Review of Interferometric SAR- Activities at the Stuttgart University, Institute of Navigation (INS)

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ABSTRACT

INSAR tests have been performed with ERS-1 SAR-data, mainly at the Bonn test site, so far. DEMs could be computed, which agreed with GPS- and official data sets to better than two meters. Also heights of buildings and forests were measured with at least this accuracy. As regards the differential interferometry (D-INSAR), the sensitivity to 1 cm height variations of corner reflectors could be verified in the cooperative experiment conducted together with POLIMI and ESA. "Moving fields" in the cm-region were also identified during the D-INSAR- tests. The detected height changes of the fields in the cm-region turned out to be originated by the farmers' field activities. Various other results are reported and future activities shortly described.

INTRODUCTION

SAR interferometry (INSAR) has been investigated and developed at INS for the following purposes:

- To assess the capabilities of spaceborne INSAR, and in particular to estimate its accuracy, reliability and its usefulness for various practical applications.
- To demonstrate its capabilities of the INSAR- technique per se for practical applications in Europe and even in remote areas like the Antarctica.
- To investigate the usefulness of combinations of interferogrammes, coherence measures, and SAR intensity data for classification purposes, land use mapping and monitoring.
- To integrate data sets and methods of optical remote sensing, GIS, and SAR/ INSAR-techniques for combined applications.

We are also dealing with the development and experimental application of differential interferometry techniques (D-INSAR) for the future monitoring of geodynamic activities, ice movements, land sliding etc. Finally we are investigating open questions concerning future spaceborne interferometric mission demands. Related publications of the INS are listed as references.

1. THE BONN TEST SITE

Excellent possibilities for INSAR- experiments and studies were provided by the fact that ESA turned on the SAR-instrument during the ice phase (3-day repetition orbit), supported the tests, monitored the data acquisition, provided fast data delivery and coordinated the cooperation with POLIMI and INS. Ten passes were recorded during March 1992. In this manner, we received much information which could be evaluated to study the influence of the baseline geometry, of the time difference between the data takes, of the achievable accuracy of DEMs, etc.

1.1 Differential Interferometry

The main objectives of the experiment were devoted to differential interferometry. The POLIMI- group was responsible for data processing and the INS- group for the field tests with corner reflectors. The main results were the following:

- Lifting of single corner reflectors (CRs) by 1 cm could be identified; the POLIMI data evaluation came to the result that out of 19 CRs, two were lifted, one 9 mm, the other one 8 mm. Indeed, only the two identified CRs were lifted, both by 1 cm. It has to be emphasized that the experiment was performed "blind": The data processing group was only informed of the actual lifting of the CRs (how many, which ones, to which amount), after it had presented its own results.
- Additionally POLIMI detected a "moving field", which seemed to have changed its height by approx. 1 cm during the 3 days of passes 9 and 10. Various explanations were discussed: Real physical change (but why?), change of soil wetness and consequently change of signal penetra-

tion (but why only in this one field?), influences of the wet component of the atmosphere (however this should also have had an effect at the neighbouring fields), influences of the ionosphere (but this would effect the whole test site of about 200 km^2). Meanwhile both groups, POLIMI and INS, found 3 other "moving fields". From 3 of these fields, a ground check and discussion with the farmers seems to explain the results: Between the passes the farmers harrowed the fields, sowed sugar beets or beans resp. and densified the soil. The surface was originally ploughed (before the winter). So, the actual height of surface was really changed in height in the order of a few cm. We intend to test and verify this method of identifying farming activities in more detail, as we find this very important in view of possible use for the tasks of prediction of agricultural inventory as early as spring.

We could not yet receive a corresponding confirmation for field 4. However, in all 4 cases we can ask ourselves why the coherence remained relatively high in the SAR- data and why the backscatter practically did not change. One of the explanations might be related to the fact that the lines of treatment (ploughing, harrowing, densifying) were close to the direction of the SARs slant range. So, we have to investigate the question in more detail now, to become certain about the effects and the constraints of phenomena detection.

1.2 Construction of DEMs

Various lengths of baselines allowed to determine the 3-D topography and to compare it with results of GPS- position determination. As expected, the accuracy improved with the length of the baseline, at least as long as the coherence is not affected too greatly. The optimum results we achieved amount to 1,3 m rms and a bias of -20 cm for a length of baseline of about 600 m. For the assessment of the accuracy we used open areas of bare soil and measurements with GPS. The INSAR- derived DEM values deviate, of course, at land covered areas (urban, forests) from the official DTM, as they are based on the reflections from the top level and not from the ground surface. Two methods are, therefore, possible to determine the height of the buildings and of the canopy, before testing the results by ground truth. A first method can use the height changes occuring in the INSAR- derived DEM at transitions from ground level to buildings, or from ground level to forests (treetops), etc. The second method is the direct comparison with the official DTM of the State of Nordrhein Westfalen, which is available in a 50 m x 50m grid. In all cases we found agreements in the accuracy level of a few meter.

1.3 Other factors

We are about to study the influences of weather conditions, seasonal effects and phenological states of plants, and how to separate them in our evaluations. Three measures are applied by us and compared for that purpose, the variations of the intensity, of the phase and of the coherency of the SAR- signals. The INS is studying the phenomena especially in the Bonn test site and in the Freiburg test site (close to the Swiss/German border), where we have also detailed ground truth data available. Especially for the second ice phase (early 1994) we have planned to observe the facts in more detail on the basis of a whole sequence of SAR data sets from January till end of March and with careful observations of weather conditions, farmer activities, kinds of landcover etc. Correlation between coherence, fringe variations and intensity changes are studied. Comparison of the results with those of the 1992 period are studied as well. It is too early, yet, for conclusions.

2. PHASE UNWRAPPING, TOPOGRAPHY AND FORESTS

In the Black Forest we are about to apply various methods of phase unwrapping (we have developed some new ones during the last months) and to test the accuracy of forest height measurements as a function of seasonal, meteorological and topographic effects and for various types of trees. In order to test the actual accuracy, we shall use our airborne scanning laser altimeter, which we will fly over that region. This uses the feature that the narrow laser beams are partly backscattered at the canopy, partly on ground, and partly at the branches and twigs. We can, therefore acquire a good understanding regarding the influences of the structure and density of the trees, the influence of leaves (as a function of the season) etc., if we correlate the INSAR results with these airborne flights. Also the influence of the incidence angle can be studied, as in the Black Forest we have large variations of slopes.

3. LARGE SCENES

For many reasons it is important to study the applications of SAR- and INSAR- techniques over very large regions. We are about to apply it to the areas of Baden-Württemberg and Thuringia. The whole area is larger than 350 km x 350 km. The advantages are the availability of very detailed data of all kinds (DTM, GIS, agricultural use and inventory results, weather data, etc.). Also very different topography, field sizes, crops etc. are to be monitored. In cooperation with agricultural ministries, statistical offices, and industrial partners we are trying to demonstrate the operational use of SAR- techniques and to learn the advantages vs. optical remote sensing techniques and the benefits of using INSAR techniques. As a first results we can state that we can benefit very much from the fact that segmentation is much easier by optical means than SAR- techniques. We use the field boundaries of the optical data -which will not vary over many years- and perform the SAR- classification within the boundaries. So, we can consider all pixels within the related area as one set. This is of great advantage for the classification. We can, for example, determine the mean value within the individual fields, eliminate the mixpixels close to the boundaries, can determine the textures within the fields etc. To some extent speckle effects can be filtered out. Present results look promising, but for the real quantification over a larger region we have to investigate more dataa sets than available, yet.

It is our goal to determine how often and at what times of the year we can best classify land use, changes and activities in fields etc. Thus far, we have already studied the application of optical remote sensing data for such agricultural purposes. Although the field sizes of Baden- Württemberg are very small (1 ha, for example), we succeeded in determining the areas at which winter wheat was grown with an accuracy of 96% to 98 %, compared to the conventional tedious methods of ground truth. This was possible by making use of the GIS, and through stratification methods. In the future, we hope to become at least as good with SAR/INSAR and GIS, and to extend the classification to the ten most predominant types of crops grown in the area. An additional benefit is that to the data could be acquired independently of the weather.

4. ANTARCTICA

We also have test sites in Antarctica to study the application of INSAR in topograpgic mapping and to monitor changes in the ice/ snow cover and the flow of ice there. Various tests have been performed and topographic maps have been generated, demonstrating that the software we use can also work , if the satellite orbits differ considerably (not parallel and in different heights). Variations of backscatter features due to snow storms have been experienced. We hope, for the future, to acquire a better understanding between the backscatter variations (amplitude, phase, coherence) and the type and quality of snow and ice. Even more important is the information we could collect with D-INSAR: We determined vertical surface motions of shelf ice due to tidal effects. The results agreed with GPS- measurements to an accuracy of about a few centimeters. we determined also horizontal motions of ice, but it is still a problem for us to verify that the results to be as precise as a fraction of a cm per 3 days (repetition period). We have not yet the corresponding local measurements available, which could be acquired by GPS, would it not so difficult to go to these sites in the Antarctica. We have had some difficulty to separate the various effects, which let to fringes: the topography, the horizontal and the vertical motions. But we could use the sequence of 8 SAR images from different times and with different baselines: fringes generated by the topography are a function of the baseline vector, but is are independent of time. Velocities are a function of time, but are approximately independent of the baseline. Tidal effects are periodic. So, in other words, we can separate various influences from each other.

5. GEODYNAMIC ASPECTS

Together with POLIMI, the Naples University, and the French group, we are presently studying the surface motions at Volcanic areas, areas of land slides, and in cooperation with the GFZ Potsdam, we are studying the possibilities of earth quake related phenomena by means of differential interferometry.

CONCLUSIONS

ERS-1 SAR data can be used for SAR- interferometry to determine DEMs, to detect sub-cm surface motions. It can also be used to apply coherence criteria in order to detect changes of surface features, such as variations of surface moisture, changes of the phenological state of plants, etc. We are convinced that the interferometry can be of use for numerous applications. However, further studies are needed, to understand the various effects involved. The envisaged TANDEM mission of ERS-1/ ERS-2 would be an excellent opportunity to perform such investigations.

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