ASF Sentinel-1 RTC Product Guide

The Alaska Satellite Facility

ABSTRACT

This document is a guide for users of radiometrically terrain-corrected Sentinel-1 products processed by the Alaska Satellite Facility.

Document Preparation

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Document Change Log

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1.0	10/4/2018	All	Initial release
2.0	7/24/2020	All	Update for release of HyP3 Sentinel-1 RTC datasets in Vertex
2.1	7/27/2020	All	TAL Review
2.2	10/30/2020	All	Changes to files included in the product package

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Acronyms and Abbreviations

ASF	Alaska Satellite Facility
CONUS	Contiguous United States
DEM	Digital Elevation Model
GeoTIFF	Geo-referenced Tagged Image File Format
GIS	Geographic Information System
ISO	International Organization for Standardization
KMZ	Keyhole Markup Language Zip file
NASA	National Aeronautics and Space Administration
NED	National Elevation Dataset
PNG	Portable Network Graphic File Format
RTC	Radiometric Terrain Correction
SAR	Synthetic Aperture Radar
SLC	Single Look Complex
SRTM	Shuttle Radar Topography Mission
UTM	Universal Transverse Mercator coordinate system
XML	Extensible Markup Language

1 Data Processing

1.1 Digital Elevation Models

The quality of the terrain correction results is directly related to the quality of the digital elevation models (DEMs) used in the process of geometrically and radiometrically correcting the SAR imagery. Table 1 summarizes the various DEM sources and the way they are used in the radiometric terrain correction (RTC).

Resolution	DEM	Datum	Area	Posting	Sampling
High	NED13	NAVD88	CONUS, Hawaii, parts of Alaska	1/3 arc seconds	Resampled to RTC spacing, reprojected to WGS84 UTM
Medium	SRTM GL1	EGM96	60 N to 57 S latitude	1 arc second	Resampled to RTC spacing, reprojected to WGS84 UTM
	SRTM US1	EGM96	CONUS, Hawaii, parts of Alaska	1 arc second	Resampled to RTC spacing, reprojected to WGS84 UTM
	NED1	NAVD88	CONUS, Hawaii, parts of Alaska, Canada, Mexico	1 arc second	Resampled to RTC spacing, reprojected to WGS84 UTM
	NED2	NAVD88	Alaska	2 arc seconds	Resampled to RTC spacing, reprojected to WGS84 UTM

Table 1: DEMs used and their priority in RTC processing

Figure 1 shows the coverage of the various DEM sources. The continental U.S. (CONUS), Hawaii, and parts of Alaska are covered by the National Elevation Dataset (NED) at ⅓ arc seconds (about 10 m resolution). The rest of Alaska above 60 degrees northern latitude is only available at about 60 m resolution with 2 arc seconds NED data. The best resolution for Canada and Mexico is provided by the 1 arc second NED at about 30 m. For the remaining globe, Shuttle Radar Topography Mission (SRTM) GL1 data at 30 m resolution is used. Greenland and Antarctica are mostly covered by ice and glaciers and not suitable for terrain correction. For areas in Eurasia above 60 degrees northern latitude, no suitable DEMs are available.

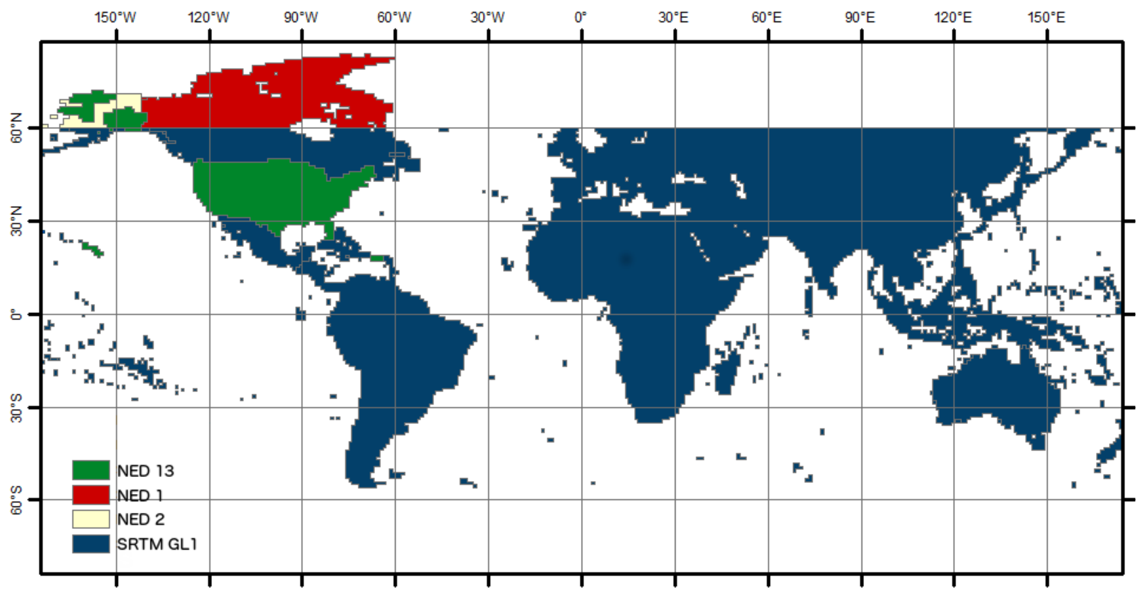


Figure 1: Coverage of the various DEM sources used for terrain correction

The DEMs were pre-processed by ASF to a consistent raster format (GeoTIFF) from the original source formats: height (*.hgt), ESRI ArcGrid (*.adf), etc. Many of the NASA-provided DEMs were provided as orthometric heights with EGM96 vertical datum. These were converted by ASF to ellipsoid heights using the ASF MapReady tool named *geoid_adjust*. The pixel reference varied from the center (pixel as point) to a corner (pixel as area). The GAMMA software, used to generate the terrain corrected products, uses pixel as area and adjusts DEM coordinates as needed. Where more than one DEM is available, the best-resolution DEM is used for processing. DEM coverage of at least 20% from a single DEM source is required for processing to proceed.

1.2 Terrain Correction Workflow

1.2.1 Pre-processing

The first step of pre-processing is the selection of the best DEM for the terrain correction. The DEM tiles are assembled to ensure sufficient coverage for the terrain correction of the Sentinel-1 granule. The application of the calibration parameters and multi-looking are the only pre-processing steps applied to the SAR image.

1.2.2 Terrain Correction

The terrain correction is performed in slant range geometry. The actual mapping of the initial image into projected space is only applied once to mitigate the propagation of any resampling errors. All intermediate steps only update the look-up table used for the mapping.

By default, images are not coregistered to the DEM. While RTC results can be improved by matching imagery to a high-quality DEM, different acquisitions over the same area may not always be matched to the DEM in the same way, due in part to the presence of speckle. This can introduce spatial inconsistencies to the dataset, especially when viewing a time-series of RTC images. For consistency, we use the geolocation from the Sentinel-1 state vectors rather than matching the geolocation based on DEM features.

When custom-ordering imagery, however, the DEM Matching option is available for selection. In this case, the first step is the co-registration of the SAR image with a simulated SAR image derived from the DEM. An initial offset is first attempted as a single match; if it fails, a larger number of image chips are used to determine an average offset in azimuth and range direction. This initial offset is then refined using strict matching criteria. Matching may fail for three different reasons: (1) no match can be found, (2) the magnitude of the residual offset errors is greater than 2 pixels, or (3) the maximum calculated offset is greater than 50m. In any of these cases, the *dead reckoning* approach is taken when matching fails. This approach solely relies on the geolocations calculated from state vectors (the same approach used when DEM matching is not selected as an option) - no geolocation refinement is applied.

A normalization area image is generated. The terrain correction results in a radiometrically calibrated multi-looked image with gamma-nought (γ_0) power scale values. The ratio between the pixel area of the uncorrected and the corrected images is determined and stored in an image. In order to create the RTC product, the SAR image is multiplied by the ratio image. In a final step the RTC product is geocoded into map-projected space.

1.2.3 Post-Processing

After the terrain correction is completed, the RTC products are exported to GeoTIFF format. Side products including the DEM, layover shadow map, scattering area map, and incidence angle map are converted into GeoTIFF format. In addition, a README text file, browse images, item-specific ArcGIS-compatible XML metadata files, a log file, and a shapefile indicating the data extent are generated for the product.

2 Product Packaging

2.1 Naming Convention

The naming convention for the RTC products follows this pattern for its base names:
S1x_yy_aaaaaaaaTbbbbbb_ppo_RTCzz_u_defklm_ssss

Example: S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A

Element	Definition	Example
x	Mission: A or B	A
yy	Beam Mode	IW
aaaaaaaa	Start Year-Month-Day	20180128
bbbbbb	Start Hour-Minute-Second	161201
pp	Polarization	DV
o	Orbit Type: Precise (P), Restituted (R), or Original Predicted (O)	P
zz	Terrain Correction Resolution (m)	30
u	Software Package Used: GAMMA (G)	G
d	Gamma-0 (g) or Sigma-0 (s) Output	g
e	Power (p) or Amplitude (a) Output	p
f	Unmasked (u) or Water Masked (w)	u
k	Not Filtered (n) or Filtered (f)	n
l	Entire Area (e) or Clipped Area (c)	e
m	Dead Reckoning (d) or DEM Matching (m)	d
ssss	Product ID	FD6A

Table 2: Naming convention for RTC products

2.2 Default Settings

The default settings for RTC products are as follows:

Radiometry:	Gamma-0 (g)
Scale:	Power (p)
Water Mask:	No water mask applied (u)
Speckle Filter:	Not filtered (n)
Clipping:	Entire extent of input granule (e)
DEM Matching:	No matching; dead reckoning is used (d)

2.3 Image Files

All files are stored in a folder named using the above convention, and the base name for each file matches the folder name. Multiple types of image files are present in this folder.

Extension	Description	Example
_VV.tif, _VH.tif, _HH.tif, _HV.tif	Terrain corrected product stored in separate files for each available polarization in GeoTIFF format	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_VV.tif
.png	Greyscale browse image	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A.png
_rgb.png	Color browse image	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_rgb.png
.kmz	Zipped Google Earth image	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A.kmz
_rgb.kmz	Zipped Google Earth color image	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_rgb.kmz
_area.tif	scattering area map in GeoTIFF format	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_area.tif
_dem.tif	DEM used for terrain correction in GeoTIFF format	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_dem.tif
_inc_map.tif	incidence angle file in GeoTIFF format	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_inc_map.tif
_ls_map.tif	layover/shadow mask in GeoTIFF format	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_ls_map.tif

Table 3: Image files in product package

Floating point GeoTIFF files are used for the main products as well as the DEM, incidence angle map and scattering area map. An integer GeoTIFF file is used for the layover/shadow mask. PNG format is used for both the color and the greyscale browse images, which are each 2048 pixels wide. Finally, KMZ files suitable for viewing in Google Earth are included. Note that colorized browse and KMZ images can only be created for dual-polarization (SDV and SDH) granules, not for single-polarization (SSV or SSH).

2.4 Metadata Files

Along with each of the image files, there will be one or more metadata files.

Extension	Description	Example
.README.md.txt	README file	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A.README.txt
.log	Log file of the processing steps	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A.log
.tif.xml	ArcGIS compliant XML metadata	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_VV.tif.xml
.png.xml	ArcGIS compliant XML metadata	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A.png.xml
_rgb.png.xml	ArcGIS compliant XML metadata	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_rgb.png.xml

.png.aux.xml	Geolocation metadata for greyscale PNG browse image	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A .png.aux.xml
_rgb.png.aux.xml	Geolocation metadata for color PNG browse image	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A _rgb.png.aux.xml

Table 4: Metadata files and their extensions

2.4.1 README File

The text file with extension .README.md.txt explains the files included in the folder, and is customized to reflect that particular product. Users unfamiliar with RTC products should start by reading this README file, which will give some background on each of the files included in the product folder.

2.4.2 ArcGIS-Compatible XML Files

There is an ArcGIS-compatible xml file for each raster in the product folder. When ArcGIS Desktop users view any of the rasters in ArcCatalog or the Catalog window in ArcMap, they can open the Item Description to view the contents of the associated xml file. ArcGIS Pro users can access the information from the Metadata tab. These files will not appear as separate items in ArcCatalog, though if you use Windows Explorer to look at the contents of the folder you will see them listed individually. Because each one is named identically to the product it describes (with the addition of the .xml extension), ArcGIS recognizes the appropriate file as the raster's associated metadata, and integrates the metadata accordingly.

ArcGIS users should take care not to change these xml files outside of the ArcGIS environment; changing the filename or content directly may render the files unreadable by ArcGIS.

Those not using ArcGIS will still find the contents of these xml files useful, but will have to contend with the xml tagging when viewing the files as text or in a browser.

2.4.3 Auxiliary Geolocation Files

Geolocation XML files (aux files) are included for each of the PNG browse images to allow for proper display in GIS platforms.

2.4.4 Log File

A log file detailing the processing parameters and outputs are also included for reference.

2.5 Shapefile

A shapefile indicating the extent of the RTC data coverage is included in the package.

Extension	Description	Example
_shape.dbf _shape.prj _shape.shp _shape.shx	Shapefile (.shp) and supporting files	S1A_IW_20180128T161201_DVP_RTC30_G_gpuned_FD6A_shape.shp

3 SAR Scales

3.1 Power Scale

Note that the default output of Sentinel-1 RTC products from HyP3 is in power scale. The values in this scale are generally very close to zero, so the dynamic range of the RTC image can be easily skewed by a few bright scatterers in the image. Power scale is appropriate for statistical analysis of the RTC dataset, but may not always be the best option for data visualization.

When viewing an RTC image in power scale in a GIS environment, it may appear mostly or all black, and you may need to adjust the stretch to see features in the image. Often applying a stretch of 2 standard deviations, or setting the Min-Max stretch values to 0 and 0.3, will greatly improve the appearance of the image. You can adjust the stretch as desired to display your image to full advantage. Be aware that this does not change the actual pixel values.

In some cases, it may be desirable to convert the actual pixel values to a different scale. Two other scales commonly used for SAR data are amplitude and dB.

3.2 Amplitude Scale

Amplitude scale is the square root of the power scale values. This brightens the darker pixels and darkens the brighter pixels, narrowing the dynamic range of the image. In many cases, amplitude scale presents a pleasing grayscale display of RTC images. Amplitude scale works well for calculating log difference ratios (see section 4.1.2).

3.3 dB Scale

The dB scale is calculated by multiplying 10 times the Log10 of the power scale values. This scale brightens the pixels, allowing for better differentiation among very dark pixels. When identifying water on the landscape, this is often a good scale to use; the water pixels generally remain very dark, while the terrestrial pixels are even brighter (see section 4.2).

This scale is not always the best choice for general visualization of RTC products, as it can give a washed-out appearance, and because it is in a log scale, it is not appropriate for all types of statistical analyses.

4 RTC Use Examples

The RTC products are presented as Cloud-Optimized GeoTIFFs (COGs), a user-friendly format that is GIS compatible. The products do not include pre-generated overviews, so users may need to generate pyramids to display the images efficiently in a GIS environment.

The side-looking geometry of SAR imagery leads to geometric and radiometric distortions. RTC adjusts images so that the values relate to actual topographic features, alleviating shadows, foreshortening, and layover effects inherent to SAR images. These corrected images can then be used as “just another layer” within a GIS, and can be combined with other datasets in a number of ways.

The two satellites that comprise the Sentinel-1 mission each have a 12-day repeat cycle, so most areas of the earth will have imagery at least every 6 days, but many areas have coverage even more frequently, making this SAR dataset a very useful tool for monitoring rapid or sudden landscape changes. In addition, SAR is not impacted by either cloud cover or lack of light, so RTC imagery can be collected at any time, and in areas or situations where cloud cover often causes problems for other imagery types.

The following sections present examples of how one might use RTC datasets to identify areas of change and integrate RTC datasets into other datasets for enhanced results. We also present a bibliography of some of the scientific literature making use of Sentinel-1 RTC datasets.

4.1 Change Detection Using RTC Data

There are a number of ways that SAR data sets can be used to identify areas of change. Here are two examples of what you can do in a GIS environment.

4.1.1 Seasonal Change

Stacking RTC images into a multiband image (Figure 2) allows the user to display different times of year at the same time, using the color bands to highlight areas that differ in radar backscatter values from one month to the next.

To generate this type of image, choose three images that capture different seasons or months of interest. These can either be individual RTC images from different times of the year, or rasters displaying the monthly median calculated from multiple RTC images collected in the same month.

Combine the three images into a multiband raster and assign each to a different color band. The resulting RGB image highlights areas where there are distinctive differences among the three source image values.

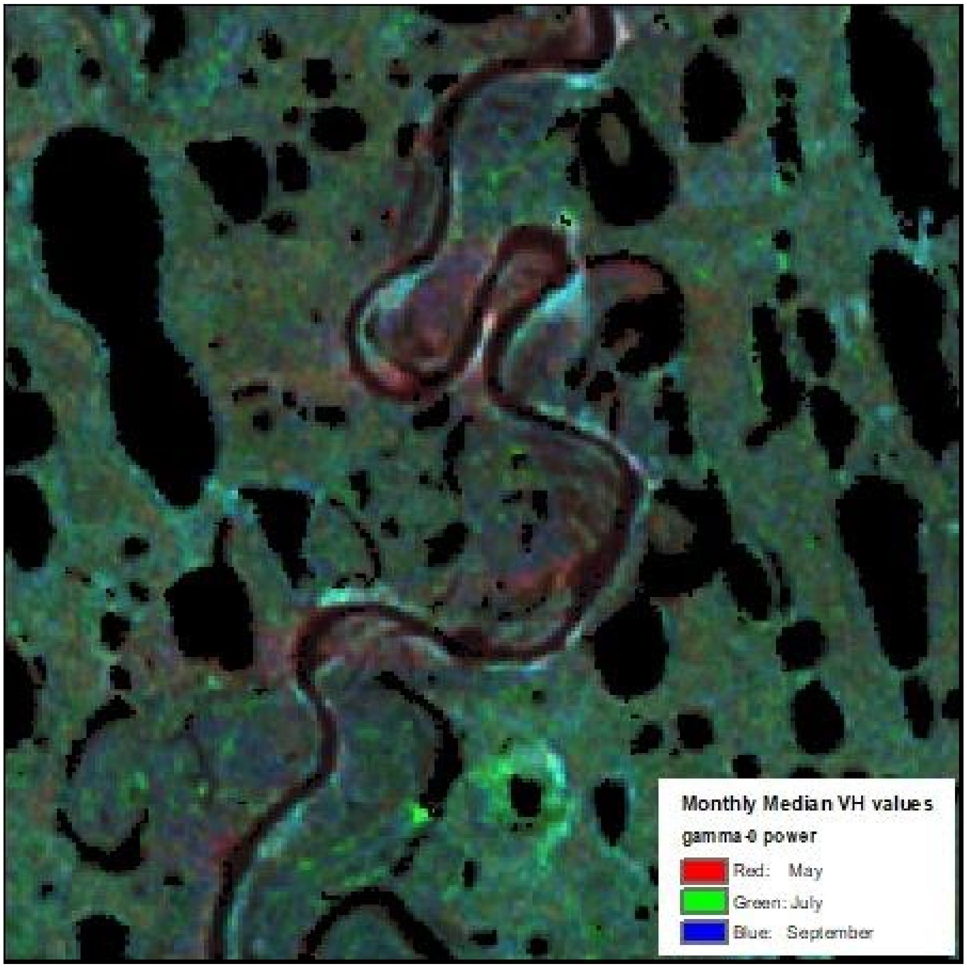


Figure 2: Monthly median VH gamma-0 power values for May, July and September, displayed as a multiband RGB (May, July, Sept) image.

4.1.2 Quantifying Change over Time

A simple and informative approach to change detection is the calculation of the log difference between two RTC datasets from different dates. By calculating Log10(date2/date1) and applying a classified symbology, it is easy to identify areas where change occurred, as well as the direction of the change. Negative values indicate a decrease in radar backscatter over time, while positive values indicate an increase in backscatter.

In the example below (Figure 3), RTC images from before and after heavy rains caused a dam breach. The area where the reservoir was located displays a significant increase in backscatter (symbolized in red). This positive change is driven by land that was once covered by standing water, which generally has very low backscatter, now being exposed saturated soil, which generally returns very high backscatter values. In surrounding areas, decreases in radar backscatter (symbolized by blue), are possibly the result of agricultural fields undergoing desiccation/hardening of the surface soil following the heavy rainfall and standing water. Areas with little change in backscatter are displayed in yellow.

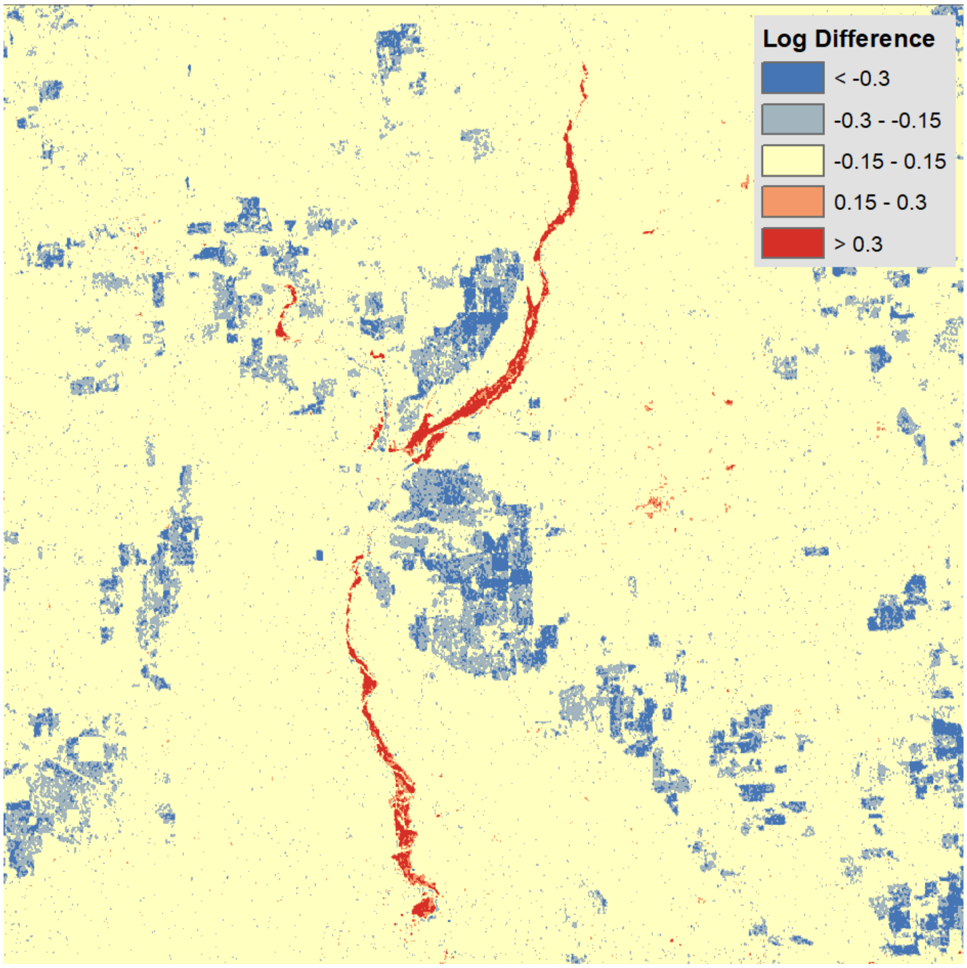


Figure 3: Log Difference Raster with Classified Symbology

4.2 Identifying Surface Water

Calm surface water has a very low radar cross section. Most of the signal is reflected off the smooth surface, due to the high dielectric constant of freshwater, so little to none of the signal is returned as backscatter. Because of this, it is often easy to delineate surface water using a simple threshold value, where all pixels below the threshold are assumed to be water.

You can easily visualize the water extent using various thresholds by applying a classified symbology with two classes. It is often best to use dB scale datasets for identifying surface water. In many cases, there will be a bimodal distribution of values in an RTC image containing surface water, with the first peak comprised mostly of water values, and the second peak containing all the remaining values. A good first step is to select a break point between those two peaks, then adjust the value as needed to generate a good water mask (Figure 4).

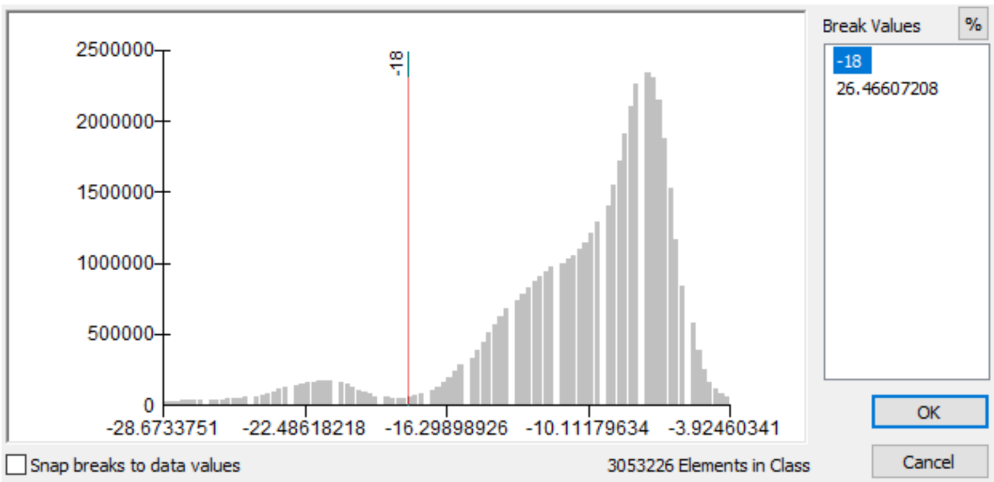
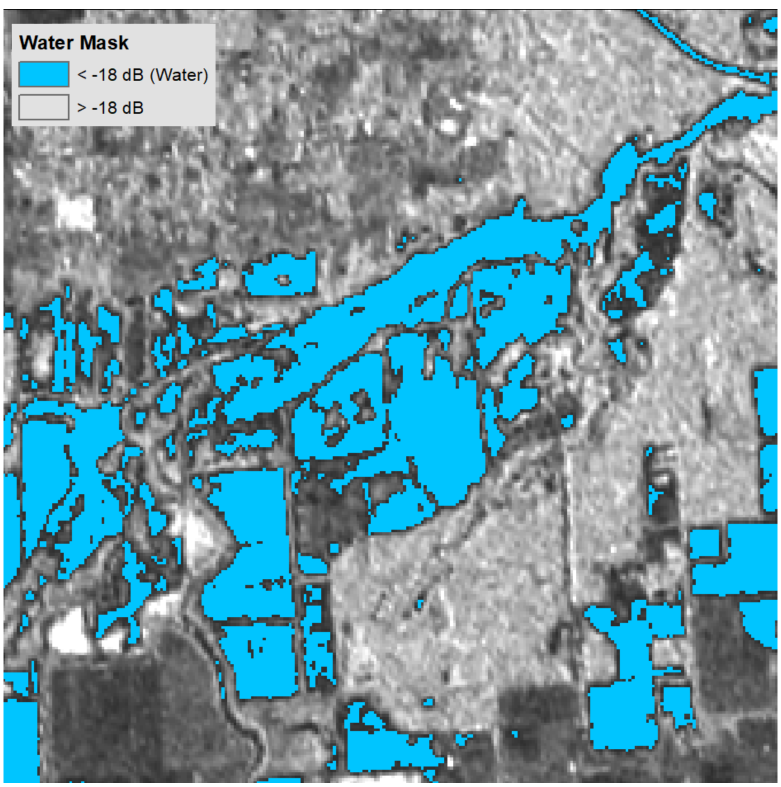


Figure 4: Setting the break point to fall between the two peaks of the histogram



Once you have determined the appropriate threshold (Figure 5), you can reclassify the RTC image to include only those pixels that fall below the threshold value, providing a water mask that can be used for analysis or to overlay with other imagery to show the water extent.

Figure 5: Water Mask

4.3 Combination of RTC Image with other Remote Sensing Data

One of the main advantages of using RTC imagery with its all weather and day/night capabilities is the combination with other remote sensing data such as optical data. In the example below, the backscatter information of the Sentinel-1 SAR image (Figure 6) is used to enhance the spectral information of the optical Landsat 8 image (Figure 7) in the urban area of Pavia, Italy. Figure 8 shows the image fusion result of an IHS transformation. In this transformation the color channels red, green and blue (RGB) are first converted into a different color representation: intensity, hue and saturation (IHS). In the second step the optical intensity is replaced by the SAR image, before IHS is transformed back to RGB.

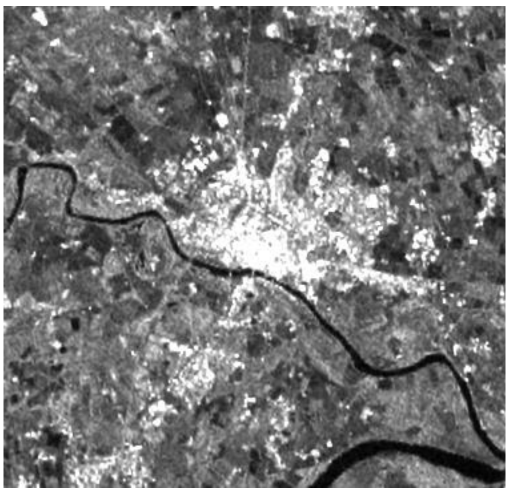


Figure 6: Sentinel-1 RTC image

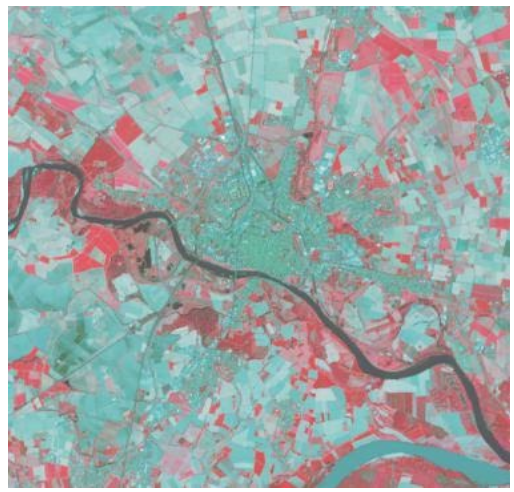


Figure 7: False color composite (bands 5, 4, 3) of a Landsat 8 image

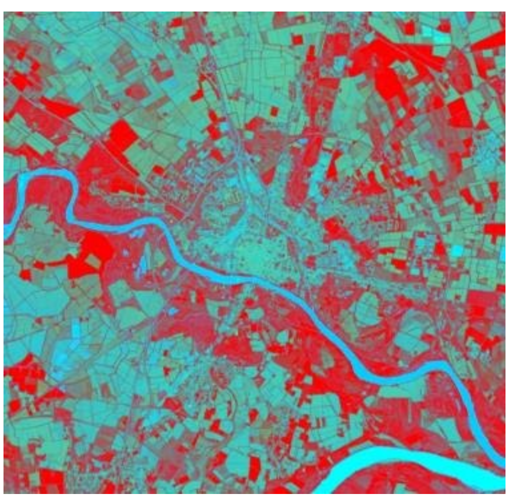


Figure 8: Image fusion result of SAR and optical imagery

The color values for the two rivers in the SAR image are far more similar to each other than in the optical image. The vegetated areas (highlighted in red) show up more uniformly in the data fusion result than in the optical false color composite image. Image fusion uses the complementary nature of the different sources to generate an enhanced product.

5 ArcGIS Toolbox

ASF has developed a custom ArcGIS Toolbox for working with RTC datasets in either ArcGIS Desktop or ArcGIS Pro. It includes tools for converting between different SAR scales, calculating the log difference between two images, generating RGB Decomposition (false-color) products, and reclassifying a raster to generate a water mask. For more information and to download the toolbox, visit our website: https://asf.alaska.edu/how-to/data-tools/gis-tools/.

6 Application Examples in the Literature

The following journal articles represent some of the work being done using Radiometric Terrain Corrected Sentinel-1 data sets.

Crop Monitoring

Clauss, K., Ottinger M. and Kuenzer, C. 2018. Mapping rice areas with Sentinel-1 time series and superpixel segmentation. *International Journal of Remote Sensing*, **39**(5):1399-1420. DOI: 10.1080/01431161.2017.1404162

Nguyen, D.B., Gruber A. and Wagner, W. 2016. Mapping rice extent and cropping scheme in the Mekong Delta using Sentinel-1A data. *Remote Sensing Letters*, **7**(12):1209-1218. DOI: 10.1080/2150704X.2016.1225172

Disaster Response

Markert, K.N., Chishtie, F., Anderson, E.R., Saah, D., Griffin, R.E. 2018. On the merging of optical and SAR satellite imagery for surface water mapping applications. *Results In Physics*, **9**:275-277. DOI: 10.1016/j.rinp.2018.02.054

Twele, A., Cao, W., Plank, S. and Martinis, S. 2016. Sentinel-1-based flood mapping: a fully automated processing chain. *International Journal of Remote Sensing*, **37**(13):2990-3004. DOI: 10.1080/01431161.2016.1192304

Land Classification and Change Detection

Muro, J., Canty, M., Conradsen, K., Hüttich, C., Nielsen, A.A., Skriver, H., Remy, F., Strauch, A., Thonfeld, F. and Menz, G. 2016. Short-Term change detection in wetlands using Sentinel-1 time series. *Remote Sensing*, **8**(10):795. DOI: 10.3390/rs8100795

Rüetschi, M., Schaepman, M.E., Small, D. 2018. Using Multitemporal Sentinel-1 C-band backscatter to monitor phenology and classify deciduous and coniferous forests in Northern Switzerland. *Remote Sensing*, **10**(1):55. DOI: 10.3390/rs10010055

7 Data Access

To view or download Sentinel-1 RTC products, please see the links below:
Vertex: https://search.asf.alaska.edu/
API: https://asf.alaska.edu/api/

For details on accessing data, including other SAR datasets, see ASF's Get Started guide: https://asf.alaska.edu/how-to/get-started/

To access data recipes, which are step-by-step tutorials for processing and working with SAR data, see ASF's tutorials page:
https://asf.alaska.edu/how-to/data-recipes/data-recipe-tutorials/