JNCC Sentinel-1 Backscatter Data Provision Service

SAR processing Methodology

DEFENCE AND SPACE

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SAR Processing Overview

Satellite: Sentinel-1 A/B **Revisit Time**: 6 days (InSAR configuration)

INPUT product: S1_GRD_HR VV-VH (Sentinel-1 Interferometric Wide Swath Mode Ground Range Detected High Resolution Level-1 Product)

OUTPUT (SAR derived observables generated by the processing)

1) Terrain corrected absolute backscattering coefficient Sigma0 and Gamma0 linear scale (**suffix: TC**)
2) Terrain corrected and Radiometrically Normalised Kellndorfer (with Local incidence angle projected on the slant range plane) backscattering coefficient Sigma0 and Gamma0 linear scale and after speckle removal in linear and db scale (**suffix: RTC**)
3) Terrain corrected and Radiometrically Normalised Small method backscattering coefficient Gamma0 linear scale and after speckle removal in linear and db scale (**suffix: FTC**)

Script language: Bash LINUX calling functions libraries, embedding the SAR defined processing chains, and configuration file.
Use of POSITIONAL parameters to allow few processing combination

Script features

- Selection of polarisation (VV or VH or VV and VH);
- Reading directly Sentinel-1 (A/B) data in ZIP;
- Option to apply a multi-looking process;
- Option for assembly (up to 3 slices)
- Option for Precise Orbit Ephemerides correction (RESORB, POEORB); in case not available use one in the product
- Option for selection of image interpolation method during Terrain Correction;
- Option for DEM selection: SRTM 3 sec or External DEM (APGB 5m);
- Radiometric Normalisation. Both the local incidence angle correction or local illuminated area correction (terrain flattening based [RD-2]) can be implemented to compensate the topography and normalise the local variation of the scattering;
- Option for selecting different Output Coordinate Reference Systems (British National Grid, Irish Grid TM75 – EPSG 29902 , UTM-WGS84);
- Option for the Speckle filtering (Refined Lee, GammaMap)
- Output format: GeoTIFF-BigTIFF format;
- Logging

Positional parameters to be provided to the script for options selection

$1 → type of products to be processed: =1 GRD ; =2 SLC ## inserted to allow modularity for future SLC processing

$2 → number of slices to be processed (up to 3 adjacent slices):

$3 → polarisation to be processed: =1 (VV&VH); =2 (VV); =3 (VH)

$4 → Dem used in the processing: =1 (APGB); =2 (SRTM)

$5 → Precise orbits: =1 (RESORB if not found use the one in the product); =2 (POEORB)

$6 → Multilooking factor: =1 (Az=1 & Rg=1); =2 (Az=2 & Rg=2) etc:

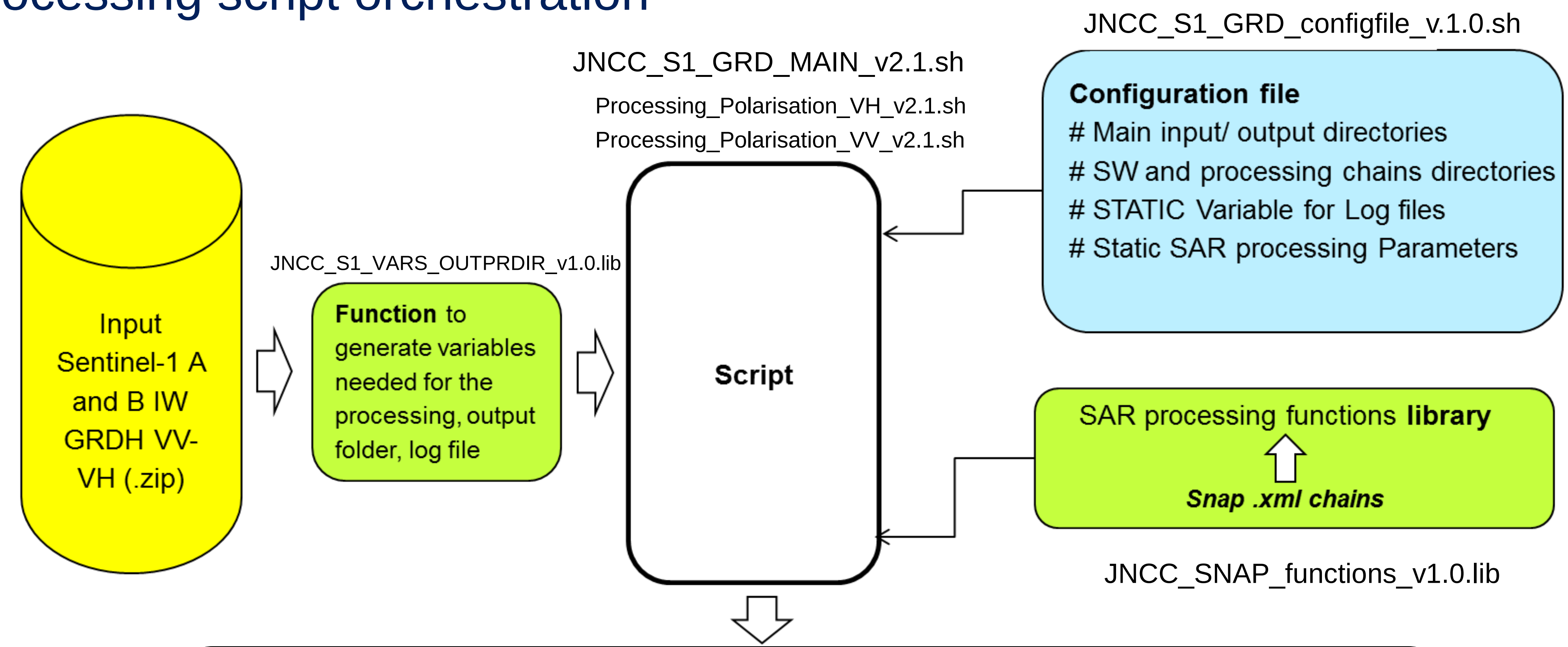
$7 → Image interpolation method during terrain correction: =1 (nearest neighbour) =2 (bilinear) =3 (BICUBIC_INTERPOLATION)

$8 → DEM Resampling method during terrain correction: =1 (bilinear) =2 (e.g.: Bicubic INTERPOLATION)

$9 → CRS for Terrain Corrected outputs: =1 (OSGB 1936 - EPSG:27700); =2 (EPSG:29902); =3 (UTM WGS 84)

${10} → determines the type of applied speckle filter: 1 (=Refined Lee); 2 (=GammaMap)

Processing script orchestration



OUTPUTS

- Terrain corrected absolute backscattering coefficient Sigma0 and Gamma0 linear scale (suffix: TC)
- Terrain corrected and Radiometrically Normalised Kellndorfer method backscattering coefficient Sigma0 and Gamma0 linear scale and after speckle removal in linear and db scale (suffix: RTC)
- Terrain corrected and Radiometrically Normalised Small method backscattering coefficient Gamma0 linear scale and after speckle removal in linear and db scale (suffix: FTC)

Processing Log file

Configuration file

INPUTS directories

export MAIN_DIR=“./JNCC/MAIN" ##== MAIN DIRECTORY with DEM, Input dataset and Outputs
export BASKET_INDIR="${MAIN_DIR}/Basket" ##== directory containing S1_GRDH.zip products to be processed
#####
export EXTDEMFILE="${MAIN_DIR}/EXT_DEM/APGB_Qgis.tif" ##== External APGB DEM
export EXTDEMNOVAL="-32768.0" ## External DEM No data value
OUTPUT directories
export MAIN_OUTDIR="${MAIN_DIR}/OUTPUT" ##== MAIN OUTPUT DIRECTORY where products output folders will be created
After Processing
export PROZIP_DIR="${MAIN_DIR}/ZIP_PROCESSED" ##== directory where S1.zip data are moved after processing
SW and processing xml chains directories
export GRAPHSDIR="./JNCC/script/xml" ##== DIRECTORY with snap xml graphs for the processing
export SNAP_HOME="/opt/snap/bin" ##== SNAP (version 5) directory
export SCRIPT_DIR=“.JNCC/script"

STATIC Variable for Log files

Processing Parameters

UTM map projection parameters
export UTMPROJ="UTM Zone 31"   ### e.g. "UTM Zone 30" , "UTM Zone 22, South“
export centralmeridian="-3.0" ### e.g. "-3", "-51“
export false_northing="0.0" ### e.g. "0.0"

Single Slice Processing

SLICE-1 image: creation of variables needed for the processing, output folder ${SLICE_1_OUTDIR} and logfile ${SLICE_1_LOG}

For each TR POL (=VV, VH):
Processing in SAR GROUND RANGE geometry

Border removal (select TR polarisation), Thermal Noise Removal, Absolute Calibration (sigma0, gamma0, beta0), Precise Orbit

GEOCODING of Absolute (ellipsoid) Sigma0 and Gamma0

TR Absolute Sigma0 and Gamma0 Multilooked (if applied) and Terrain Corrected with SRTM3sec

TR Absolute Sigma0 and Gamma0 Multilooked (if applied) and Terrain Corrected with APGB

GEOCODING and radiometric normalisation with Kellndorfer approach

TR (if applied) Multilooked, Terrain corrected an Radiometric normalised Sigma0 and Gamma0 (Kellndorfer approach with projected SR local incidence angle) with SRTM3sec

TR (if applied) Multilooked, Terrain corrected an Radiometric normalised Sigma0 and Gamma0 (Kellndorfer approach with projected SR local incidence angle) with APGB DEM

GEOCODING and radiometric normalisation with Small approach

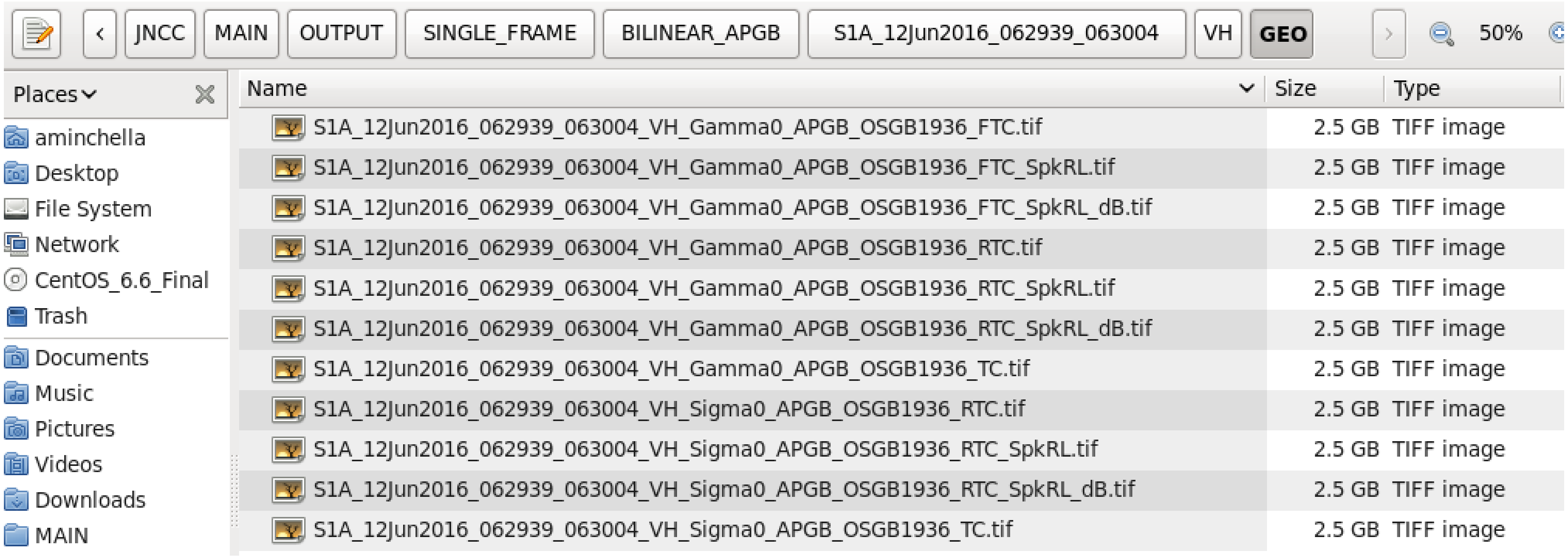
TR (if applied) Multilooked, Terrain corrected an flattened Gamma0 (SMALL method) with APGB DEM

VV polarisation – single frame full resolution (10m)

JNCC_S1_GRD_MAIN_v1.0.sh 1 1 2 1 1 1 2 1 1 1

Bilinear Interpolation for external DEM
Bilinear Interpolation for the image resampling

VH polarisation – single frame full resolution (10m)



JNCC_S1_GRD_MAIN_v1.0.sh 1 1 3 1 1 1 2 1 1 1

Bilinear Interpolation for external DEM
Bilinear Interpolation for the image resampling

VV polarisation – 2 assembled consecutive frames assembled full resolution (10m)

JNCC_S1_GRD_MAIN_v1.0.sh 1 2 2 1 1 1 2 1 1 1

Bilinear Interpolation for external DEM
Bilinear Interpolation for the image resampling

VH polarisation is of same size

Backscattering Coefficient

Radar backscatter: Ellipsoid-normalisation

Conventional Radar Backscatter

- Backscatter coefficients [dB/m²] are *ratio of scattered to incident power* per unit area:

$$\beta = k \cdot \frac{P_s}{P_i} \qquad \beta^0 = \frac{\beta}{A_\beta} \qquad \sigma_E^0 = \frac{\beta}{\underline{A}_\sigma} \qquad \gamma_E^0 = \frac{\beta}{\underline{A}_\gamma}$$

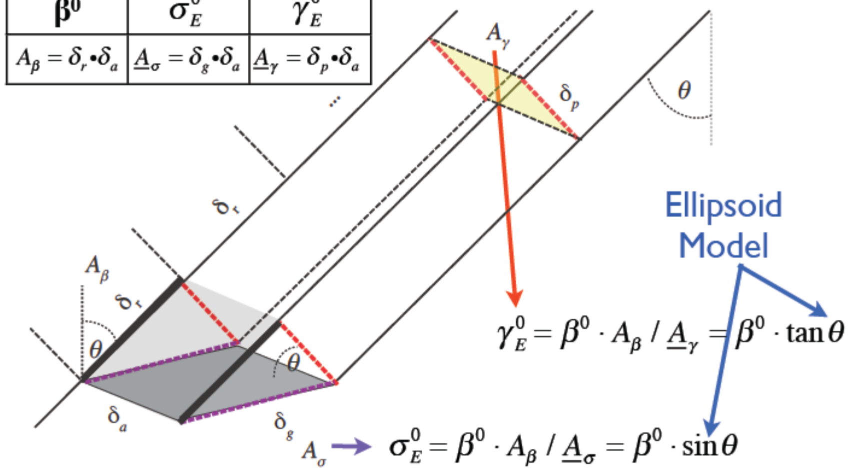
- Known: transmitted & received power P_t & P_r
- Derive: incident & scattered power P_i & P_s from P_t & P_r

$$\beta^0 = k \cdot \frac{f_2(P_r)}{f_1(P_t)} \cdot \frac{1}{A_\beta} \qquad \sigma_E^0 = k \cdot \frac{f_2(P_r)}{f_1(P_t)} \cdot \frac{1}{\underline{A}_\sigma} \qquad \gamma_E^0 = k \cdot \frac{f_2(P_r)}{f_1(P_t)} \cdot \frac{1}{\underline{A}_\gamma}$$

David Small (RSL UZH) - QWG ESRIN 2009.10.27-28

Ground Illuminated Area

β^0	σ_E^0	γ_E^0
$A_\beta = \delta_r \cdot \delta_a$	$\underline{A}_\sigma = \delta_g \cdot \delta_a$	$\underline{A}_\gamma = \delta_p \cdot \delta_a$



$$\gamma_E^0 = \beta^0 \cdot A_\beta / \underline{A}_\gamma = \beta^0 \cdot \tan\theta$$

$$\sigma_E^0 = \beta^0 \cdot A_\beta / \underline{A}_\sigma = \beta^0 \cdot \sin\theta$$

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<u>Ellipsoid-normalisation</u>

Calibrated sigma nought for detected products can be derived as:

$$\sigma_{i,j}^0 = \underbrace{\boxed{\frac{DN_{i,j}^2}{K}}}_{\beta^0} \sin\left(\alpha_{i,j}\right)$$

Introducing Terrain-Normalisation

Name	Symbol	Normalisation Reference	Derivation
Beta Nought	β^0	Area formed by Sample Intervals in Slant Range / Azimuth Plane	$\beta = k \cdot P_s / P_i$ $\beta^0 = \beta / A_\beta$
Sigma Nought	σ_E^0	*Ellipsoid* Ground Area	$\sigma_E^0 = \beta^0 \cdot A_\beta / \underline{A}_\sigma$
Gamma Nought	γ_E^0	*Ellipsoid* Ground Area projected in plane ⊥ to Look Direction	$\gamma_E^0 = \beta^0 \cdot A_\beta / \underline{A}_\gamma$
Gamma Taut	γ_T^0	Integrated *Terrain* Area projected in plane ⊥ to Look Direction	$\gamma_T^0 = \beta^0 \cdot A_\beta / A_\gamma$

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Backscattering Coefficient

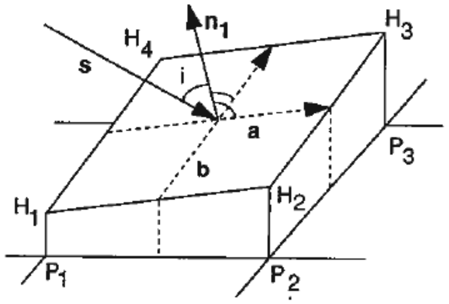
Radar backscatter: slope-normalisation by LIM (local incidence mask)

Normalisation for local variation of scattering area: $\sigma^0_{Norm} = \sigma^0_{Ellipsoid} * \frac{\sin\theta_{DEM}}{\sin\theta_{Ell.}}$ Kellndorfer et al., TGRS, Sept. 1998.

θ_{DEM}

Local incidence angle projected into the range plane

Local incidence angle



Small method for slope normalisation

Local Incidence Angle Mask (LIM)

- The most common slope-normalisation methodology found in the literature is best placed between ellipsoid- and terrain-based normalisation conventions
- Normalisation for local variation of scattering area:

$$\sigma^0_{NORLIM} = \sigma^0_E \cdot \frac{\sin\theta}{\sin\theta_m}$$

Kellndorfer et al.,TGRS, Sept. 1998.

- Fails to account for scattering area variations caused by terrain in non-neighbouring DEM samples

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Summary of Normalisation Conventions

Convention	1	2	3	4	5
	β^0	σ_E^0	γ_E^0	σ_T^0	γ_T^0
Earth Model	***None***	***Ellipsoid***		***Terrain***	
Reference Area	A_β	$\underline{A}_\sigma$	$\underline{A}_\gamma$	A_σ	A_γ
Area Derivation	$\delta_r \cdot \delta_a$	$\delta_g \cdot \delta_a$	$\delta_p \cdot \delta_a$	$\int_{DHM} \delta_g \cdot \delta_a$	$\int_{DHM} \delta_p \cdot \delta_a$
Normalisation	$\beta^0 = \frac{\beta}{A_\beta}$	$\beta^0 \cdot \frac{A_\beta}{\underline{A}_\sigma} = \beta^0 \cdot \sin\theta_e$	$\beta^0 \cdot \frac{A_\beta}{\underline{A}_\gamma} = \beta^0 \cdot \tan\theta_e$	$\beta^0 \cdot \frac{A_\beta}{A_\sigma}$	$\beta^0 \cdot \frac{A_\beta}{A_\gamma}$

SAR Products in Map Geometry

GTC	NORLIM	RTC
σ_E^0 or γ_E^0	$\cancel{\sigma}_T^0$ or $\cancel{\gamma}_T^0$	γ_T^0
$\sigma_E^0 = \beta^0 \cdot \sin\theta_e$ $\gamma_E^0 = \beta^0 \cdot \tan\theta_e$	$\sigma_E^0 \cdot \frac{\sin\theta}{\sin\theta_m}$ $\gamma_E^0 \cdot \frac{\sin\theta}{\sin\theta_m}$ Kellndorfer et al., TGRS, Sept. 1998.	$\beta^0 \cdot \frac{A_\beta}{A_\gamma}$

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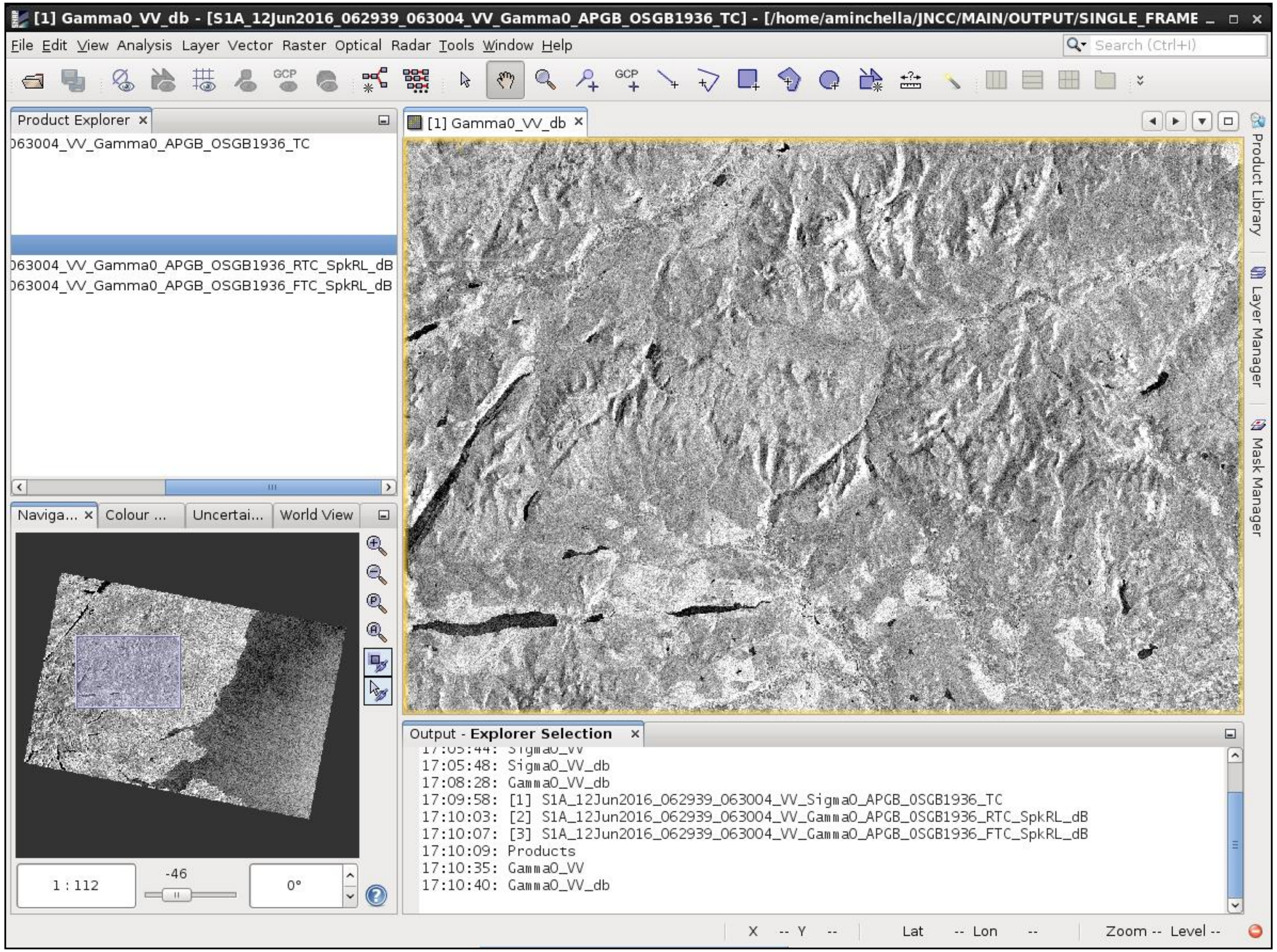
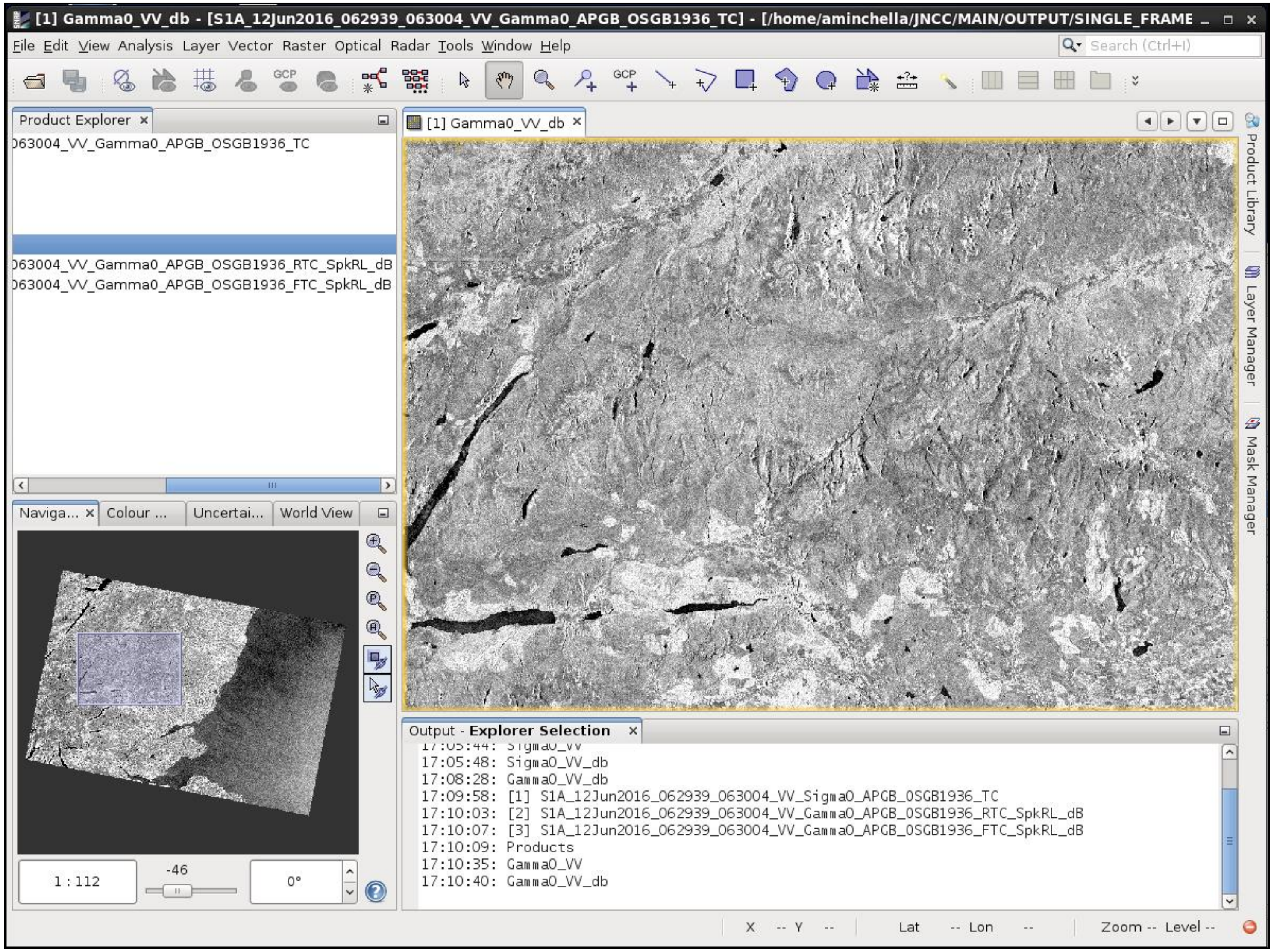
Terrain corrected absolute backscattering coefficient Gamma0 (TC)



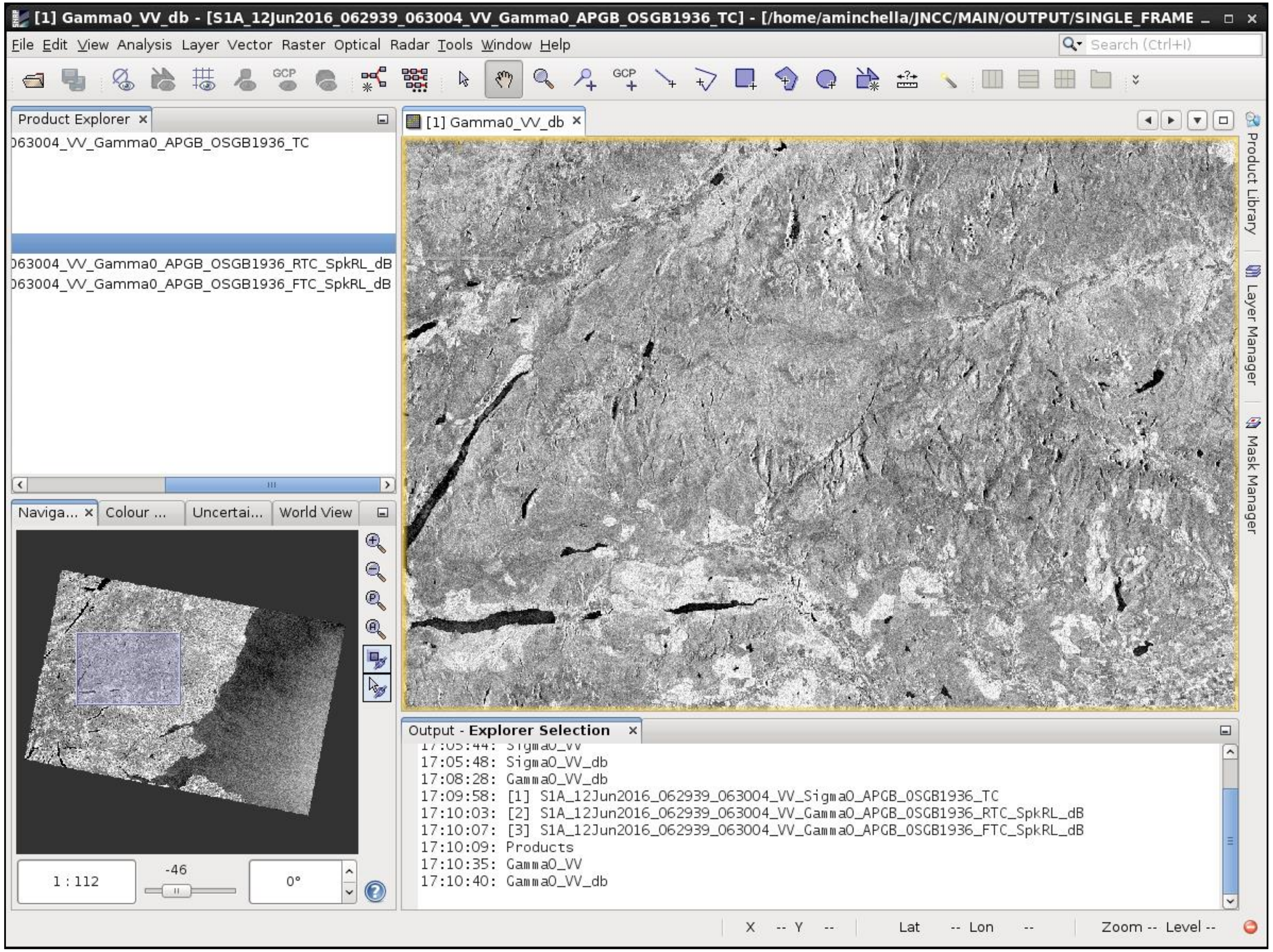
Example of VV polarisation
DEM: APGB
CRS: OSBG

Terrain corrected and Radiometrically Normalised Kellndorfer Gamma0



Example of VV polarisation
DEM: APGB
CRS: OSBG

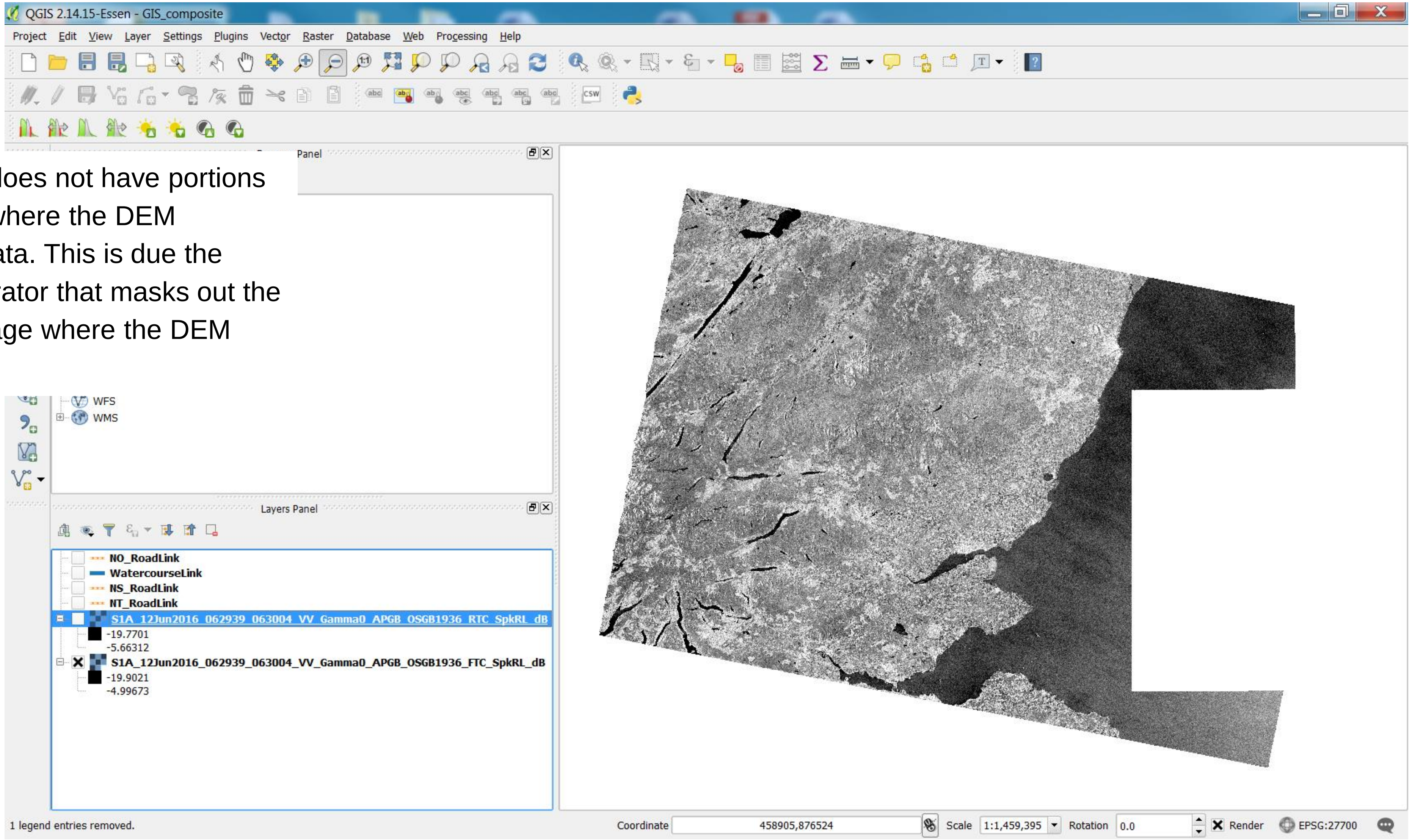
Terrain corrected and Radiometrically Normalised Small Gamma0



Example of VV polarisation
DEM: APGB
CRS: OSBG

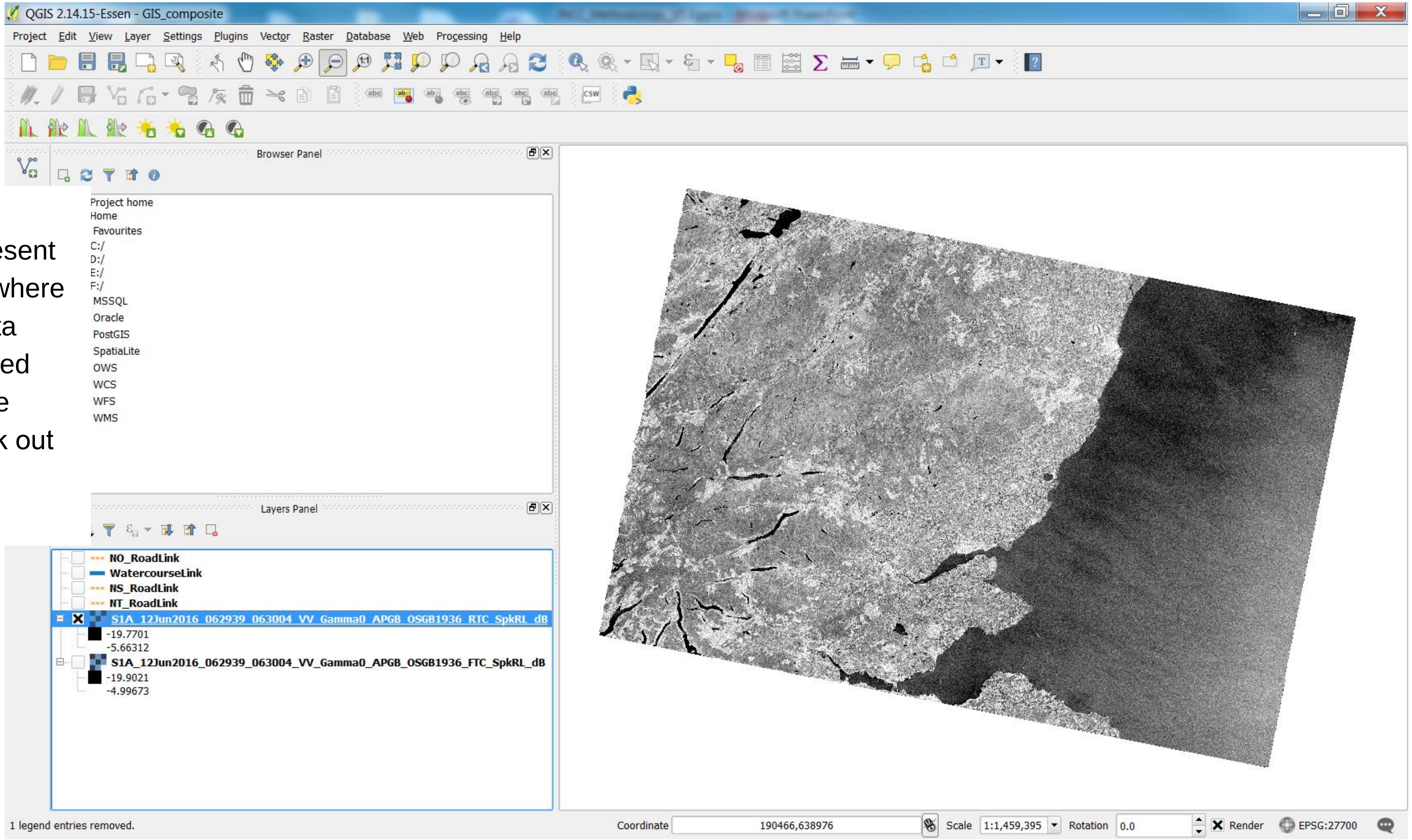
Gamma0 VV FTC (dB) – Small method

FTC product does not have portions of the image where the DEM contains no data. This is due the flattening operator that masks out the part of the image where the DEM has no data.



Gamma0 VV RTC (dB) - Kellndorfer

In the sea area, artefacts are present in form of lines where the DEM No-data value are replaced with a zero value (option off “mask out areas without elevation”)



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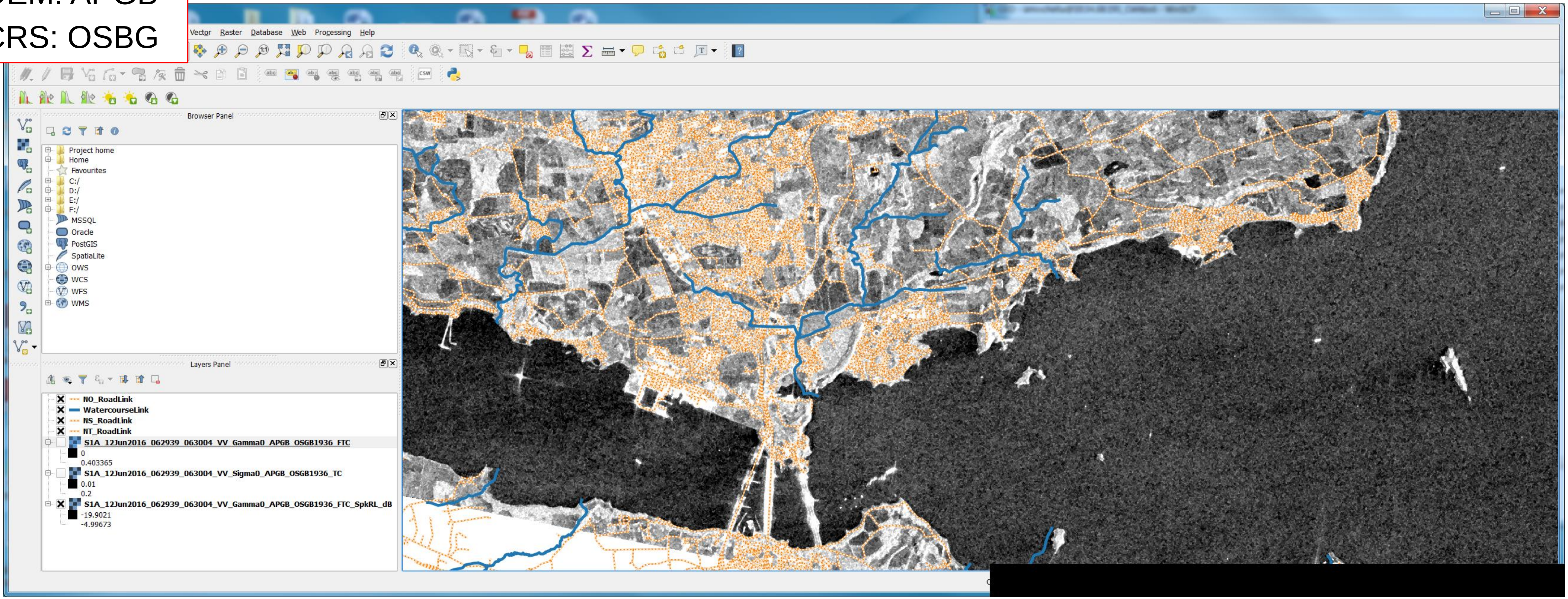
Horizontal accuracy: Overlay with OS Open Roads and Rivers

DEM: APGB

CRS: OSBG



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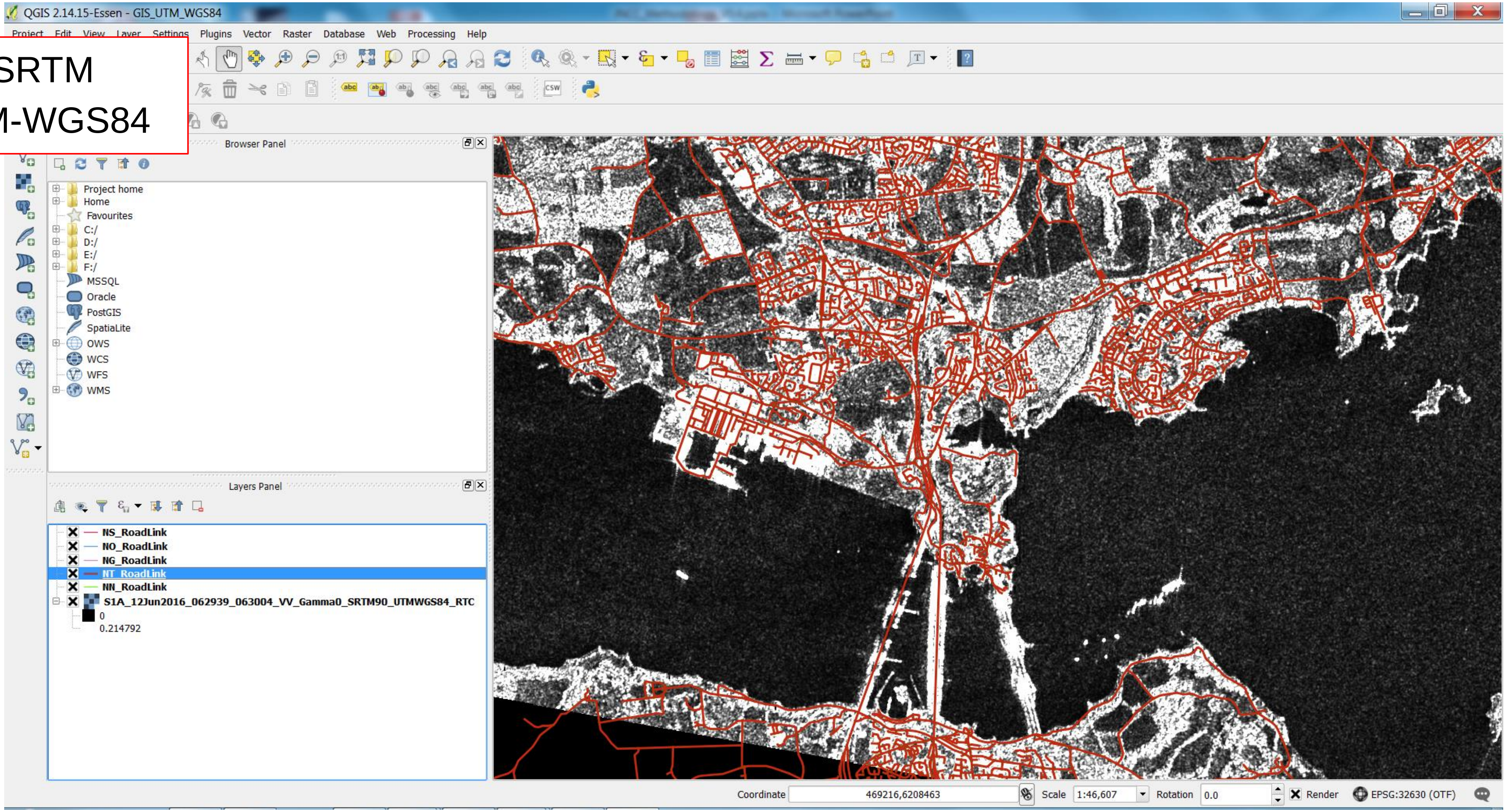
Horizontal accuracy: Overlay with OS Open Roads and Rivers

DEM: SRTM

CRS: UTM-WGS84



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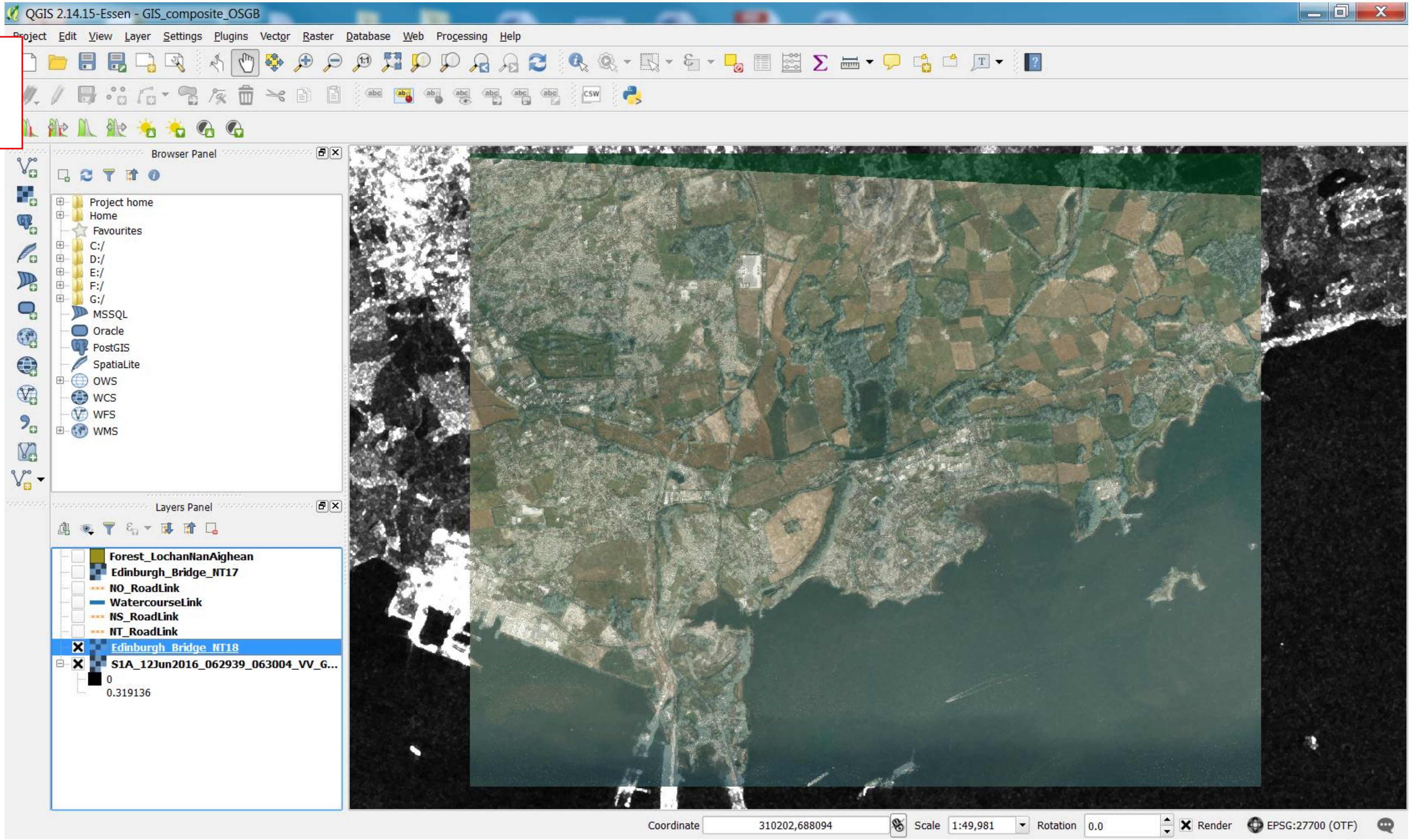
Horizontal accuracy: Overlay with Aerial Imagery

DEM: APGB
CRS: OSBG



Radiometry: Gamma0-VV comparison

Statistics in linear and dB scale have been computed over 4 different cover types:

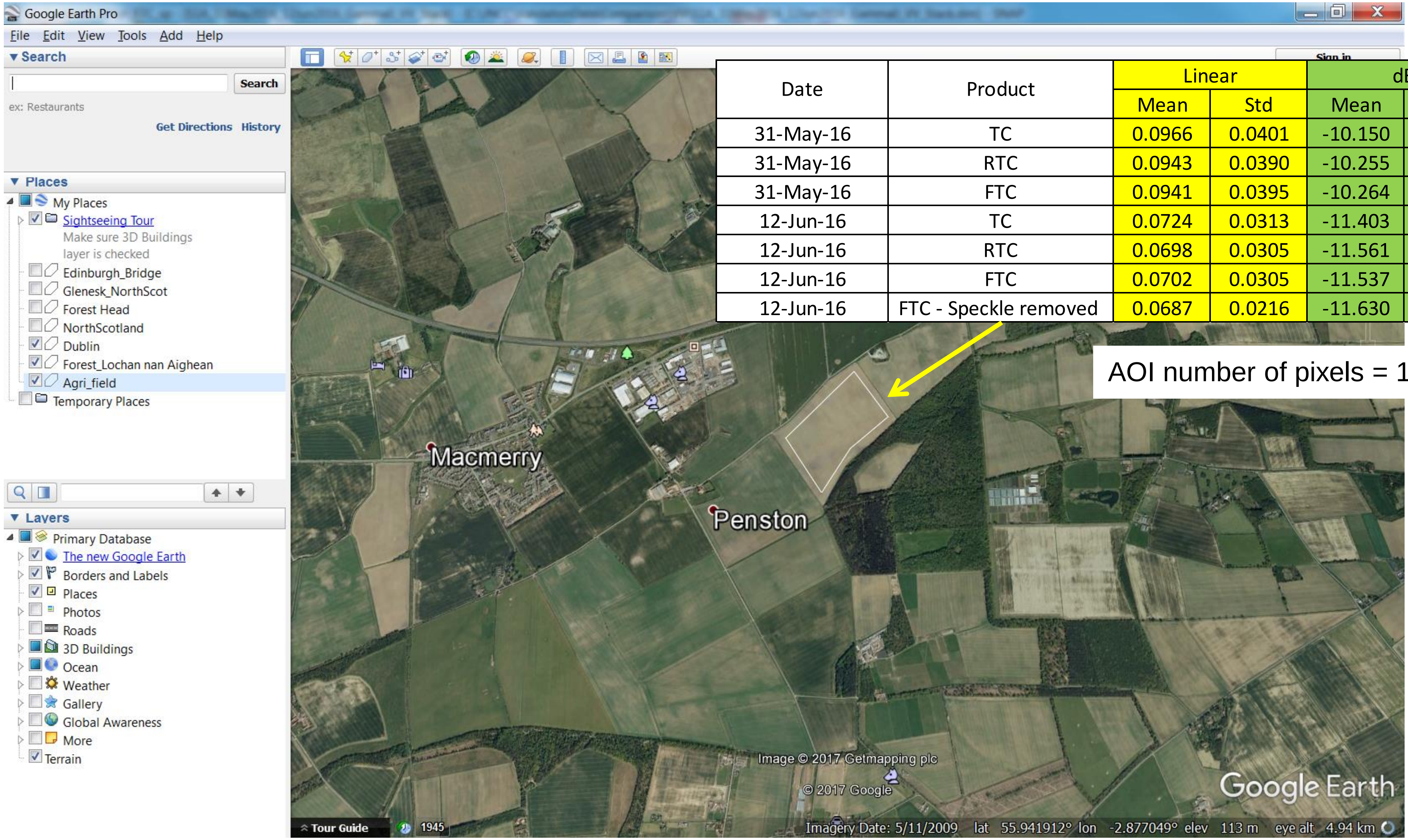
- Agricultural field
- Forest
- Industrial area
- Water (lake)

The statistics have been computed from the Gamma0-VV TC, RTC, FTC, FTC speckle reduced products generated by using the APGB DEM and in two subsequent dates, 31 May 2016 and 12 June 2016:

S1A_IW_GRDH_1SDV_20160531T062938_20160531T063003_011499_011886_34C6
S1A_IW_GRDH_1SDV_20160612T062939_20160612T063004_011674_011DFE_7BA3

Results are showed in the following slides

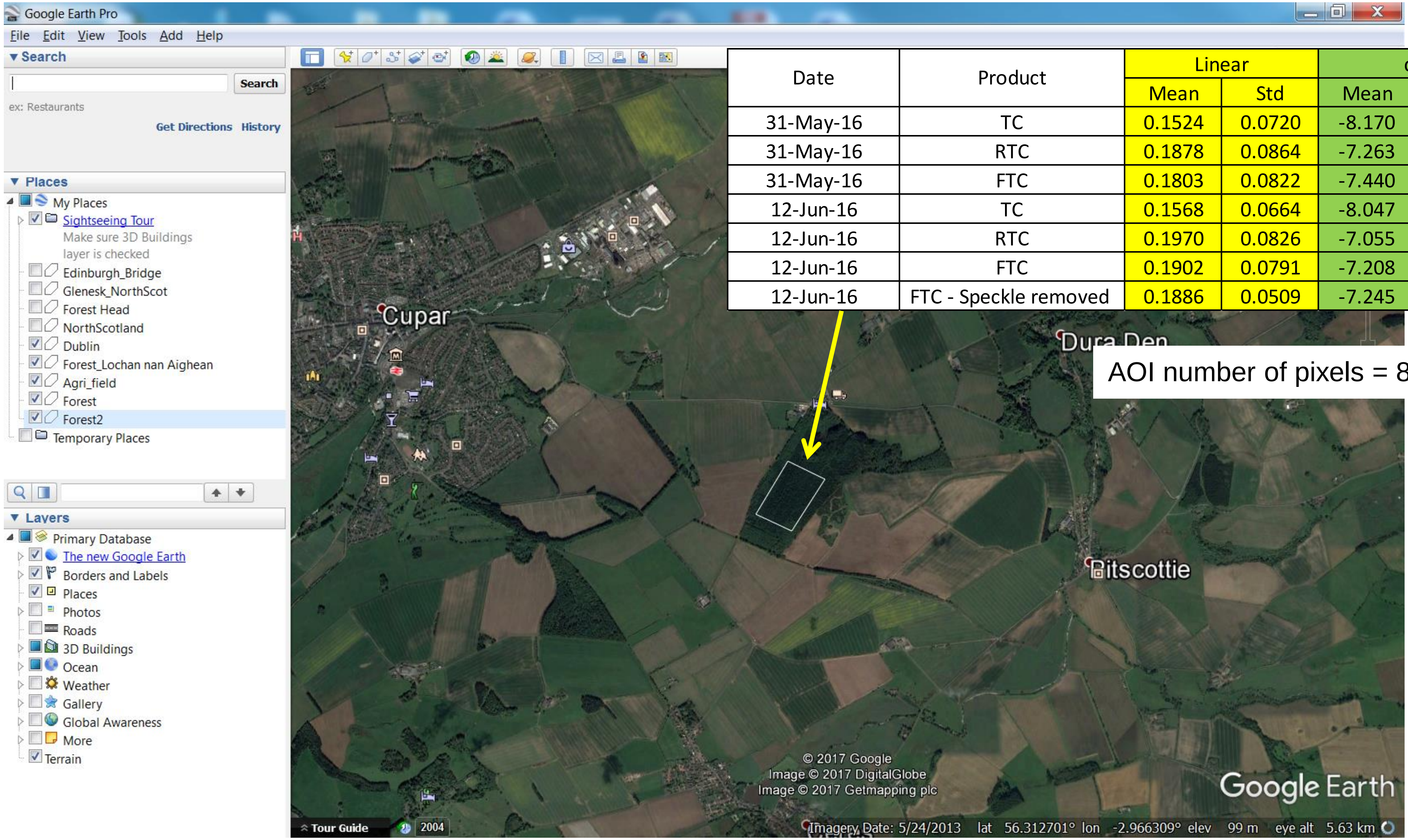
Statistics comparison Gamma-0 VV: agricultural field @ Penston



Date	Product	Linear		dB	
		Mean	Std	Mean	Std
31-May-16	TC	0.0966	0.0401	-10.150	1.508
31-May-16	RTC	0.0943	0.0390	-10.255	1.503
31-May-16	FTC	0.0941	0.0395	-10.264	1.522
12-Jun-16	TC	0.0724	0.0313	-11.403	1.560
12-Jun-16	RTC	0.0698	0.0305	-11.561	1.574
12-Jun-16	FTC	0.0702	0.0305	-11.537	1.567
12-Jun-16	FTC - Speckle removed	0.0687	0.0216	-11.630	1.187

AOI number of pixels = 1526

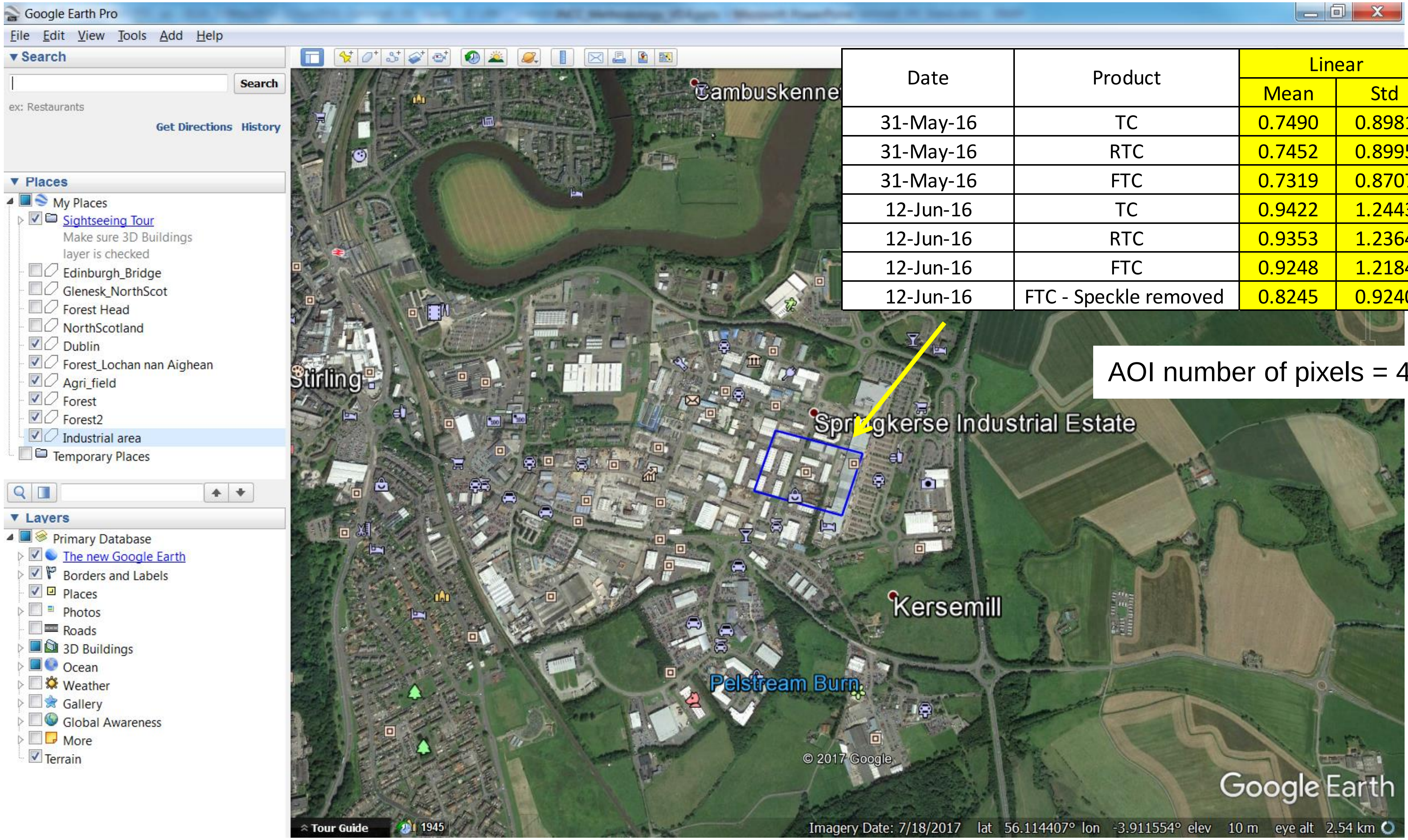
Statistics comparison Gamma-0 VV: Forest @ Dura Den



Date	Product	Linear		dB	
		Mean	Std	Mean	Std
31-May-16	TC	0.1524	0.0720	-8.170	1.680
31-May-16	RTC	0.1878	0.0864	-7.263	1.644
31-May-16	FTC	0.1803	0.0822	-7.440	1.631
12-Jun-16	TC	0.1568	0.0664	-8.047	1.533
12-Jun-16	RTC	0.1970	0.0826	-7.055	1.521
12-Jun-16	FTC	0.1902	0.0791	-7.208	1.510
12-Jun-16	FTC - Speckle removed	0.1886	0.0509	-7.245	1.038

AOI number of pixels = 817

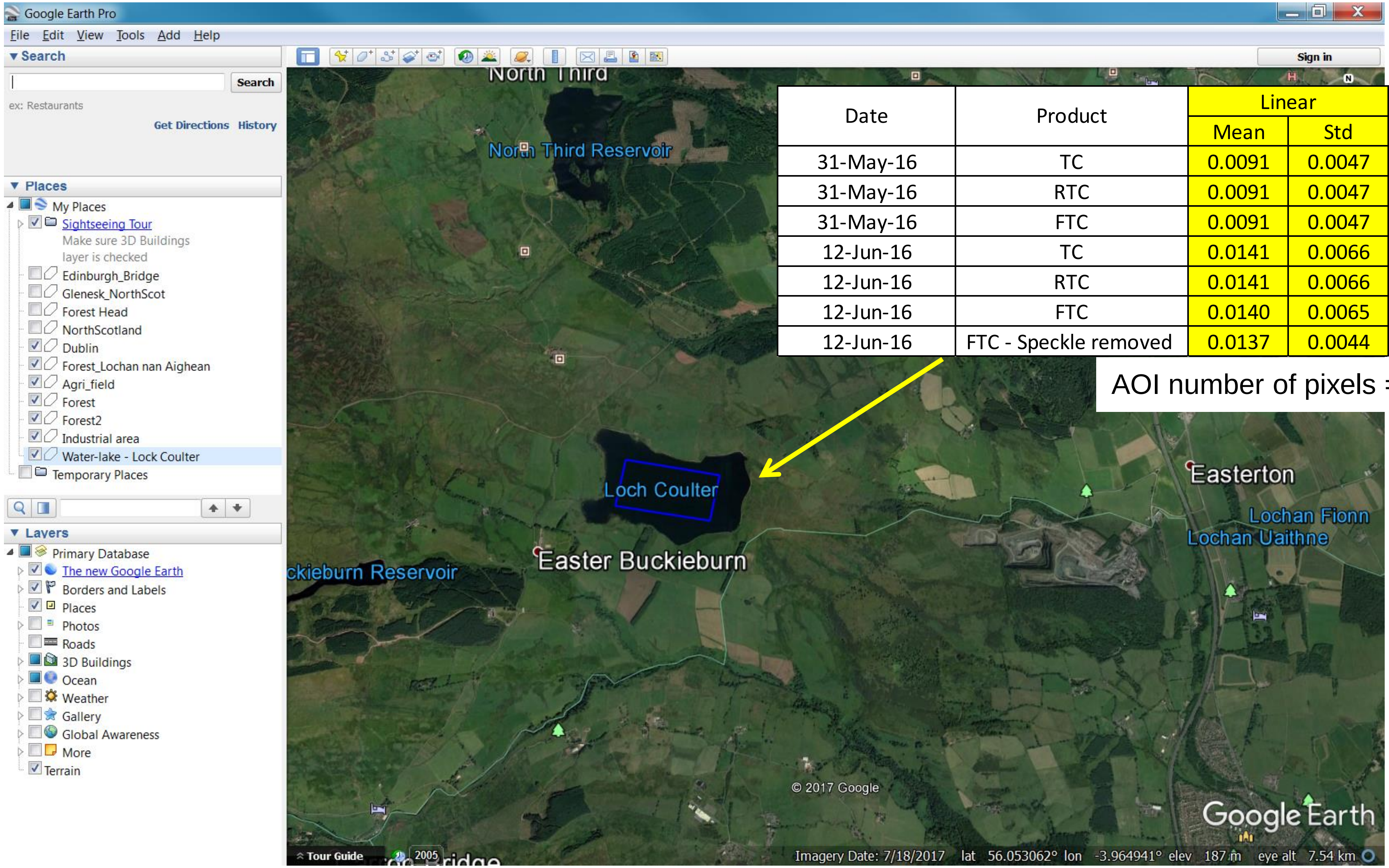
Statistics comparison Gamma-0 VV : Industrial Area @ Pelstream Burn



Date	Product	Linear		dB	
		Mean	Std	Mean	Std
31-May-16	TC	0.7490	0.8981	-1.255	3.422
31-May-16	RTC	0.7452	0.8995	-1.277	3.438
31-May-16	FTC	0.7319	0.8707	-1.355	3.404
12-Jun-16	TC	0.9422	1.2443	-0.259	3.656
12-Jun-16	RTC	0.9353	1.2364	-0.290	3.658
12-Jun-16	FTC	0.9248	1.2184	-0.340	3.650
12-Jun-16	FTC - Speckle removed	0.8245	0.9240	-0.838	3.265

AOI number of pixels = 458

Statistics comparison Gamma-0 VV: Water lake @ Loch Coulter



Date	Product	Linear		dB	
		Mean	Std	Mean	Std
31-May-16	TC	0.0091	0.0047	-20.410	1.808
31-May-16	RTC	0.0091	0.0047	-20.410	1.808
31-May-16	FTC	0.0091	0.0047	-20.410	1.808
12-Jun-16	TC	0.0141	0.0066	-18.508	1.668
12-Jun-16	RTC	0.0141	0.0066	-18.508	1.668
12-Jun-16	FTC	0.0140	0.0065	-18.539	1.656
12-Jun-16	FTC - Speckle removed	0.0137	0.0044	-18.633	1.210

AOI number of pixels = 2725

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Analysis

- Impact on results by operator that use DEM: result with and without concatenation are different for Terrain corrected product (TC, RTC, FLT)
- Resampling Method used for the DEM is bilinear. However it could be changed by using its positional parameter
- FTC product does not have portions of the image where the DEM contains no data. This is due the flattening operator that masks out the part of the image where the DEM has no data.
- When a different CRS respect to the one of the DEM is used then an error in the horizontal positional accuracy is introduced.

  → Recommendation: It is advised to preserve the CRS of the DEM as output CRS of produced output
- RTC product: in the sea area can present artefact where the DEM is absent and replaced with 0 by SNAP

  → Recommendation DEM APGB to be extended for covering as well part of the sea to avoid possible presence of artifacts

Technical challenges overcome/anticipated

- Provided APGB DEM geotiff format not accepted in SNAP → solution: opened into Qgis and saved again in geotiff with size up to 48GB.
- size of produced outputs