TECHNICAL ASPECTS OF ENVISAT ASAR GEOCODING CAPABILITY AT DLR

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ABSTRACT

Based on experience with the geocoding systems for ERS-D-PAF (GEOS), the SIR-C/X-SAR (GEOS) and SRTM missions (GeMoS), geocoding functionality has been extended for Envisat ASAR data. The existing Envisat ASAR Geocoding System (EGEO) can handle all Level 1-b image products (IMS, APS, IMP, APP, IMM, APM, WSM and GM1).
Complementary to geocoded products provided by ESA (IMG, APG) the geocoding procedure applied at the German Aerospace Center (DLR) makes use of a DEM to achieve higher geolocation accuracy. The resulting geocoded image is either defined as EEC (Enhanced Ellipsoid Corrected) or as ETC (Enhanced Terrain Corrected). These products mainly differ in the underlying DEM used for geocoding. The EEC utilizes GLOBE, while the ETC utilizes the "best" DEM available in the data base. This "best" DEM can be assembled from different DEM data sets (e.g. derived from SRTM, ERS, …). Further differences such as the interpolative (EEC) and rigorous (ETC) geocoding approach will also be outlined. Furthermore, an incidence angle mask can be generated.
The necessary upgrades for geocoding ASAR stripline products (e.g. IMM, WSM) will be presented. Stripline products cover a large area along track, as they consist of concatenated stand-alone products ("slices"). Thus the updates of relevant parameters have to be taken into account.

1. INTRODUCTION

Based on the experience of the geocoding systems for ERS-D-PAF (GEOS), the SIR-C/X-SAR (GEOS) and SRTM missions (GeMoS) geocoding functionality was extended for Envisat ASAR data [1, 2, 3]. The existing Envisat ASAR GEOcoding System (EGEO) can handle all Level 1-b image products (IMS, APS, IMP, APP, IMM, APM, WSM and GM1) [4].
Complementary to geocoded products provided by ESA (IMG, APG) the geocoding procedure applied at the German Aerospace Center (DLR) makes use of a Digital Elevation Model (DEM) to achieve higher geolocation accuracy. The two output product types available are the Enhanced Ellipsoid Corrected (EEC) and the Enhanced Terrain Corrected (ETC). The main difference between these products is the underlying DEM used for geocoding. While the EEC utilizes GLOBE (with a resolution of 1km x 1km), the ETC utilizes the best DEM available in the data base. The DEM data base (DEM-DB) stores and provides elevation information from different sources (e.g. SRTM X/C-band, ERS) and at different resolutions. It is used for the ortho-rectification process and geometric calculations. The rectification procedure is based on the range-Doppler approach as described in [5]. While the EEC generation utilizes a 3D interpolative approach in order to reduce the computation time, the ETC generation applies the rigorous range-Doppler approach. The imaging geometry of the ETC can be further improved by ground control point measurement and image adjustment. A Geocoded layover shadow and Incidence angle Mask (GIM) can be generated as a by-product to ETC.
The system was built up in co-operation with the Remote Sensing Laboratories of the University of Zürich (Switzerland) and Joanneum Research, Graz (Austria).

2. SAR GEOCODING

2.1 Geometric Distortions in SAR Images

Due to the side looking geometry of SAR-systems undulated terrain is significantly distorted during the SAR mapping process. The most important and well known local image distortions are foreshortening, layover, and **s**hadow [6]. But also the range displacement effect needs to be considered that causes elevated features to be mapped in false range positions – namely to closely to near range. These effects as well as the varying ground resolution caused by varying slopes can be corrected using a digital elevation model.
Two approaches are applied to geocode ASAR images and will be discussed in the following chapters. Common to all cases is the backward geocoding also denoted as object-to-image approach.

2.2 Rigorous Range Doppler Approach

For each output pixel, which defines a co-ordinate triple (easting, northing, height) in the output map projection, the corresponding azimuth and range positions in the input image have to be determined. This is based on the Range-Doppler (1) and range equations (2) applicable to SAR images. Due to the dynamic imaging principle of SAR this is an iterative and hence time consuming search procedure. The orbit position is varied until the range and Doppler equations are simultaneously fulfilled [7].

$$F_1(i,j) = f_{DC} - \frac{2 \cdot (\vec{p} - \vec{s}) \cdot (\dot{\vec{p}} - \dot{\vec{s}})}{\lambda \cdot |\vec{p} - \vec{s}|} = 0 \qquad (1)$$

$$F_2(i,j) = r_0 + m_r \cdot j - |\vec{p} - \vec{s}| \qquad (2)$$

(i,j) are the pixel co-ordinates where i are the azimuth and j the range positions. f_{DC} is the Doppler reference function applied during the SAR processing. p and s are the earth surface point and sensor position vectors, λ is the SAR sensor wavelength and r_0 and m_r the slant range offset and the pixel spacing.

2.3 3D Interpolative Approach

The principle of this approach is to perform the rigorous transformation for grid points and using an interpolation to fill the grid cells [8]. The radar image range and time co-ordinates are determined by interpolating between anchor points. At first a three-dimensional grid of points (co-ordinates in easting, northing, height) is generated and the corresponding pixel co-ordinates (in azimuth and range) of the input image are determined using the rigorous Range-Doppler approach. The grid covers the output area and its height extension spans the entire elevation range of the underlying DEM. Starting from the azimuth and range co-ordinates at a reference elevation correction terms in azimuth and range are interpolated using the individual height values from the DEM. In order to correct non-linear terrain effects a quadratic term for height interpolation is considered.

The main purpose of the interpolative approach is to reduce the computing time for generating a geocoded product. Tests showed that the throughput can be improved by at least a factor of 5 compared to the rigorous geocoding [9]. Geometric degradation depends on the grid size. In context of the TerraSAR-X project it was shown, that the interpolative approach is precise from the geometric point of view if the mesh size is less or equivalent to 1000 m on ground [9]. In comparison errors caused by accuracy deficiencies of e.g. the DEM and the sensor model parameters cause significantly larger location errors.

2.4 Implementation Issues

Both, the rigorous and the 3D-interpolative ellipsoid correction are parametric geocoding approaches. They are independent from the radar wavelength and can be applied to other space- or airborne SAR data as well. Besides Envisat-ASAR the current version of the geocoding system supports input from ERS, J-ERS, Radarsat-1, SIR-C / X-SAR and DLR's airborne system ESAR. The pixel spacing of the in- and output data as well as the Doppler reference function are parameterized and are stored in configuration files. Even though most SAR processors refer to zero-Doppler the geocoding system is able to consider other reference functions. Multi-polarized data are considered as multi-layer images.

3. ENVISAT ASAR GEOCODED PRODUCTS

Complementary to geocoded products provided by ESA (Image Mode Ellipsoid Geocoded Image - IMG, Alternating Polarization Mode Ellipsoid Geocoded Image - APG) the geocoding procedure applied at DLR makes use of a DEM to achieve higher geolocation accuracy.

All ASAR Level 1-b image products produced from the Level 0 data (besides IMG and APG) can serve as input for the Geocoding System. The input ASAR images can be grouped into those produced as stand-alone products, and those produced as stripline products.

Stand-alone image products are ordered as a scene. The scene size is about 100 km along track by the swath width for the swath from which the data is acquired (between 56 and 100 km wide). Stand-alone image products comprise the following product types: Image Mode Single Look Complex (IMS), Image Mode Precision Image (IMP), Alternating Polarization Mode Single Look Complex (APS), Alternating Polarization Mode Precision Image (APP), Image Mode Ellipsoid Geocoded Image (IMG) and the Alternating Polarization Mode Ellipsoid Geocoded Image (APG).

Stripline images contain image data for an entire segment, up to a maximum size of 10 minutes per product for Image Mode Medium Resolution Image (IMM), Alternating Polarization Medium Resolution Image (APM) and Wide Swath Medium Resolution Image (WSM) and up to a full orbit for the Global Monitoring Medium Resolution Image (GM1). Therefore several sub-images called "slices" are concatenated together in order to form the entire stripline image. The structure of the stripline image is identical to that of the stand-alone image products except the data sets contain data concatenated from several slices in time ordered sequence.

In the following, the EGEO output products, namely EEC, ETC and GIM will be described and some examples will be shown.

3.1 Enhanced Ellipsoid Corrected (EEC)

The EEC is a multi-look detected product supporting geographic projection, UTM / UPS projection as well as a set of additional projections as defined in the Coordinate Transformation Package [10]. In contrast to the IMG and APG products the EEC no longer refers to an ellipsoid, but uses a low resolution elevation model (GLOBE, with a resolution of 1km x 1km) for geocoding. Thus terrain induced distortions are reduced. In order to speed up the computing time the 3D-interpolation described in chapter 2.3 is applied. The EEC is generated automatically as there are no operator interactions required.

3.2 Enhanced Terrain Corrected (ETC)

As was the EEC, the ETC is a multi-look detected product supporting a variety of map projections. Terrain-induced distortions are corrected considering the best available DEM (external DEMs can also be integrated). In the ETC case, the rigorous interpolation described in chapter 2.2 is applied. The geometric quality depends on the height accuracy and resolution of the DEM in combination with the type of terrain and the incidence angle. DEMs from SRTM (C-band and X-SAR), ERS-derived elevation models and GLOBE provide a global basis for a terrain correction service. Optionally, ground control point (GCP) measurement and image adjustment can be applied to improve the image geometry. In [11] an overview of the GCP-free geometric accuracy of ASAR imagery is given. A GIM may also be generated as a secondary product.

3.3 Geocoded Layover Shadow and Incidence Angle Mask (GIM)

The GIM product is generated as an optional add-on to the ETC product. It provides information about the local incidence angle for each pixel of the geocoded SAR scene and about presence of layover and shadow areas [3, 7, 12].

The local incidence angle is the angle between the radar beam and a line perpendicular to the slope at the point of incidence. For its determination, it is necessary to know the slant range vector and the local surface normal vector. Areas of SAR shadow are determined via the off-nadir angle, which in general increases for a scan line from near to far range. Shadow occurs as soon as the off-nadir angle reaches a turning point and decreases when tracking a scan-line from near to far range until the off-nadir angle reaches the value again, that it had at the turning point.

Areas of SAR layover are determined via the slant range distance, which in general increases for a scan line from near to far range. Layover occurs as soon as the slant range reaches a turning point and decreases when tracking a scan-line from near to far range. In order to separate active and passive layover a two step procedure scanning from near to far and back is required.

The GIM product exhibits the same cartographic properties as the geocoded output image with regard to output projection and cartographic framing. The content is the local terrain incidence angle and additional flags indicating whether or not a pixel is affected by shadow and/or layover.

3.4 Examples of Geocoded Products

3.4.1 IMS Product

Fig.1 shows an Enhanced Terrain Corrected image based on an IMS product of the area around Munich, Germany (ASA_IMS_1PNDPA20020822_093719_000000162008_00437_02495_0003.N1). The DEM used was derived via combination of SRTM-X data and elevation data derived from ERS-Tandem pairs. Ground control points were measured to perform image adjustment. The SRTM-X amplitude was superimposed to perform an overall visual check of position accuracy (SRTM-X has a horizontal accuracy of about 20m, [2]).

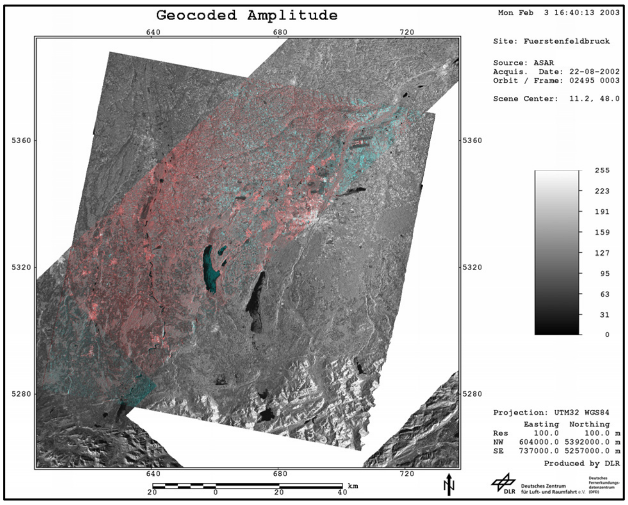


Fig. 1. Geocoded IMS Product

3.4.2 IMM Product

Stripline images (IMM, APM, WSM and GM1) can reach an azimuth extension of several thousand kilometers by concatenating several sub-images (slices). The product contains annotation data for each slice in time ordered sequence.

For the geocoding process, a range polynomial is calculated from the annotation data. While it consists of the near range distance and the slant range sample spacing for slant range images (IMS, APS) it contains a polynomial for ground range products. This polynomial is necessary for the ground range to slant range conversion during the geocoding process.

For stand-alone products, a constant range polynomial is applied as only one annotation data set is attached. For products covering a large area along track (stripline images) a constant range polynomial would lead to significant displacement in range (due to the elliptic shape of the earth). Thus the updates annotated for the different slices have to be taken into account.

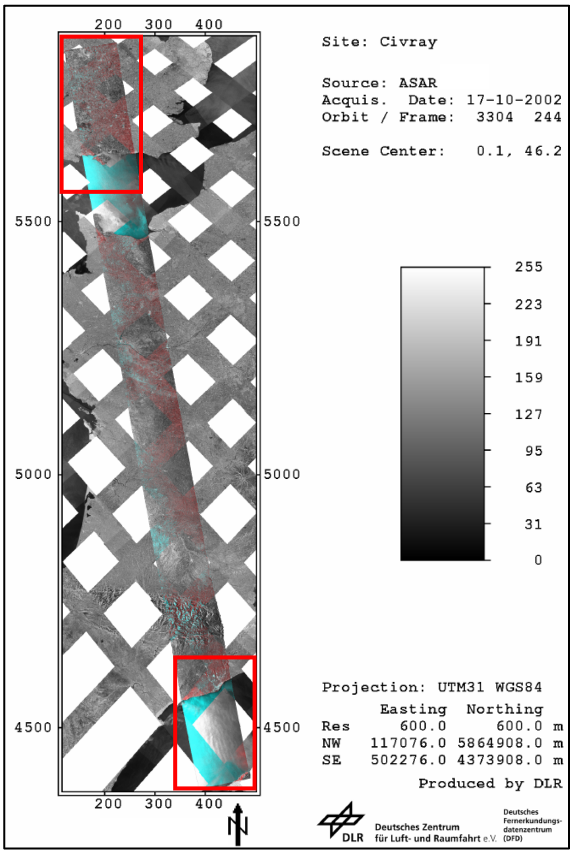


Fig. 2. Geocoded IMM Product

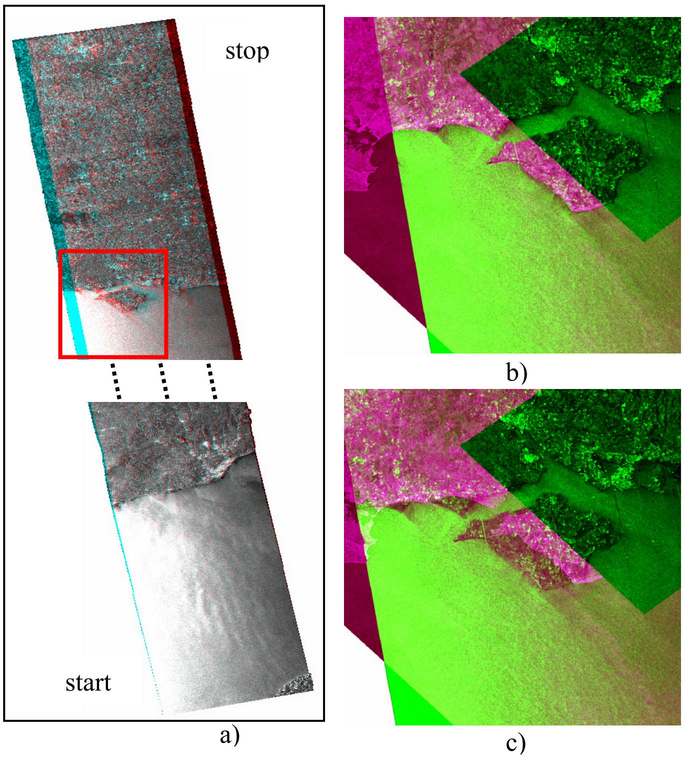


Fig. 3: a) Constant (blue) vs. variable range poly. (red)
b) SRTM Ampl. (pink) vs. variable range poly. (green)
c) SRTM Ampl. (pink) vs. constant range poly. (green)

Fig. 2 shows a geocoded IMM product (ASA_IMM_1PXPDE20021017_213603_00000222201 0_00244_03304_0036.N1). The used DEM was combined from SRTM-X and SRTM-C elevation data. It has an azimuth extension of about 1500 km (147 slices) covering an area from the Mediterranean Sea over France up to Great Britain. The SRTM-X amplitude was superimposed to perform an overall visual check of position accuracy.

Fig. 3a) shows two superimposed, geocoded IMM products (in the areas indicated by the red rectangles in Fig. 2). While the blue one was generated with a constant range polynomial the red one was generated with a variable range polynomial. The range offset increases with increasing azimuth length (towards north). At the scene end, the range offset reaches a maximum of about 9 km (towards near-range). Fig. 3b) and Fig. 3c) show a clip of the IMM product superimposed with the SRTM-X amplitude. While the IMM geocoded with the variable range polynomial matches with the SRTM-X Amplitude (Fig. 3b), the IMM geocoded with the constant range polynomial shows a distinct offset (Fig. 3c). Reference [11] also shows examples of correction of this effect.

3.4.3 WSM Product

Fig. 4 shows a WSM image (ASA_WSM_1PNPDK 20030324_153316_000000552014_00498_05562_1713. N1) geocoded for the SIBERIA-II project [13]. In this context approximately 400 WSM images were automatically processed. The DEM used was combined from SRTM-X, SRTM-C and GLOBE data (cf. chapter 4.1). No ground control points were measured for image adjustment. The product is located at the northern end of the SRTM coverage (at a latitude of about +60°). Thus the SRTM-X amplitude does not cover the complete WSM image to the north and the typical gaps in the SRTM-X amplitude occur towards the south.

In Fig. 5, a clip of the WSM image is shown superimposed with the SRTM-X amplitude (red). The precise match of the river indicates the location accuracy achieved for the WSM products.

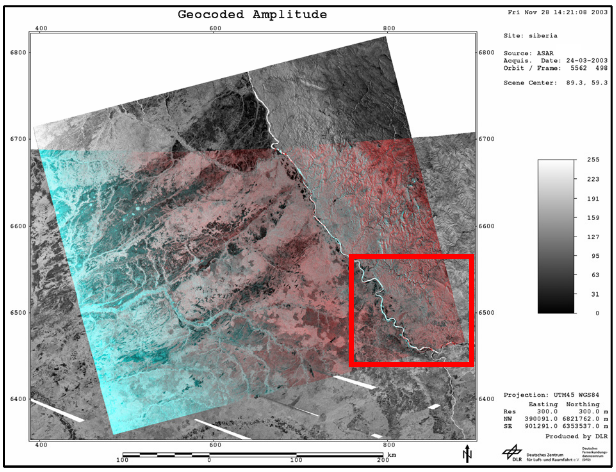


Fig. 4. Geocoded WSM Product

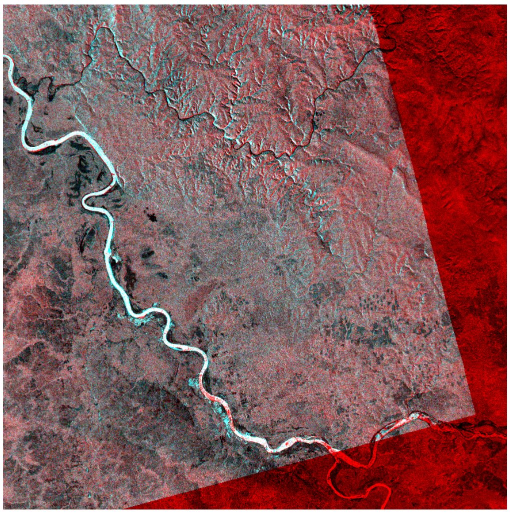


Fig. 5. Geocoded WSM with SRTM-X amplitude (red)

4. DIGITAL ELEVATION MODEL DATA BASE

The task of the Digital Elevation Model Data Base (DEM-DB) is the storage and provision of elevation information for the ortho-rectification process and geometric calculations. The DEM-DB supports multiple resolutions and keeps the elevation data in tiles. The data files are stored on disk via the conventional Unix file system. The data base organisation as well as the elevation data representation is in geographic co-ordinates. DEMs of different sources can be organised in separate projects. Within each project a tree structure from North to South is created in 1° steps. Beneath this directory the next level is sorted from East to West, again in 1 degree increments. At this level DEMs are stored provided in 1“ resolution or lower (e.g. 3”). One tile completely covers 1°x1°. Areas where no elevation information is available are masked. Each tile contains an overlap of 30” to the south and the west to the adjacent tiles. Higher resolution DEMs lead to 0,01° cells below the 1°- level. The finest resolution supported is 0,01”.
Different elevation models like the SRTM C-band and the SRTM X-band derived elevation products are stored in different projects. This enables the separation of different qualities, DEM sources and the minimisation of disk space.
The DEM data base itself consists of the file configuration and management system and two levels of software modules for file access and data manipulation.
The utility level provides all functions for data access and data base maintenance based on a predefined geographic area. An “import” function for example creates the directory structure, splits the DEM file into the corresponding tiles and inserts those tiles. The “get” function supplies the DEM tiles of a geographic area on local disk.
The application level provides further processing capability like transformations into different map projections and geodetic datum, merging and mosaicking of different resolutions and qualities [14] as well as DEM colour shading and visualization [15].
The operational ETC generation utilizes DEMs in

- DTED level 2 (SRTM X-band globally, C-band for the US, regionally ERS-derived),
- DTED-1 (SRTM/C-band globally, regionally other DTED-products),
- DTED-0 (GLOBE) where no other DEM information is available.

4.1 Example for DEM provision

Fig. 6 shows the DEM used for geocoding the WSM image introduced in chapter 3.4.3. It was composed from SRTM-X, SRTM-C and GLOBE elevation data.
The different resolutions of different DEM sources get visible in Fig. 7 (covered area: ~26km by 26km). For example in Fig. 7a) SRTM-X data (south) is combined with GLOBE data (north). One clearly sees the different level of detail between the 1’’ SRTM-X and the 30’’ GLOBE data. In Fig. 7b) additionally SRTM-C elevation data (3’’) was utilized for DEM generation. The SRTM-C data covers a slightly larger area towards the north than SRTM-X data. Thus it was incorporated into the DEM to improve the geocoding process. SRTM-C data is generally used for DEM generation where no SRTM-X data is available (gaps).

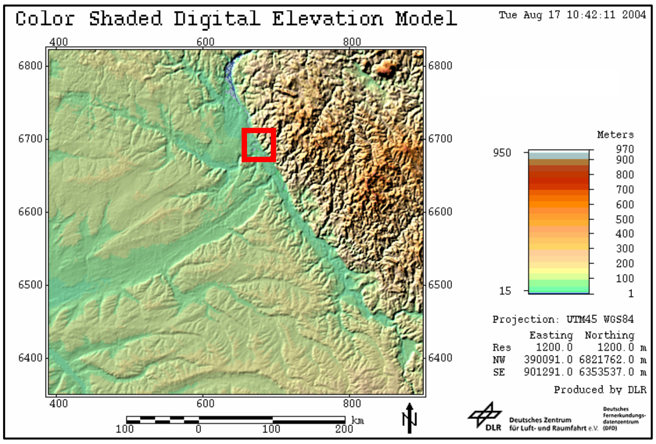
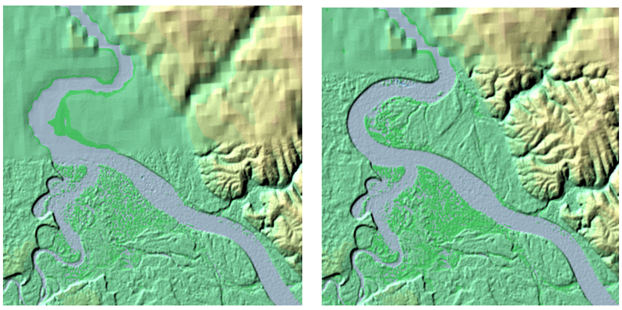


Fig. 6. DEM Mosaic from SRTM-X, SRTM-C and GLOBE data



a) b)

Fig. 7: a) Combination SRTM-X and GLOBE
b) Combination SRTM-X, SRTM-C and GLOBE

5. CONCLUSION

The Envisat ASAR Geocoding System (EGEO) is able to geocode all Level 1-b image products. Two products are available, the Enhanced Ellipsoid Corrected (EEC) and the Enhanced Terrain Corrected (ETC). In contrast to the standard products IMG and APG the EEC no longer refers to an ellipsoid, but uses a low resolution elevation model (GLOBE) for reducing terrain induced distortions. In the case of the ETC, the best available DEM is used for terrain correction. SRTM serves as a backbone for this global ortho-rectification service. Ground control point measurement and image adjustment can be applied where necessary. A Geocoded Layover Shadow and Incidence Angle Mask can also be generated.

Two geocoding approaches are applied to produce EEC and ETC, respectively. The 3d interpolative approach provides comparable results to the rigorous approach but has a higher throughput [9].

Besides Envisat-ASAR data EGEO also supports input from ERS, J-ERS, Radarsat-1, SIR-C / X-SAR as well as from DLR's airborne system ESAR. At the moment EGEO is being further enhanced to provide geocoding capability for the upcoming high resolution satellite TerraSAR-X [16].

6. REFERENCES

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