Geometric Performance of ENVISAT ASAR Products

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***Abstract* - We describe validation measurements of the geometric accuracy of ASAR images, measured redundantly via independent methods. Our tests include image (IM), alternating polarisation (AP), and wide swath (WS) mode acquisitions over a variety of test sites. ASAR's slant range products (IMS/APS) require a slightly different validation methodology than ground range precision (IMP, APP) and medium resolution products (IMM, APM, WSM). A third approach is required for ellipsoid-geocoded products (IMG, APG).**

The most highly accurate validation is possible with single-look complex (SLC) data (IMS & APS products), as all other product types lose resolution during multilooking. For a library of ground control points (GCPs) including map features such as bridges or road intersections, as well as (where available) transponders and corner reflectors, we use surveyed or map-measured position information (together with the delay value in the case of transponders) to solve the Zero-Doppler iteration and predict the position of the GCP as an azimuth and slant range coordinate in the radar image.

In the case of ground range products (e.g. IMP, APP, IMM, APM, WSM) the predicted slant range value is additionally transformed by a slant to ground range transformation to determine the predicted image coordinate. The GCP feature is then either measured by inspection of a detected image, or localized automatically within the neighbourhood of the prediction.

GCPs are measured within the radar geometry image products, derivative geocoded products, and topographic maps, providing their measured map, radar geometry, and nominally geocoded GTC locations. Radar image locations are compared to map reference values and statistics of differences are tabulated. We compare the accuracies of the estimates achievable using transponders and map GCPs.

Based on the suite of products (and accompanying orbit information) available to us, we establish a methodology for estimating a preliminary sampling window start time bias. The multiple validation and estimation techniques used ensure robust determination of ASAR geolocation accuracy.

Keywords: SAR, Geometry, Transponder, DEM, ENVISAT, ASAR, ESA

I. Introduction

The quality of ASAR product localisation is vital to the satellite's ground segment, as well-calibrated *a priori* geolocation enables simple overlays of ASAR data with information from independent sources. The range and azimuth timing, state vector quality, cartographic and geodetic parameters, and multiple slant/ground range transformations must be carefully integrated into the geocoding system to minimise introduction of mislocation errors.

Initial experiences with ERS-1 geometry were reported in [4]. We report here first experiences with ASAR products processed by ESA's payload data segment (PDS) including the UK-, I-, and D-PAC's (processing and archiving centres).

A. Map Ground Control Points

To reduce speckle and improve readability, slant range single look complex images were detected and multilooked in azimuth. The multilook factor used was calculated on the basis of the mid-scene nominal incidence angle to produce approximately square pixels. Ground control points were chosen within each multilooked radar geometry image. Image location predictions based on each point's map position were then compared with the direct GCP measurements, and the mean and standard deviation of the differences was tabulated.

B. Transponder Control Points

Although corner reflectors can be treated in the same way as other map-read ground control points, prediction of transponder image positions requires integration of the delay term [5]. The strong transponder echo return allows more precise determination of its central image co-ordinates using oversampling.

C. SRTM & ASAR Overlays

Geolocation errors were also controlled using overlays of geocoded ASAR products with well-calibrated SRTM geocoded amplitudes [3] and each other [6] (e.g. geocoded slant and ground range products).

II. Prediction Accuracies

Results were obtained from test sites in Flevoland (NL), Ottawa (Canada), and Zürich (Switzerland).

A. Flevoland, The Netherlands

For a set of six APS data sets acquired over Flevoland, the position of each transponder in radar geometry was predicted based on the state vector and timing annotations. Only two of the ASAR transponders were visible within the six acquisitions: Zwolle and Swifterbant. The image areas surrounding the predicted slant range image location are shown in Fig. 1 with multilook factors of 3x15 and 1x5 (range x azimuth).

Note the consistent relatively large azimuth error. Prediction differences (prediction minus image measurement) are tabulated in terms of single look complex (SLC) samples (typically ~3-4m in azimuth; 7.8m in slant range) in Table I. Map GCPs were measured in each image and compared with predictions based on Dutch 1:25K and 1:50K topographic map readings. Statistics for all map GCPs within each scene are also shown in Table I. Note that the map GCP-derived values generally agree well with the transponder-derived numbers.

The large azimuth shift is likely due to the relatively low quality of the state vectors provided. All products were processed with restituted orbit quality (annotation code `FR`). More

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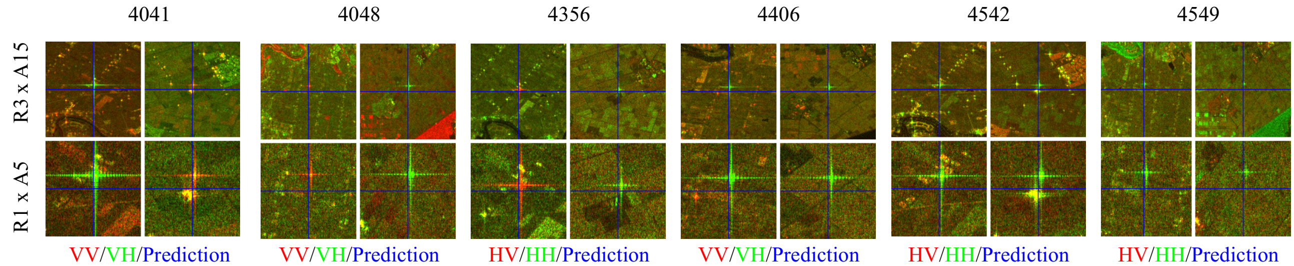

Fig. 1: Transponder close-ups within multilook detected APS slant range image: left Zwolle, right Swifterbant - Flevoland, The Netherlands

TABLE I: FLEVOLAND PREDICTED VS. MEASURED TRANSPONDER LOCATIONS IN SLANT RANGE IMAGE [SLC SAMPLES]

APS Orbit	Beam	Zwolle		Swifterbant		Map GCPs	
		Δa	Δr	Δa	Δr	Δa	Δr
4041	IS7 D	90.87	-3.23	89.43	-4.02	90.1±4.3	-2.9±0.9
4048	IS1 A	111.84	-3.39	112.97	-4.08	107.7±4.0	-3.8±0.9
4356	IS5 D	39.52	-3.14	37.99	-3.92	38.1±4.1	-3.3±1.0
4406	IS4 A	88.81	-3.44	89.01	-4.03	84.9±3.0	-3.6±1.0
4542	IS7 D	87.19	-3.06	85.74	-3.88	87.3±3.3	-2.6±0.9
4549	IS1 A	111.14	-3.35	111.59	-4.03	100.4±4.0	-3.9±1.1

accurate results would be expected using preliminary or precise quality DORIS orbit products [5].

The consistent "individual" range bias for each transponder is likely due to error in the delay term for each transponder, estimated to be approximately 10 nanoseconds [2].

An *a priori* geometry terrain-geocoding test was conducted to assess end-to-end system performance. The APS products were terrain-geocoded using the GLOBE elevation model sampled at 12.5m. A selection from the Flevoland (NL) results is shown in Fig. 2. The differences are generally consistent with statistics obtained from slant range GCPs [5]. An overlay of well-calibrated SRTM data with geocoded ASAR data shows consistent shifts (Fig. 3), mainly in azimuth.

We overlaid *a priori* terrain-geocoded APP and APS products derived from the same data acquisition to test for systematic differences between product types. An example of one such overlay is shown in Fig. 4. No significant shifts were detected, indicating (as expected) that the extra slant to ground range conversion step during geocoding required for ground range products does not appear to introduce additional geometric uncertainty. Although the APS/APP relative error is minimal, their absolute mislocations remain large (mainly due to the poor orbit quality).

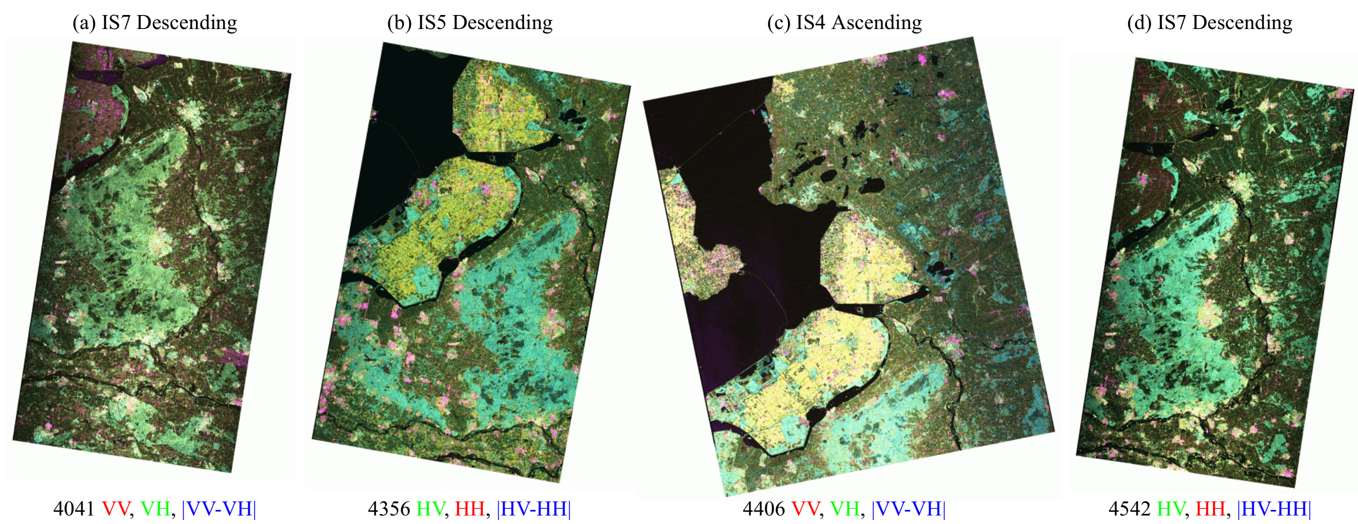

Fig. 2: *A priori* (no GCP refinement of geometry) terrain-geocoding of APS products - Flevoland, The Netherlands

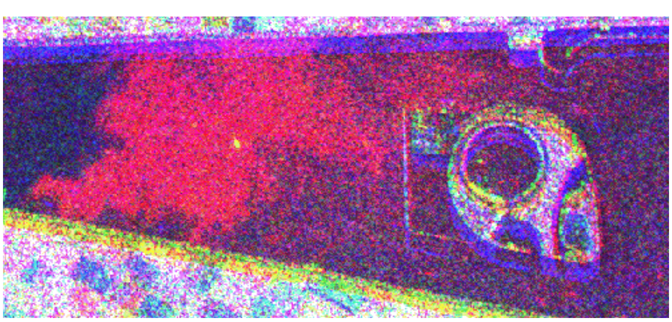
Fig. 3: SRTM/ASAR overlay - Flevoland, The Netherlands

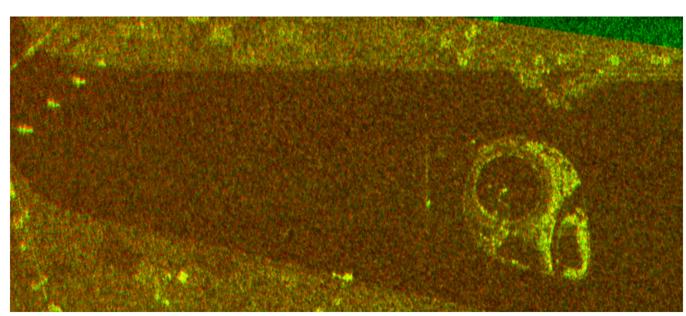
Fig. 4: APP (ground range) & APS (slant range) product *a priori* GTC 4542 overlay comparison - Flevoland, The Netherlands

B. Ottawa, Canada

The Canadian radarsat transponders were also used for validation of ASAR geometry. The four transponders are distributed across Canada: we investigated three scenes acquired over Ottawa. As in Flevoland, predictions were based on surveyed locations as well as the state vector annotations and the transponder delay term. The predicted and measured locations are juxtaposed in Fig. 5. The transponder appears not to have responded in orbit 4259. Note how the radarsat transponder returns a linear polarisation at 45°, with components in both H and V polarisations. The ASAR transponders in the Netherlands return single H or V polarisations (see Fig. 1). Quantitative comparisons for Ottawa are shown in Table II. The sign of the differences between predicted and measured transponder position is consistent with the Flevoland results, possibly due to systematic errors in the state vectors and the sampling window start time. The slightly larger range difference may be due to uncertainty in the delay value used for the transponder.

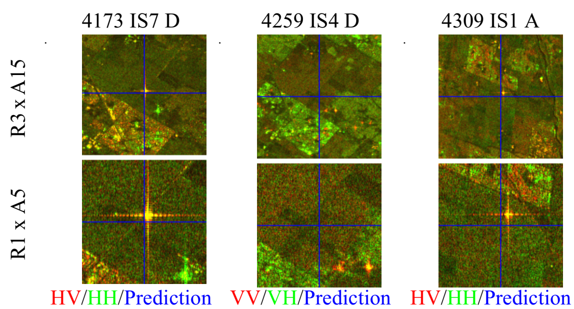

Fig. 5: APS Ottawa transponders: predictions & measurements

TABLE II: OTTAWA PREDICTED VS. MEASURED TRANSPONDER LOCATIONS IN SLANT RANGE IMAGE [SLC SAMPLES]

APS Orbit	Beam	Transponder		Map GCPs	
		Δa	Δr	Δa	Δr
4173	IS7 D	34.2	-4.3	25.5±6.3	-8.0±3.5
4259	IS4 D	-	-	37.7±5.0	-7.2±1.1
4309	IS1 A	57.3	-8.1	57.0±2.2	-7.6±1.7

C. Wide Swath Mode over Switzerland

A single WSM product was available for study, covering Switzerland, western Austria, and southern Germany. In wide swath scenes, multiple map reference systems often become involved, and the standard ESA processor PF-ASAR updates the slant/ground range polynomial transformation repeatedly along azimuth. As an end-to-end geocoding system test, an *a priori* terrain geocoding was conducted using the 25m resolution DHM25 DEM from swisstopo within Switzerland; and the 1km GTOPO30 outside the country. The geocoded result is overlaid on the height-cycled DEM in Fig. 6. In a manner similar to IMG and APG product validation [6], control points were measured in the WSM-GTC: we tabulated map vs. image differences and found a largely constant shift mainly in range on the order of hundreds of metres. The cause of the shift is the subject of ongoing investigation.

III. DISCUSSION

The quality of the state vectors provided in each product's header annotations varies from the poorest flight segment predicted (`FP`) or restituted (`FR`) to the more accurate DORIS

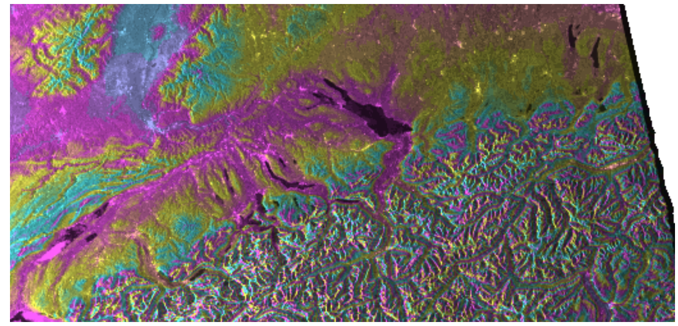

Fig. 6: *A priori* WSM product terrain geocoding - Switzerland - 1000m height colour cycle

preliminary (`DOR_POR_AX`), and precise (`DOR_VOR_AX`) state vector qualities. All products investigated here were processed with flight segment restituted (`FR`) state vectors. This limits their utility for geometric validation purposes: more accurate results are to be expected once DORIS precise quality state vectors become available.

The sampling window start time bias may be calculated by using mean bias values from map GCPs measured on many transponder scenes to refine each transponder's delay term. The SWST bias would then be calculated by evaluating the mean prediction vs. measurement for all transponders present. Use of the improved SWST bias in future products would improve the quality of the range prediction. Improvements to azimuth prediction require better state vector quality.

IV. CONCLUSIONS

Based on overlay comparisons, slant and ground range products appear not to be subject to any inter-product shifts.

The prediction accuracy of targets in radar geometry images is dependent on the quality of the satellite state vectors available, as well as the surveyed ground position information, and (in the case of transponders) a delay term. A definitive calculation of the sampling window start time bias will have to await availability of products processed with DORIS precise orbit state vectors. In order to by-pass the transponder delay term, a corner reflector campaign will be carried out in 2003 in Zürich, Switzerland. This will allow robust determination of the sampling window start time bias.

ACKNOWLEDGMENT

This work was supported by ESA-DLR subcontracts. The authors wish to acknowledge Harry Jackson (ESA-ESTEC) and Betlem Rosich (ESA-ESRIN) for fruitful discussions and assistance in the preparation of this paper.

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