological area with difficult access
- Iraq: remains of an old city

### *9.3.1 Archaeology: proposed Seed Questions*

1) What is the specific role of polarimetry in this application?

### *9.3.2 Archaeology: discussion and recommendations*

- Polarimetry can contribute in the detection or identification of linear/long features much better than other techniques.

- Added value for end-users: to be assessed.

# 10 APPLICATIONS OF SAR POLARIMETRY ON LAND: SOIL MOISTURE AND WETLANDS SESSION (PREPARED BY RIDA TOUZI, SHANE CLOUDE)

## 10.1 Session Summary

**T. Jagdhuber et. Al.: Polarimetric Decompositions for Soil Moisture Retrieval from Vegetated Soils in TERENO Observatories**

- The presentation showed the existence of new extensive quadpol data sets and supporting ground data in Europe collected by DLR's novel F-SAR for surface parameter studies. Demonstrated an approach using ICTD to estimate sub-canopy moisture. Current results show good trends with season and location but some variance in estimates. Future work will involve using improved volume scattering models to improve accuracy of estimates.

**F. Charbonneau et. Al.: RCM Compact Polarimetry Applied to Watershed Study**

- This paper contained two key ideas. The first for bare surfaces a reworking of the IEM scattering model for compact products to ensure estimation of surface parameters from compact mode. Secondly use of InSAR coherence and phase for vegetation structure estimation. Currently using Radrasat-2, 24 day repeat so coherences are low but 4 day repeat of RCM anticipated better discrimination. Demonstrated polarization synthesis for compact mode to estimate signatures in scatter and coherence

**Natale et al., Soil moisture retrieval via a polarimetric two-scale and two-component scattering model**

- This paper presented a two scale fully polarimetric (T3) surface scattering model for moisture estimation of bare surfaces. Here extended to include a simple random volume component. Showed both good results and bad results when the volume model causes a bias in the retrieved parameters.

**Paillou et al., The chott El Jerid, Tunisia: Observation and interpretation of a SAR phase signature over evaporitic soils**

- A series of polarimetric Radarsat2 acquisitions was used to demonstrate the importance of the HH-VV phase information for monitoring arid environments, particularly those associated with evaporative salt plains. Clear information was shown in HH-VV phase and a tentative suggested explanation by physical modeling was presented.

**Touzi R. et al.: Polarimetric L-band ALOS PALSAR for subarctic Peatland Characterization and monitoring**

- In this study, the potential of polarimetric L-band ALOS for peatland subsurface water monitoring is demonstrated. The Touzi decomposition is applied on a series of ALOS acquisitions collected over the Wapusk National Park, and the potential

of the scattering type $\Phi_{\alpha s}$ is demonstrated for peatland subsurface water flow monitoring. While $\Phi_{\alpha s}$ provides information on peatland subsurface water flow, the conventional radiometric information provided by HH, HV, VV, as well as the Freeman decomposition parameters, and the Cloude-Pottier alpha-H cannot detect peatland subsurface water variations. Such potential is very promising for low cost and operational monitoring of subarctic bog-fen transformations related to climate change.

## 10.2 Proposed Seed Questions

1) Can we say that all the polarimetric SAR information is fully exploited by existing incoherent target decomposition (ICTD) parameters? Is there still additional information that can be extracted with all the abandoned tools (developed between 1950 and 1994) in the Polarization optimization theory ?

   Target Polarization Information Extraction: Example of Abandoned Tools

   - Polarization optimization theory (Ko 56, Kennuaugh 56, Boerner 80, Van Zyl 89)
   - Completely polarized wave extrema (Kostinski-Boerner 86)
   - Polarization signature (Van Zyl 88)
   - Completely polarized and unpolarized component (Evans 1988)
   - Poelman multinock filter (Poleman 76)
   - Contrast optimization of partially coherent targets (Ionnidis79, Swartz 88)
   - Extrema of the degree of polarization & scattered wave intensity (Touzi 92)
   - .... And Others..???

2) We have seen some interesting results for using polarimetric phase information in wetlands but as yet not with widespread confirmation by the community. What barriers are there to progress on this issue?

3) Can quadpol decomposition be used for robust sub-canopy moisture estimation? If not, what problems remain...are existing vegetation models used in quadpol decomposition adequate for the task?

4) Is compact mode the best dual-pol option for surface moisture/parameter estimation? What are calibration requirements on RCH-RCV for surface parameters? Are they primarily noise or polarimetric limited?

5) Does the quality of polarimetric space-borne SAR data from recent missions meet the needs for accurate estimation of moisture and wetland classification & monitoring?

## 10.3 Seed question 1 discussion and recommendations

*Incoherent target scattering decomposition (ICTD) has become the Standard tool for wetland characterization and classification: Are we exploiting all the polarimetric SAR information with the ICTD?*

- Cloude-Pottier, Freeman, Yamagushi, and Touzi Decompositions provide excellent results in terms of wetland classifications.
- It is to be recommended that for surface moisture and wetland studies a wide range of polarisation analysis techniques (such as coherent decompositions, signature analysis and optimization approaches) should be considered by the community rather than just few ICTD techniques which may not be best suited to some applications.
- It was noted that such wide diversity of tools does already exist in software such as Polsarpro but the applications community should be encouraged to make much wider use of them

## 10.4 Seed question 2 discussion and recommendations

*We have seen some interesting results for using polarimetric phase information in wetlands but as yet not with widespread confirmation by the community. What barriers are there to progress on this issue?*

- The target scattering type $\phi_{\alpha s}$ (generated by the Touzi decomposition) is shown to be sensitive to peatland subsurface water flow, and as a result, the phase information looks to be very promising for monitoring subarctic peatland (bog-fen) transformation related to climate change.
- Paillou has demonstrated how useful the HH-VV phase can be for monitoring arid environments, particularly those associated with evaporative salt plains.

**Recommendation**

- Such approaches require both full quadpol data and low noise floor (HV of low S/N) and hence impact on system requirements for future SAR systems.
- There is also a strong seasonal (spring to fall under no snow conditions) coverage requirement which may not be met by future satellite missions
- It is strongly requested to allow adaptation of quadpol mode availability to suit seasonal requirements for subarctic and boreal wetland monitoring.
- It is strongly wished that L-band ALOS-2 planned mode coverage would permit polarimetric acquisitions over subarctic and boreal region from the spring run off (June-July) to the fall (October) for the operational monitoring of subarctic and Boreal peatland transformation.

## 10.5 Seed question 3 discussion and recommendations

*Can quadpol decomposition be used for robust sub-canopy moisture estimation?*

*If not, what problems remain...are existing vegetation models used in quadpol decomposition adequate for the task?*

- We saw here some evidence that the volume models available are not yet robust enough for operational applications and more research is required to find better improved models for use in decompositions.

  However it was noted that more complex models will increase the number of parameters which may take inversion outside of polarimetry alone. One possibility is to include PolInSAR in surface studies but so far suitable data is limited.

## 10.6 Seed question 4 discussion and recommendations

*Is compact mode the best dual-pol option for surface moisture/parameter estimation? What are calibration requirements on RCH-RCV for surface parameters? Are they primarily noise or polarimetric limited?*

- While it has been shown that the Compact can be efficient for bare soil moisture estimation (HV of insignificant return), further R&D is required to see if the dual-receive polarization measurements completed with one transmitted polarization (CP) can generate like HV accurate soil moisture estimation under vegetation cover.

- Among the RH, RV, RR, and RL, RL looks to be the most promising for soil moisture estimation. Others validations are needed in preparation of the upcoming Canadian constellation (RCM) that will include 3 satellite equipped with scanSAR compact.

- Cal-Val requirement on the Compact: RH-RV: 0.5 dB in radiometry and phase within 15°

  - Received polarization synthesis and accurate generation of the RR-RL from RH-RV

  - Non circularity of the transmitted CP has to be calibrated for.

- The Compact will become operational with the upcoming Canadian constellation the RCM. The wide swath mode (up to 350km) should lead to the operational use of polarization information for optimum soil moisture mentoring.

  - Potential barrier : NESZ=-17 dB

## 10.7 Seed question 5 discussion and recommendations

*Is the quality of polarimetric space-borne SAR data from recent missions sufficient for quantitative geo- & bio-physical parameter retrieval?*

- ALOS and Radarat2 excellent: antenna isolation (better than -35 dB) + low noise floor (NESZ about -34 dB).
- TerraSAR: Experimental polarimetric Mode
  - ✓ HH and VV well calibrated.
  - ✓ HV needs to be calibrated (-25dB contamination by HH and VV)
- Calibrated HV information should be used with care (high NESZ).

- Recommend the design of the new mission with low noise floor (-34 dB) and high antenna isolation (-30 dB) for accurate single, dual (HH-HV, VVVH & Compact) and quad-pol polarization information extraction.

## 10.8 Data

PolinSAR 2011: The operational use of polarimetric SAR is not demonstrated yet it is just at study levels. We should take advantage of the easier access to polarimetric data with the new satellite SAR (Radarsat2, ALOS, and TerraSAR-X) to conduct experiments and investigation that will demonstrate and create the need for operational use of fully polarimetric data in various applications.

- Many thanks to ESA, CSA, JAXA and DLR for the effort they are making to make available full-polarimetric Radarsat-2, ALOS and TerraSAR data.

- The larger availability of polarimetric Radarsat2, Alos, and TerraSAR data should widen the polarimetric R&D community and will permit the demonstration of key applications that promote and address the need for operational use of SAR polarimetric and POl-InSAR information in key international issue such as wetland protection and monitoring of the climate change on ecosystem and forests .

# 11 APPLICATIONS OF SAR POLARIMETRY: OTHER SESSION (PREPARED BY ERIC POTTIER, WEN HONG)

During this session 7 presentations were given upon 4 different topics, as follows:

## 11.1 PolSARpro: Seed questions discussion and recommendations

*An education tool, processing assistant, or application demonstrator ?*

*Feedback from the users are very important for the future development !*

*WHAT DO YOU NEED **?***

**Full consensus from the research community for the continuity of the development of PolSARpro** : **YES**

Actions :

- Feedbacks from the users (dynamic development)
- Applications driven
- Simulator package (PolSARproSIM) -> Scott Hensley
- Pol-InSAR dedicated functionalities -> Andrea Minchella (NEST)
- Coherent decomposition -> Rhida Touzi

## 11.2 Multi-channel Analysis (time-series, multi-incidence angle, multi-polarimetric channel ...): seed questions discussion and recommendations

*Change information contains more knowledge when taking multi-channel into consideration. Effect on the system acquisition mode (complexity). Change detection methodology: mature ?*

Comments during the round-table:

- The mechanism of Polarimetric characteristics in understanding 'physical changes' in change detection need to be further explored.
- Time series technique is surely helpful in change detection.
- Suitable and enough data sets are necessarily needed to support this research, specific campaigns need to be organized.
- Scattering mechanisms affected by multi-incidence angles can't be ignored

**Recommendations** :

- Trying to find an important time-serie dataset (> 10 images)

- Could be a common validating dataset for the community.
- Comparing performance of algorithms
- Dedicated session (?)

## 11.3 Segmentation/Classification: seed questions discussion and recommendations

*1) Different approaches combining pre-processing (decomposition) or features extraction.*

*2) Sensitivity to the size of the analysis window, distribution (non-gaussian, Wishart …) ?*

*3) Sensitivity to the acquisition mode (incidence angle, orbit …) ?*

***4)** Radar vs Optical classification ?*

Taking into account the acquisition configuration

**Recommendations :**

- Including in PolSARap a theme concerning the influence of the incidence angle for all types of application.

### *11.3.1 Pol-InSAR and urban area application: seed questions discussion and recommendation*

***(open question)***

Comments during the round table

- Modeling and Methodology used in nature scenario seems difficult to be applied in urban area, such as for vehicle and other urban canyon.
- Urban application is still on the way to satisfy end users requirements according to automation, efficiency, cost and etc.
- Yamaguchi and related research work on polar. Contrast enhancement should be restudied.

# 12 POLINSAR ORGANISATION FEEDBACK

- POLinSAR platform for crowd sourcing
- 2 minutes presentation at session end for poster related to session
- Shorten sessions
- Tweets!!!
- Seed questions preparation via abstract or registration
- Enhanced bibliography in POLSARAP publication
- Double poster session exposure time
- Special session and publication at other conferences