Coastal Erosion from Space

Coastal Erosion events:

in Nerja (Spain) *in Kilkee (Ireland)* *in St Laurent mouth (Canada)*

Pre-processing Verification and Quality Control

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Applicable and reference documents

Id	Description	Reference
AD-1	Product Validation report	SO-TR-ARG-003-055-PVR
AD-2	Pre-processing ATBD	SO-TR-ARG-003-055-ATBD-SL

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1. Pre-processing Verification

To verify the co-registration process, we can use the statistics computed from the logfile which shows the number of points excluded at each stage of the AROSICS quality control checks. These data were recorded into a spreadsheet for each Master image, and the percentage of original tie points which had been removed after the AROSICS checks had been performed was calculated for each Target image co-registered with the Master. This enabled the identification of features which made the co-registration more difficult, as Target images with these features would more often have a higher percentage of their tie points flagged as erroneous by the AROSICS checks and removed.

The data over each area is validated by summarising the table for each location into a single spreadsheet row so that it can be compared easily to other regions in a single spreadsheet. There is a minimum limit to the number of tie points required by the AROSICS software for a good quality of co-registration. Beyond this, the co-registration is unable to be completed. Similarly, some tiles were not able to be co-registered due to the low initial number of tie points seeded onto the tile, which were subsequently all rendered invalid by the AROSICS checks. The main cause of this is heavy cloud cover over the land areas present in the image, leaving few areas where tie points could be reliably seeded, and cloud shadow impacting those areas during tie point checking. The other main feature which can impact co-registration is a lack of urban features within a tile to accurately match between products. Urban features are static and remain so across long temporal periods, making them ideal for co-registration. Urban features present across the entirety of a tile means that co-registration can accurately be performed over all parts of a product and minimise the effect of local shifts.

Currently this process has been implemented for the three sites shown in Table 1.1:Summary table of S2 co-registration validation, and is planned to be used for the remainder of the S2 sites and Landsat sites over the rest of the project.

Table 1.1:Summary table of S2 co-registration validation

Location			Products			
Region	S2 Tile	Terrain type	Total S2 products co-registered	< 15% tie points rejected	> 15% tie points rejected	Invalid co-registrations
Barcelona	31TDG	Urban/Mountainous	75	37	38	0
Start Bay	30UVA	Agricultural	85	1	31	53
Perranporth	30UUA	Agricultural	45	2	43	0

Barcelona has many features which allow for a good co-registration, namely a dryer climate which is cloud-free for a large part of the year, a coastal location close to the waterline ROI, and large urban areas which are used for more accurate tie points. Conversely, Start Bay is in a more rural location, meaning fewer urban features for tie points to use and more agricultural land. Agricultural features may be used for co-registration provided that both products are temporally close to each other and imaged under closely matching conditions, as shown in Figure 1.1:Co-registration shift of a Barcelona product (original product on the left, co-registered product on the right). The tie point (yellow dot) uses an agricultural field boundary. The pixel shift is shown in the lower right of the images (red circle).

Figure 1.1:Co-registration shift of a Barcelona product (original product on the left, co-registered product on the right). The tie point (yellow dot) uses an agricultural field boundary. The pixel shift is shown in the lower right of the images (red circle).

The weather is also cloudier for a higher proportion of the year over Start Bay than Barcelona, meaning there are fewer suitable cloud-free Sentinel-2 images which can be matched to available VHR imagery. The overlap of the Sentinel-2 tile to this region also means that over ¾ of the tile is water, further reducing the area the tie points can reliably use. This can be mitigated by increasing the number of tie points over the land area using the grid_res (grid resolution) parameter during the co-registration process setup. Perranporth Beach is a similar environment to Start Bay, however with the advantage of a land buffer from Atlantic wind, resulting in fewer instances of cloud in the Sentinel-2 tiles co-registered. These observations are reflected in the ratios of rejected tie points present for each area. Barcelona had the lowest percentage of its tie points rejected across all co-registered images, Perranporth had more tie point rejections but co-registrations could still be completed, and Start Bay had a large percentage of images unable to be co-registered due to all tie points being rendered invalid. Examples of these terrain differences are shown in Figure 1.2: VHR images showing topography of Barcelona (Top) and Perrenporth Bay (bottom) coastal regions, where the contrast between the urban Barcelona and the rural Perrenporth is clearly seen, Start bay, located in the same geographical region as Perrenporth, has the same terrain.

Figure 1.2: VHR images showing topography of Barcelona (Top) and Perrenporth Bay (bottom) coastal regions

Once Table 1.1:Summary table of S2 co-registration validation has been expanded to include all site locations, verifying which locations are more heavily affected by tie point removal through AROSICS checks can be performed. This will involve identifying the locations within each product where tie points are most frequently removed, and using this to anticipate where additional co-registration parameters can be used to mitigate the larger removal of tie points over regions containing a higher proportion of these features.

2. Pre-processing Quality Control

Quality control of the pre-processing procedure ensures that the co-registered Sentinel-2 and Landsat 5/8 imagery being produced for use in the processor using the methodology outlined in the pre-processing ATBD conform to the defined baselines and are performed to a suitable accuracy.

The quality of a co-registration can only be as good as the images being used in the co-registration. A bad Master image, or a bad matchup between the Master and Target image, will result in an invalid co-registration regardless of the quality of the process. For this reason, selecting a good candidate VHR image to begin the co-registration with is very important. Several criteria were used in the VHR image selection in order to ensure that subsequent co-registrations performed using the image were of the best possible quality.

Selected VHR images could not have been recorded at an angle off-nadir of greater than 12°. Through tests using VHR data to co-register Sentinel-2 and Landsat images, it was seen that the quality of co-registration achieved on products which had been recorded at angles greater than 12° was poor at best. Past this, the geolocation of points on the image can become distorted by elevation features present on the ground. Alternatively, if a VHR image was available orthorectified, this would also be suitable. Orthorectified images have geolocation distortions corrected for using a Digital Elevation Model (DEM), so imaging angle and terrain features do not impact the image geolocation.

The selected VHR images also have to prominently feature any local urban regions. These areas provide the basis for the best co-registrations, due to the presence of unchanging angular features which make for good tie points between the Master and Target images. In the absence of any prominent features, a larger image area was selected to encompass as many smaller urban features as possible within the image boundaries. Similarly, to maximise the usability of the image both from a co-registration standpoint and as a test for VHR waterline/shoreline extraction techniques, the image was to include as little water as possible, yet have part of the shoreline visible if the shoreline region overlapped with the target AOI associated with that area, as shown in the Preliminary Selection of Validation Sites document. This could not be done in all VHR image selections due to the location of the prominent urban region but was accommodated for where possible.

The boundary of the VHR image was also required to align with a suitable Sentinel-2 product in order to facilitate the start of the co-registration process. A suitable Sentinel-2 product was one which was cloud-free over the region covered by the VHR image boundary, and in close temporal proximity to the date the VHR image is recorded to minimise any surface changes between the two. An additional criterion to the VHR image selection is that the image must be a rectangular polygon with sides aligned parallel to North. This is to minimise the presence of No-Data regions in the final delivered image, which interfere with the AROSICS co-registration algorithm.

Finally, the budget for VHR image purchase is limited so image selections were kept as small as was necessary while still meeting the criteria listed above. The sites the VHR images were acquired from had a lower limit of 25km^2 on the size of the image which could be purchased, so these boundaries resulted in image sizes of between 25-35km^2.

The following process is performed as part of the AROSICS software, the full methodology of which is detailed in the Pre-Processing ATBD and (Scheffler et al., 2017). Five checks are incorporated into the AROSICS co-registration methodology once the spatial shifts to the tie points in the master and target images have been calculated, and adjustments and exclusions are made to the shifts based on the outcome of these checks to ensure that the final product is co-registered accurately with respect to the master image.

The first check, which AROSICS performs to the spatial shifts, is to measure the shift between tie points from the master image and the co-registered target image. If correctly co-registered, the measured shift should be zero in both x/y planes for a given set of tie points. If a non-zero shift is detected for any of the tie points, then a matching correction is applied. The check is repeated for five iterations, and once the integer shifts measure zero, sub-pixel shifts are calculated using the same frequency-domain method used for the integer-pixel shifts. If non-zero values still remain in the integer-pixel shifts after 5 iterations, or the sub-pixel displacements are above the maximum set vector shift, then the tie point match is considered invalid. This process is shown below in Figure 2.1: Flowchart of the first validation check used by AROSICS (Scheffler et al., 2017).

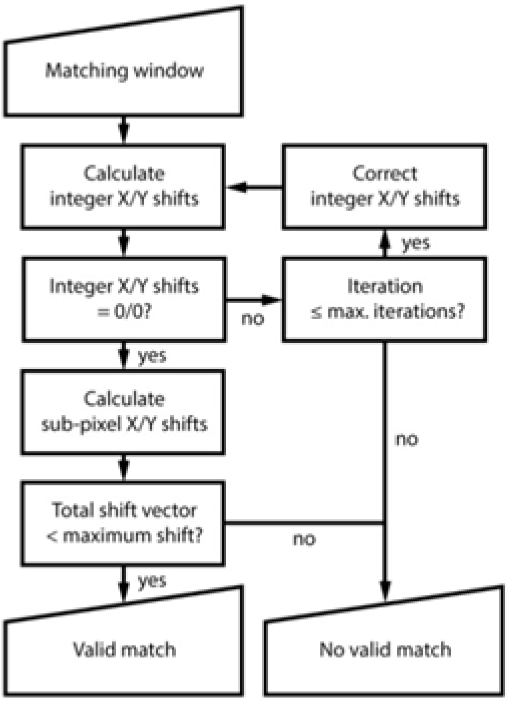

Figure 2.1: Flowchart of the first validation check used by AROSICS (Scheffler et al., 2017)

The second check is a simple threshold check on the tie point displacements to eliminate any unrealistically large displacements. It is set up as an optional check to include in the validation process, with a default setting of 5 pixels displacement to exclude. For the validation of products for coastal change purposes, two different thresholds are used depending on the product types being co-registered. For co-registration using a VHR image as master and a Sentinel-2 image as the target, a 200-pixel displacement is set as the exclusion limit. This is due to the high pixel density VHR products have compared to Sentinel-2. With co-registration only using HR images, a maximum displacement limit of 20 pixels is used.

The final three checks work together to eliminate systematic errors in the tie point shifts, and for regional shifts where repeating patterns may introduce pseudo-matches. The third check looks at the three-dimensional shape of the cross-power spectrum to determine its sharpness. This is used as measure of reliability of each respective tie-point. Three equations are used by AROSICS to compute this, which are shown in Figure 2.2: The three equations used in the third AROSICS validation check (Scheffler et al., 2017).

$$\mu_{peak} = \frac{1}{N} \sum_{\substack{-1 \leq r \leq 1 \\ -1 \leq c \leq 1}} v_{(r,c)}$$

$$\mu_{remain} = \frac{1}{N} \sum_{\substack{-1 > r > 1 \\ -1 > c > 1}} v_{(r,c)}$$

$$\sigma_{remain} = \sqrt{\frac{1}{N} \sum_{\substack{-1 > r > 1 \\ -1 > c > 1}} \left(v_{(r,c)} - \mu_{remain}\right)^2}$$

$$R = 100 - 100 \frac{(\mu_{remain} + 3\,\sigma_{remain})}{\mu_{peak}}$$

Figure 2.2: The three equations used in the third AROSICS validation check (Scheffler et al., 2017)

In the equations shown in Figure 2.2: The three equations used in the third AROSICS validation check (Scheffler et al., 2017), the value of *R* is the reliability percentage of a tie point. $v_{(r,c)}$is the value of the power spectrum at position *(r,c)*. μ_{peak} is the mean of the power spectrum values across the number of tie points within the peak of the power spectrum, and μ_{remain} is the mean of the power spectrum values across the tie points which fall outside the peak of the power spectrum. $\sigma_{remain}$is the standard deviation of the tie points outside of the power spectrum peak. The default threshold value for the reliability percentage is 30%, with any tie points beneath this excluded.

The fourth validation check was a measure of the similarity of the product areas after co-registration. This was performed using the Mean Structural Similarity Index (MSSIM), as it is sensitive to small changes between images. A returned value of 0 means no match, and a value of 1 is a perfect match. A correctly co-registered target image should be very similar to the master image. This is performed for the tie point pairs before and after co-registration, and any decrease in the MSSIM value after co-registration is flagged, and the tie points removed from further transformations.

The fifth and final check the AROSICS program performs is passing the co-registered products through the RANSAC algorithm. This algorithm works using the assumption that the tie point corrections which take place during the co-registration can be approximated using an affine transformation. RANSAC estimates the parameters required to complete this transformation, and flags any of the tie points which stand out as anomalies on the previously calculated shift vector grid when compared to this estimation. RANSAC is suspectable to providing a high outlier count relative to the input sample, so additional measures are implemented alongside the algorithm to minimise this. Bad data masks on the input products are encouraged to be used where possible to minimise the chance that an erroneous matchup caused by a region of cloud, or other effect, is flagged as an outlier. As RANSAC is the last validation step in the sequence used by AROSICS, the data is entering it pre-filtered by the other four checks and thus most erroneous tie points will have been filtered out by this stage. Lastly, multiple iterations of the RANSAC algorithm are run on the dataset, with the parameters adjusted each time depending on if the proportion of outliers to inliers is too high or low. Tests by the developers showed that 10% was a suitable threshold ratio in most cases, so the algorithm will select transformation parameters which flag 10% ± 2% of existing tie points as outliers.

The number of tie points each of these process flags is outputted as part of the log file generated during each co-registration, allowing for a record of the number of tie points removed during these checks when compared to the total number to be recorded. The Log refers to checks 1-3 as Level 1, check 4 as Level 2, and check 5 as Level 3, and is created and saved alongside the co-registered .tiff image. An example of this system is shown below in Figure 2.3: A section of the AROSICS log file showing the number of tie points flagged by each verification level for a product covering Cork, where the total number of tie points before and after the checks have been performed is also printed.

```
Initializing tie points grid...
Equalizing pixel grids and projections of reference and target image...
Calculating tie point grid (2916 points) using 14 CPU cores...
Found 1522 matches.
Performing validity checks...
240 tie points flagged by level 1 filtering (reliability).
13 tie points flagged by level 2 filtering (SSIM).
158 tie points flagged by level 3 filtering (RANSAC)
Found 1122 valid tie points.
Correcting geometric shifts...
```

Figure 2.3: A section of the AROSICS log file showing the number of tie points flagged by each verification level

The tie points themselves are also outputted as part of the co-registration as a shapefile, which allows additional checking of which tie points were excluded at each level. An example of this output is shown in Figure 2.4: Tie points flagged by each level of the AROSICS validation process, using data from the same Cork product featured in Figure 2.3: A section of the AROSICS log file showing the number of tie points flagged by each verification level.

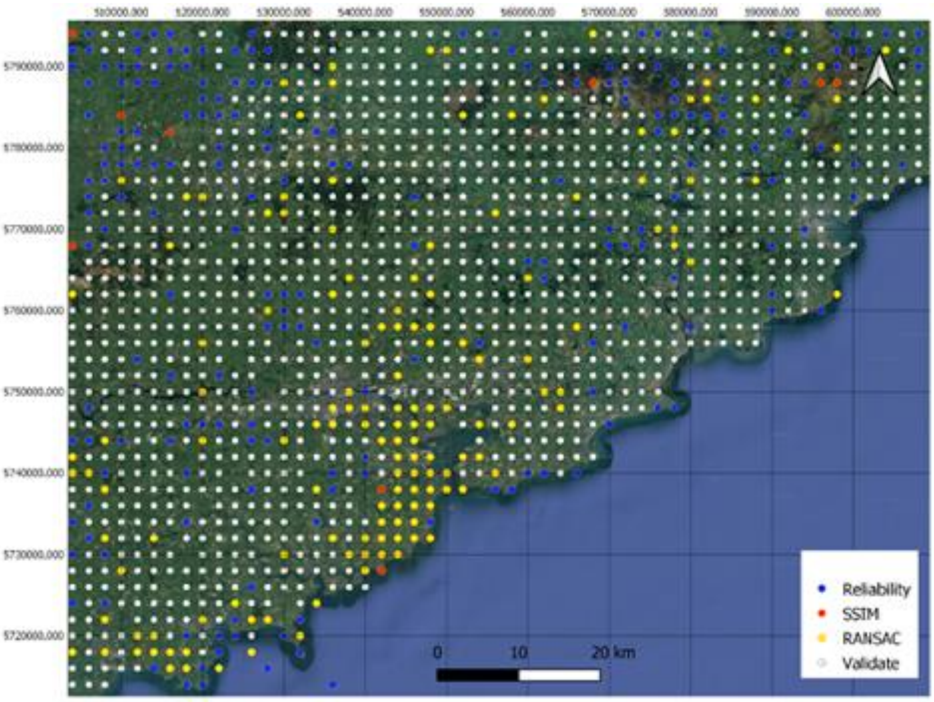

Figure 2.4: Tie points flagged by each level of the AROSICS validation process

A summary of the results of these checks will be provided in full in the Validation results table shown in Section Pre-processing, and log files showing the number of tie points removed by the checks will be provided with the co-registered product. This table allows the identification of regions which are more difficulty to successfully co-register using the AROSICS program, and where additional attention to the conditions the images are recorded under will have to be made.

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