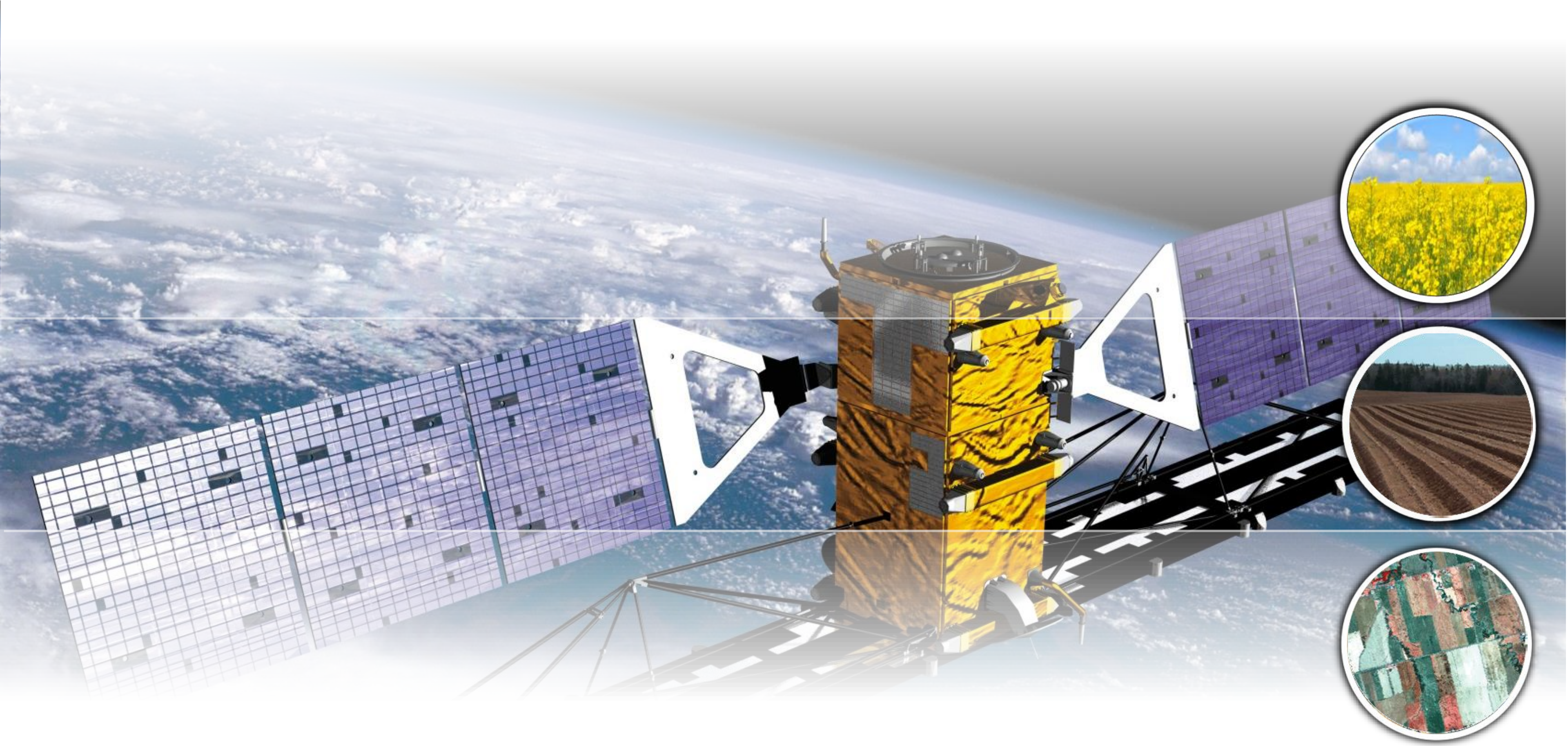


Lecture 7A:
SAR Preprocessing - Sentinel-1

Carleton University
Canada's Capital University

Natural Resources Canada | Ressources naturelles Canada

CSA ASC

Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada

Sentinel-1

Coverage:

- Sentinel-1 consists of two satellites: A (2014) and B (2016).
- Each sentinel-1 satellite has a 12 day repeat cycle.
- The two-satellites offer a 6 day exact repeat cycle at the equator in the interferometric Wide swath mode

of Acquisition:

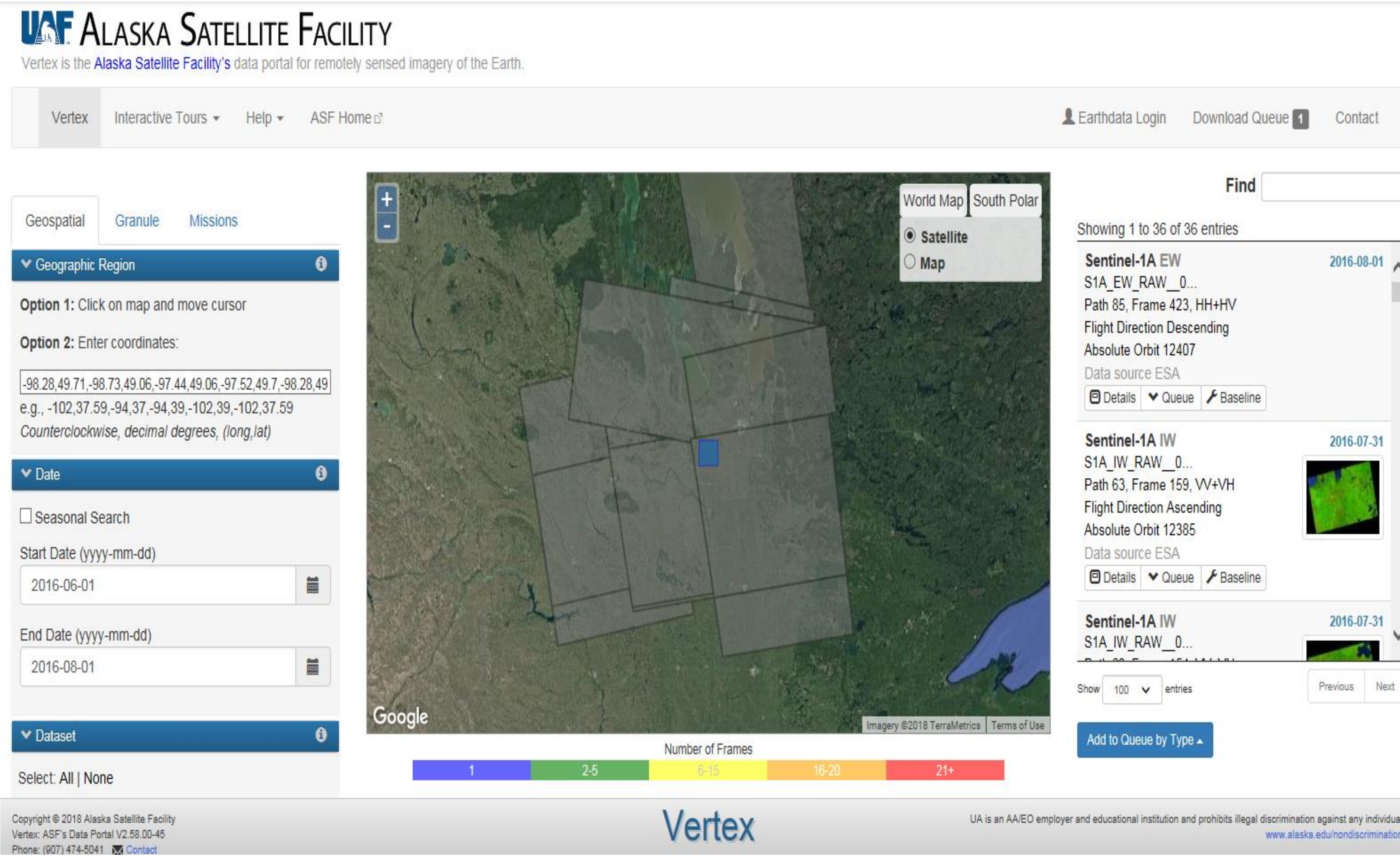
Extra Wide Swath (EW)	Interferometric Wide Swath (IW)	Stripmap (SM)	Wave (WV)
Acquired with TOPSAR using 5 sub-swaths instead of 3, resulting in lower resolution (20m-x-40m). Intended for maritime, ice, and polar-zone services requiring wide coverage and short revisit times.	Acquired with TOPSAR. Default mode over land; 250km swath width; 5m-x-20m ground resolution.	Used in rare circumstances to support emergency-management services, 5m-x-5m resolution over an 80km swath width.	Default mode over oceans; VV polarization. Data acquired in 20km-x-20km vignettes, 5m-x-20m resolution, every 100km along the orbit.

Image source:
ttps://www.esa.int/spacei
nimages/Images/2014/02/
Sentinel-1

Produce type for IW mode:

Acq. Mode	Product Type	Resolution Class	Resolution [1,2,3] [Rng x Azi] [m]	No. Looks [Rng x Azi]
IW	SLC		2.7 x 22 to 3.5 x 22	1
	GRD	HR	20 x 22	5 x 1
		MR	88 x 87	22 x 5

Download Sentinel-1 Data



Naming Convention for Images Downloaded from ASF

UAF ALASKA SATELLITE FACILITY
Making remote-sensing data accessible since 1991

Mission
S1A or S1B

Beam mode
IW (Interferometric Wide)
EW (Extra Wide)
S1 to S6 (Stripmap)
WV (Wave)

Resolution class
F (Full resolution)
M (Medium resolution)
H (High resolution)

Start date and time
YYYYMMDD - year, month, day
HHMMSS - hour, minutes, seconds

Absolute orbit number

Mission Data Take ID

MMM_BB_TTTR_LFPP_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS_OOOOOO_DDDDDD_CCCC

Product type
RAW
SLC (Single Look Complex)
GRD (Ground Range Detected)
OCN (Ocean)

Processing level
0, 1 or 2

Product class
S (SAR standard)
A (Annotation)

Polarization
SH (Single HH)
SV (Single VV)
DH (Dual HH/HV)
DV (Dual VV/VH)
HH (Partial dual, HH only)
HV (Partial dual, HV only)
VH (Partial dual, VH only)
VV (Partial dual, VV only)

Stop date and time
YYYYMMDD - year, month, day
HHMMSS - hour, minutes, seconds

Product Unique Identifier

S1A_IW_GRDH_1SDV_20160731T001533_20160731T001558_012385_0134FE_1CFC.zip

The Sample Data

Dataset:
S1A_IW_GRDH_1SDV_20160731T001533_20160731T001558_012385_0134FE_1CFC.zip

- **Acquisition date:** July 31, 2016
- **Acquisition mode:** Interferometric wide (IW)
- **Product type:** ground range detected (GRD)
- **Polarisation:** VH+ VV(DV)
- Level-1 Ground Range Detected (GRD) product is multi-looked and projected to ground range
- Phase information is lost

Why Pre-process Data?

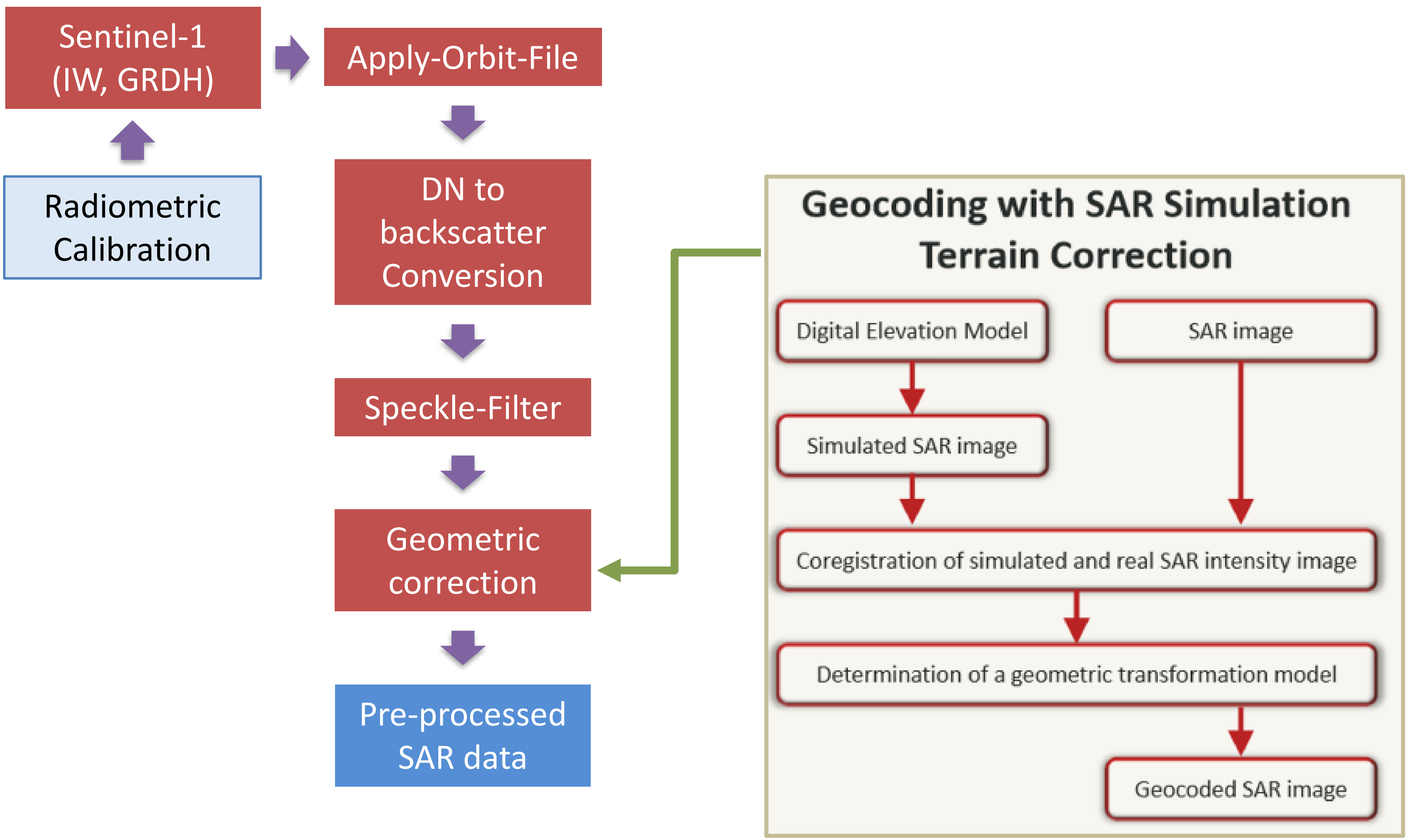
The aim of pre-processing is an improvement of the image data that suppresses unwanted noise, distortions and enhances some image features important for further applications.

Access
- Data discovery
- Data download

Pre-Process
- Speckle Noise reduction
- Geometric correction
- Image enhancement

Exploit
- Classification
- Change detection
- Estimate bio- and geophysical parameters

The Order of Pre-processing



Radiometric Calibration

Purpose:

- **Relative calibration** corrects for known variations in radar antenna and system responses to ensure uniform, repeatable measurements over time.
- **Absolute calibration** considers many factors: transmitted power levels, system biases and the absolute gain of the antenna and receiver.
- It is necessary for the comparison of SAR images acquired with different sensors, or acquired from the same sensor at different times.

Radiometric Calibration

For all Sentinel level -1 products, the following corrections are applied by default by the Instrument Processing Facility:

- Raw signal I and Q channel bias correction
- Transmitted power and receiver (instrument) gain and offset corrections
- Antenna elevation beam pattern correction
- Antenna azimuth beam pattern correction
- Range spreading loss compensation
- Inter-channel (phase and gain) correction
- Thermal noise removal.

Don’t worry!

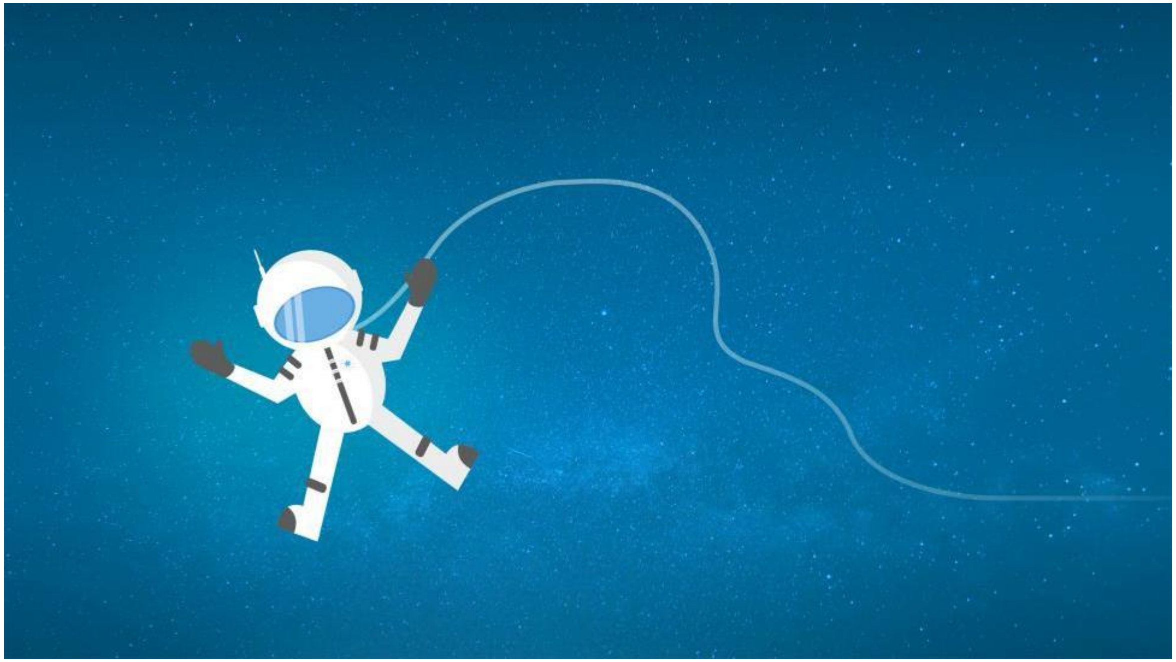
Where Are We?

No matter how fine-tuned a satellite's orbit may be, the precision location of the satellite will drift over time

- atmospheric drag and solar winds
- Earth's imperfect sphere, leading to non-uniform gravitational field
- other massive objects in the solar system perturb their orbits with their gravity

Because of this drift, periodic adjustments are needed, usually by applying tiny rocket bursts

As such it is imperative to have the most up-to-date orbital files, that tell us "where's the satellite"



Apply the Precise Orbit File

- For Sentinel-1:
  - During the acquisition the satellite position is recorded by a Global Navigation Satellite System (GNSS)
  - To assure a fast delivery of Sentinel-1 products orbit information generated by an on-board navigation solution are stored within the Sentinel-1 Level-1 products
  - The orbit positions are later refined by the Copernicus Precise Orbit Determination (POD) Service
  - Precise orbit files have less than 5 cm accuracy and are delivered within **20 days** after data acquisitions
  - The accuracy of restituted orbit files is less than 10 cm. The files are in **3 hours** after data acquisitions
  - The orbit information of Sentinel 1 can be downloaded from ESA website (https://qc.sentinel1.eo.esa.int/)

SNAP downloads orbit files and stores these into the folder …/auxdata/Orbits/Sentinel-1/

https://www.asf.alaska.edu/sentinel/data/

Converting Digital Numbers (DNs) to Backscatter

- SAR digital numbers (DNs) stored within SAR image products need to be converted to radar backscatter (σ^o).
- The conversion is mission-specific.
- Understand what conversion is needed for the products in hand
- The Look Up Tables (LUTs) provided within the Sentinel-1 Level-1 products can be used for this conversion.
- SNAP will automatically determine what kind of input product you have and what conversion needs to be applied based on the product’s metadata

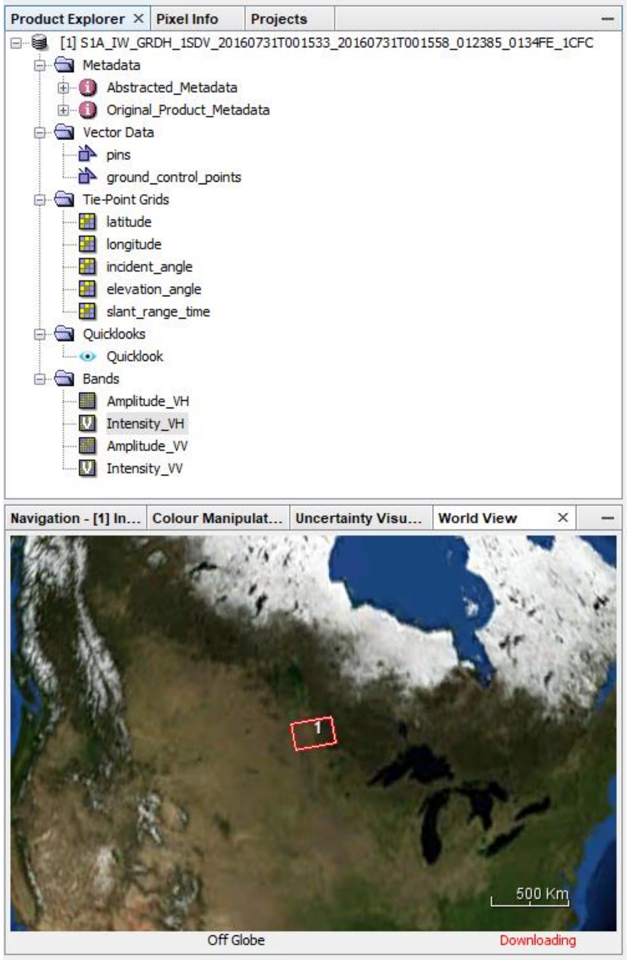
Break for Hands-On Exercise

Open, display and calibrate an image with SNAP

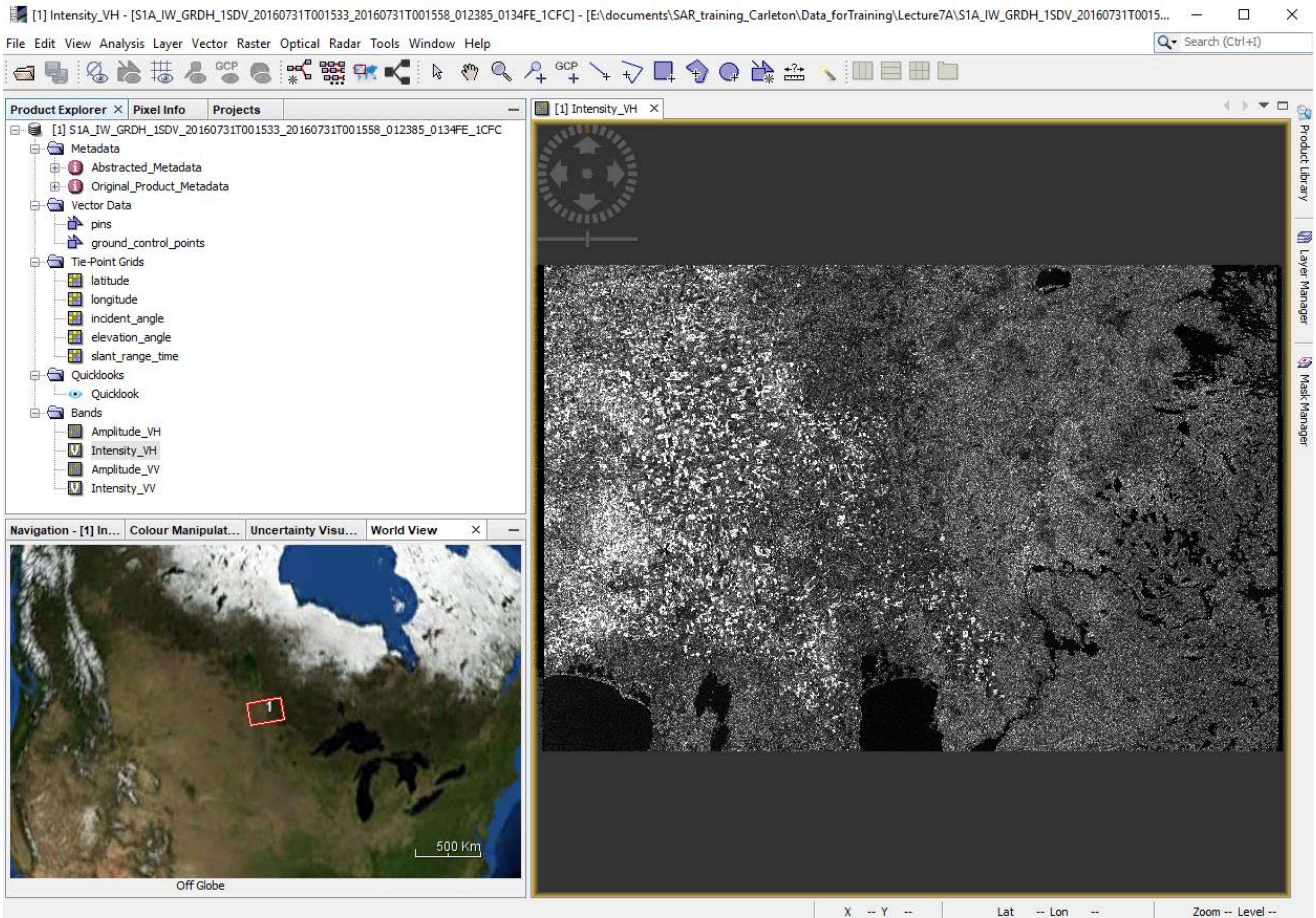
Image source: ttps://www.esa.int/spaceinimages/Images/2014/02/Sentinel-1

Open and Display the Image

1. Initiate the SNAP tool
2. In the SNAP interface, go to File menu >> open product
3. Select the folder that contains the Sentinel-1 data
4. click on the .zip file (S1A_IW_GRDH_1SDV_20160731T001533_20160731T001558_012385_0134FE_1CFC.zip)
5. open the image
6. Double click the file name to view the directories within the file, including:
   - Metadata: parameters related to the orbit and data
   - Tie Point Grids: interpolation of latitude/longitude, incidence angle, etc
   - Bands: two bands for each polarization (intensity and amplitude)
7. The Worldview window (in the lower, left-hand side) shows the coverage of the image opened
8. Double click *Intersity_VH*

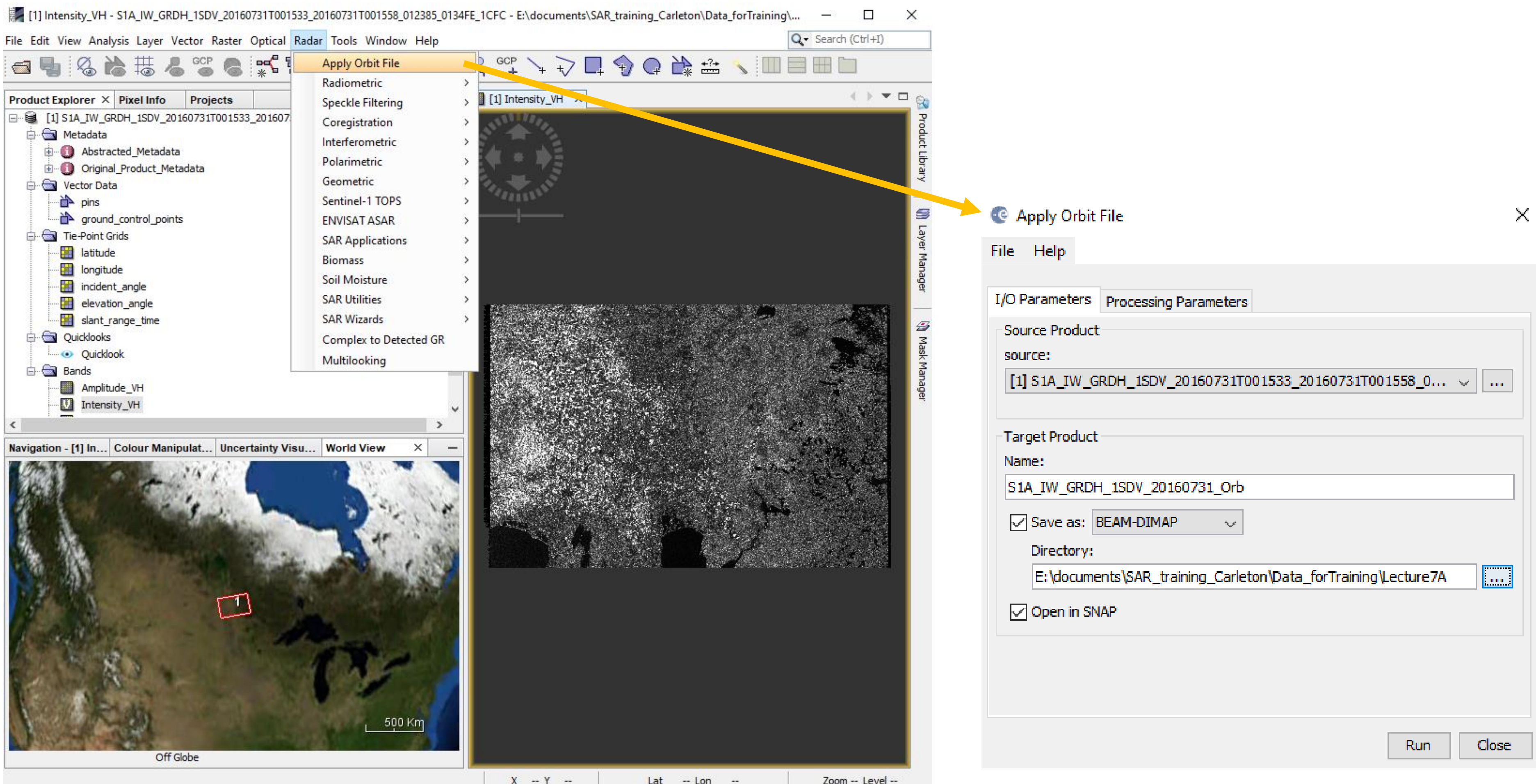


Open and Display the Image



Apply the Precise Orbit File

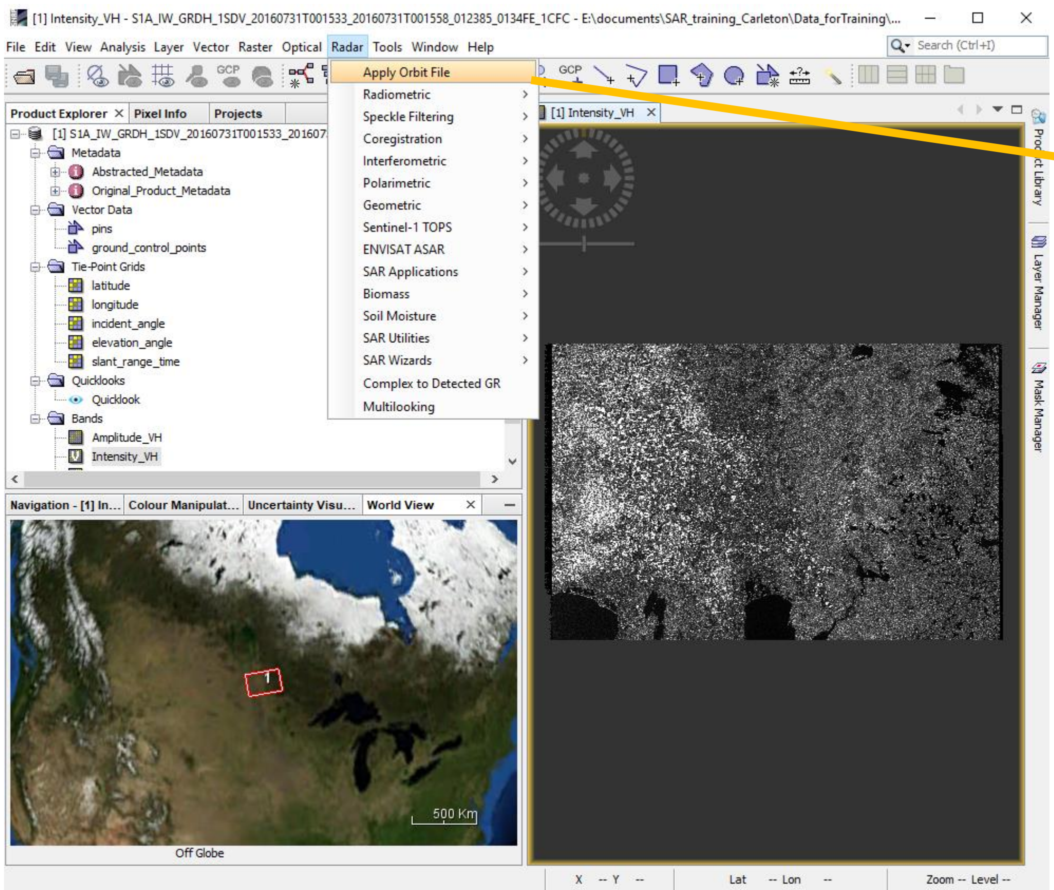
1) Go to Radar menu >> Apply Orbit File
2) In the Apply Orbit File window:
   - I/O Parameters tab:
   - source : *opened product* ; target product : output file: *S1A_IW_GRDH_1SDV_20160731_Orb*

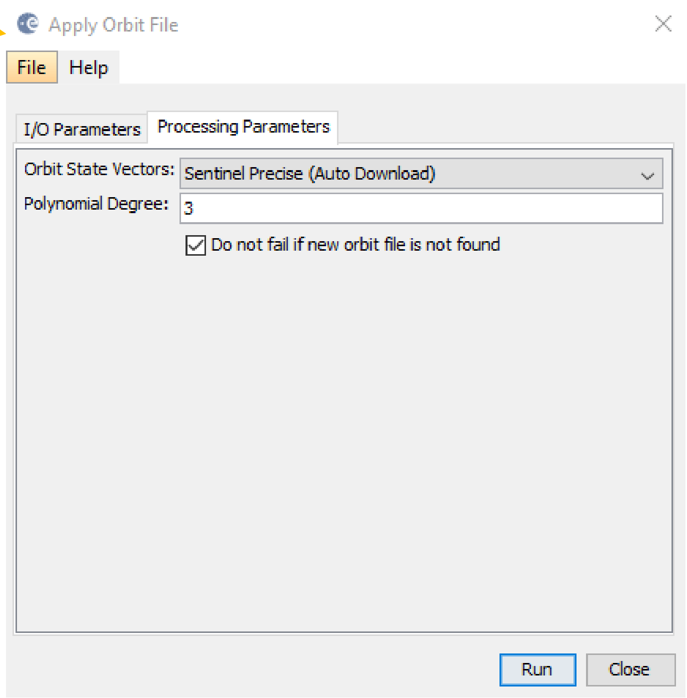


Apply the Precise Orbit File

- Processing Parameters tab:
  a) Orbit State Vectors: Sentinel Precise (Auto Download)
  b) Check "Do not fail if new orbit file is not found"

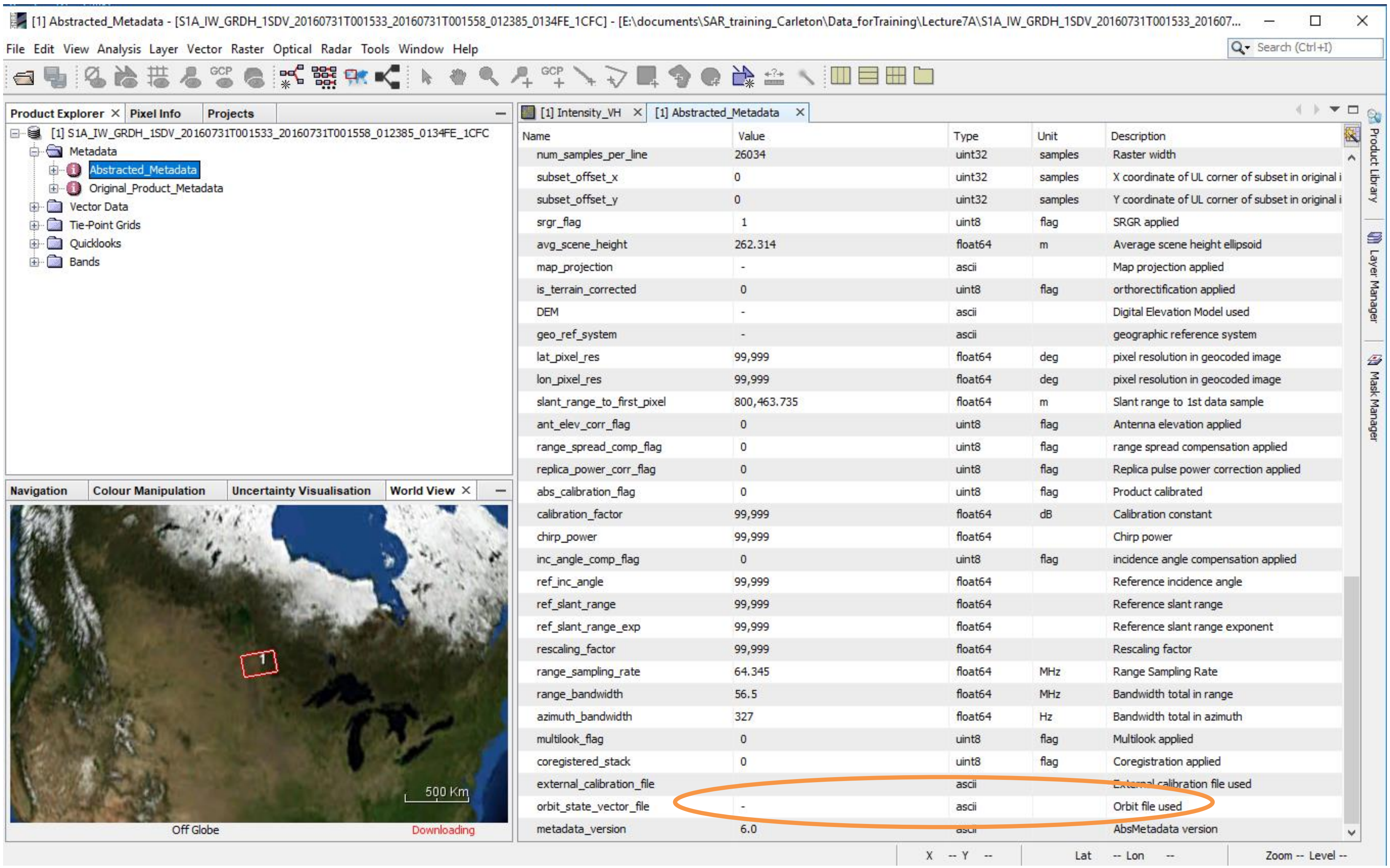
The Apply Orbit File tool creates a new image with the precise orbit ephemerides applied





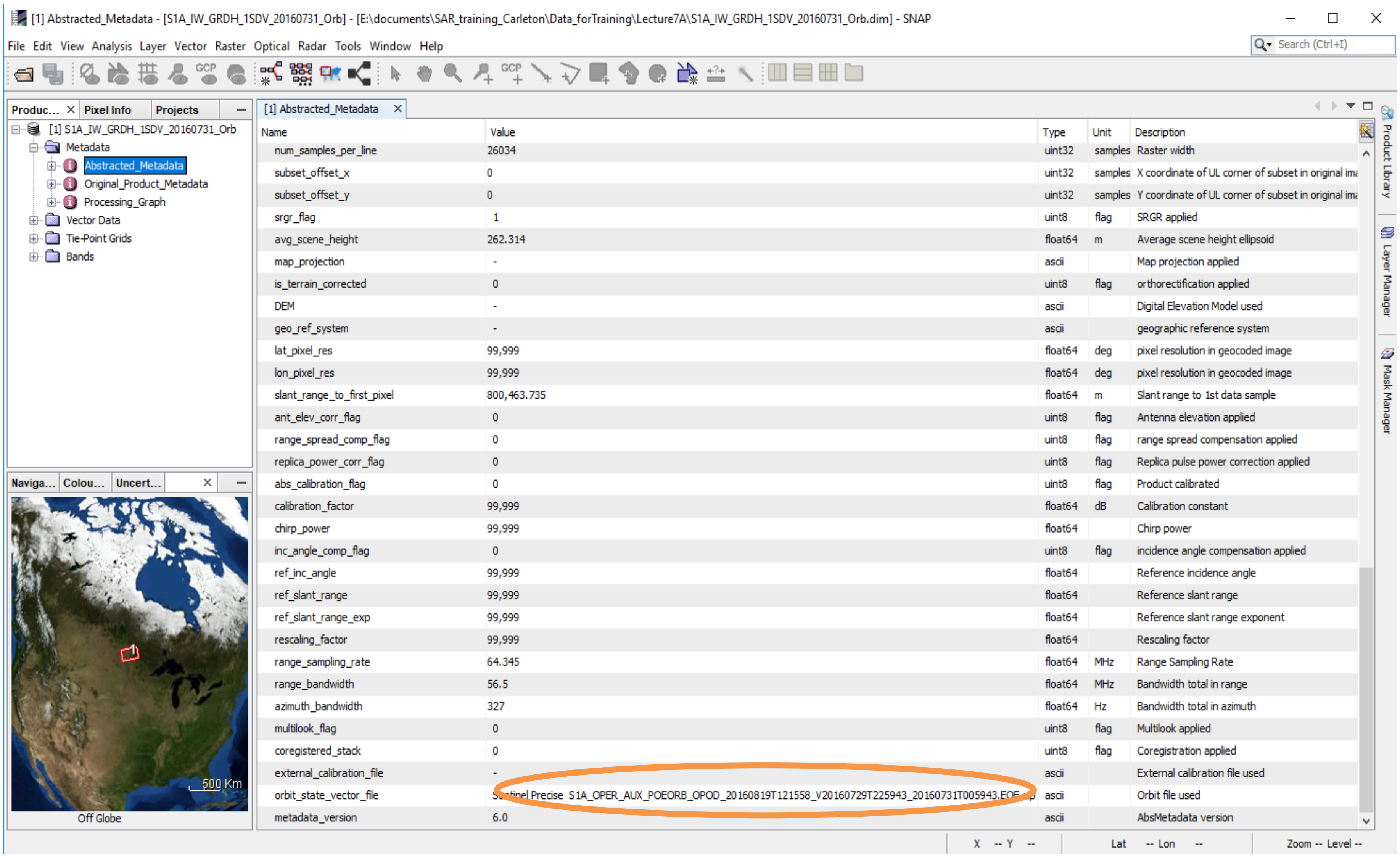
Apply the Precise Orbit File

The extracted metadata for the raw Sentinel -1 product



Apply the Precise Orbit File

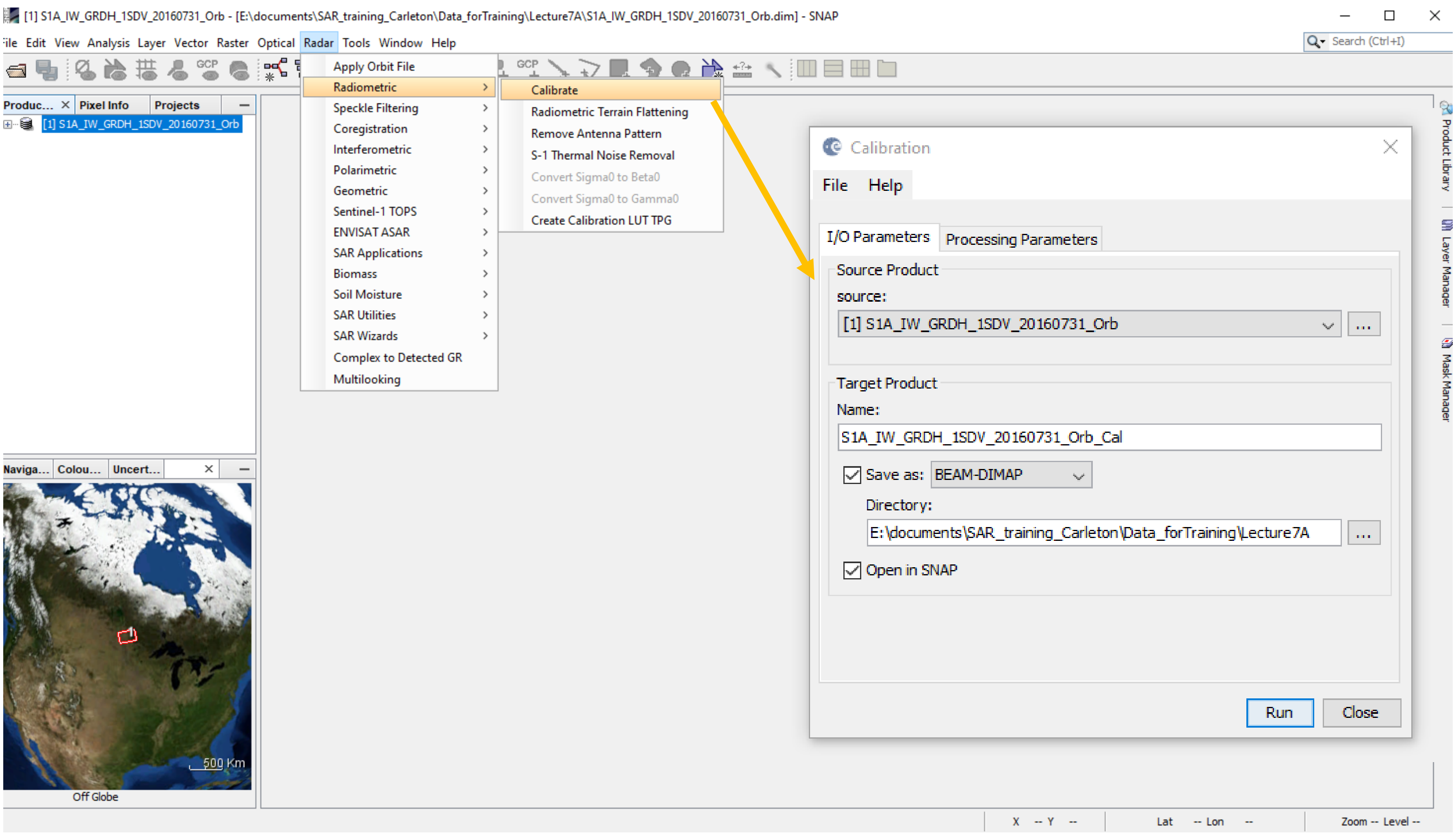
The extracted metadata for the raw Sentinel -1 product



Name	Value	Type	Unit	Description
num_samples_per_line	26034	uint32	samples	Raster width
subset_offset_x	0	uint32	samples	X coordinate of UL corner of subset in original ima
subset_offset_y	0	uint32	samples	Y coordinate of UL corner of subset in original ima
srgr_flag	1	uint8	flag	SRGR applied
avg_scene_height	262.314	float64	m	Average scene height ellipsoid
map_projection	-	ascii		Map projection applied
is_terrain_corrected	0	uint8	flag	orthorectification applied
DEM	-	ascii		Digital Elevation Model used
geo_ref_system	-	ascii		geographic reference system
lat_pixel_res	99,999	float64	deg	pixel resolution in geocoded image
lon_pixel_res	99,999	float64	deg	pixel resolution in geocoded image
slant_range_to_first_pixel	800,463.735	float64	m	Slant range to 1st data sample
ant_elev_corr_flag	0	uint8	flag	Antenna elevation applied
range_spread_comp_flag	0	uint8	flag	range spread compensation applied
replica_power_corr_flag	0	uint8	flag	Replica pulse power correction applied
abs_calibration_flag	0	uint8	flag	Product calibrated
calibration_factor	99,999	float64	dB	Calibration constant
chirp_power	99,999	float64		Chirp power
inc_angle_comp_flag	0	uint8	flag	incidence angle compensation applied
ref_inc_angle	99,999	float64		Reference incidence angle
ref_slant_range	99,999	float64		Reference slant range
ref_slant_range_exp	99,999	float64		Reference slant range exponent
rescaling_factor	99,999	float64		Rescaling factor
range_sampling_rate	64.345	float64	MHz	Range Sampling Rate
range_bandwidth	56.5	float64	MHz	Bandwidth total in range
azimuth_bandwidth	327	float64	Hz	Bandwidth total in azimuth
multilook_flag	0	uint8	flag	Multilook applied
coregistered_stack	0	uint8	flag	Coregistration applied
external_calibration_file	-	ascii		External calibration file used
orbit_state_vector_file	Sentinel Precise S1A_OPER_AUX_POEORB_OPOD_20160819T121558_V20160729T225943_20160731T005943.EOF	ascii		Orbit file used
metadata_version	6.0	ascii		AbsMetadata version

Convert Digital Number to Radar Backscatter

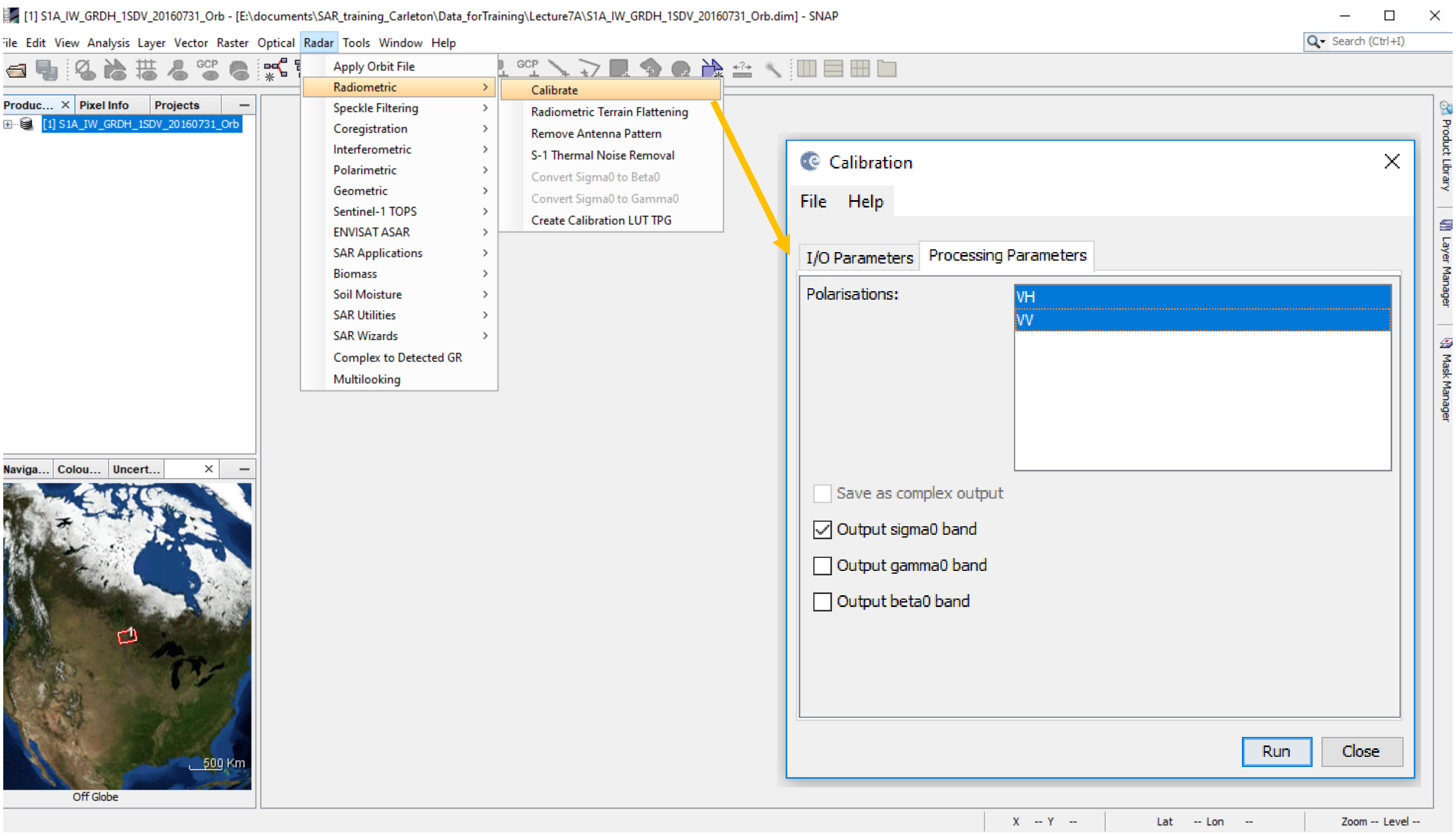
1) Go to Radar menu >> Radiometric >> Calibrate
2) In the Calibration window:
   - I/O Parameters tab: source : *S1A_IW_GRDH_1SDV_20160731_Orb*
     target product : *S1A_IW_GRDH_1SDV_20160731_Orb_Cal*



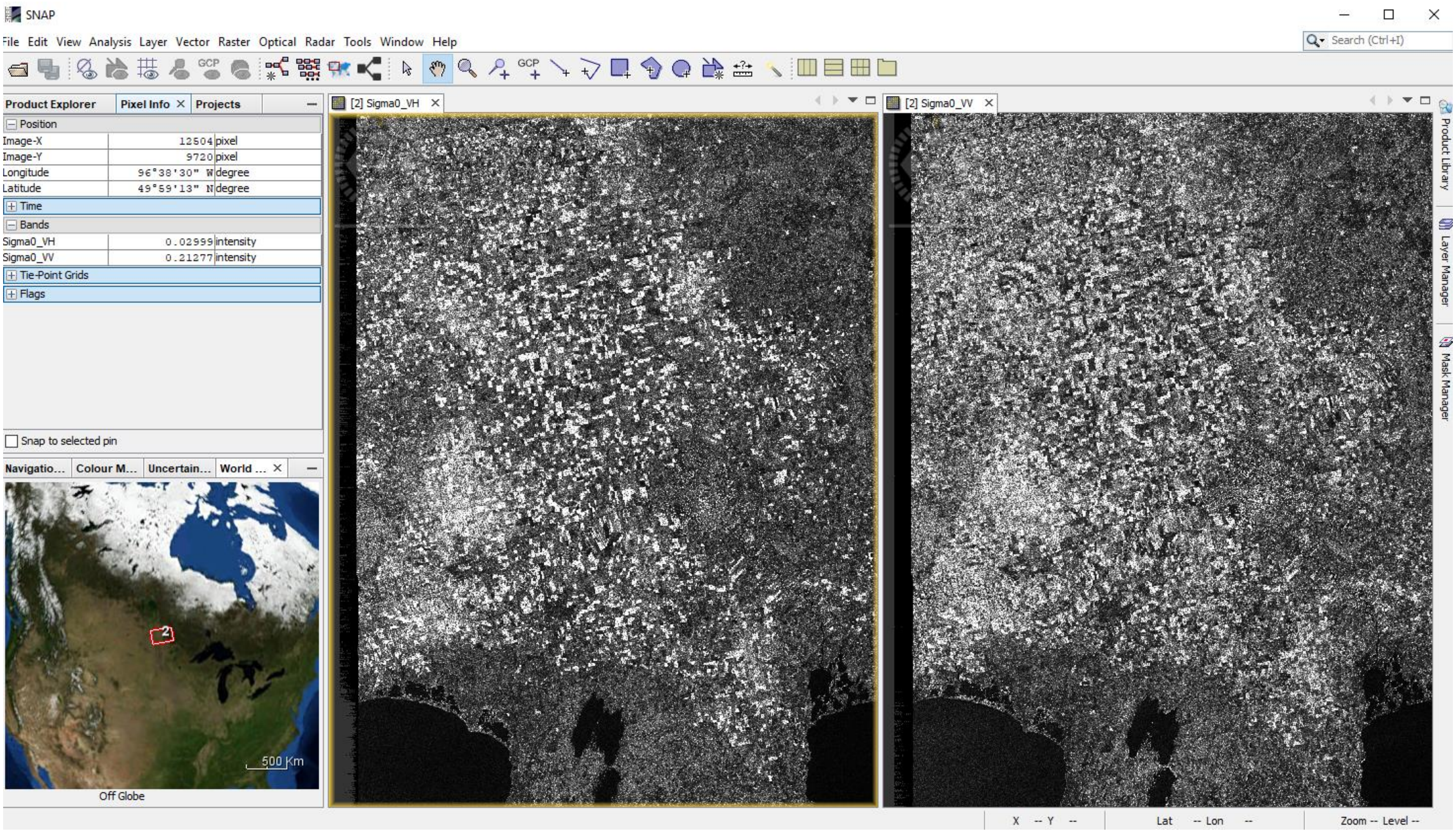
Convert Digital Number to Radar Backscatter

- Processing Parameters tab: Polarizations :
  - *select HV and VV; check Output sigma0 band*

The resulting output file should be shown in the Product Explorer panel

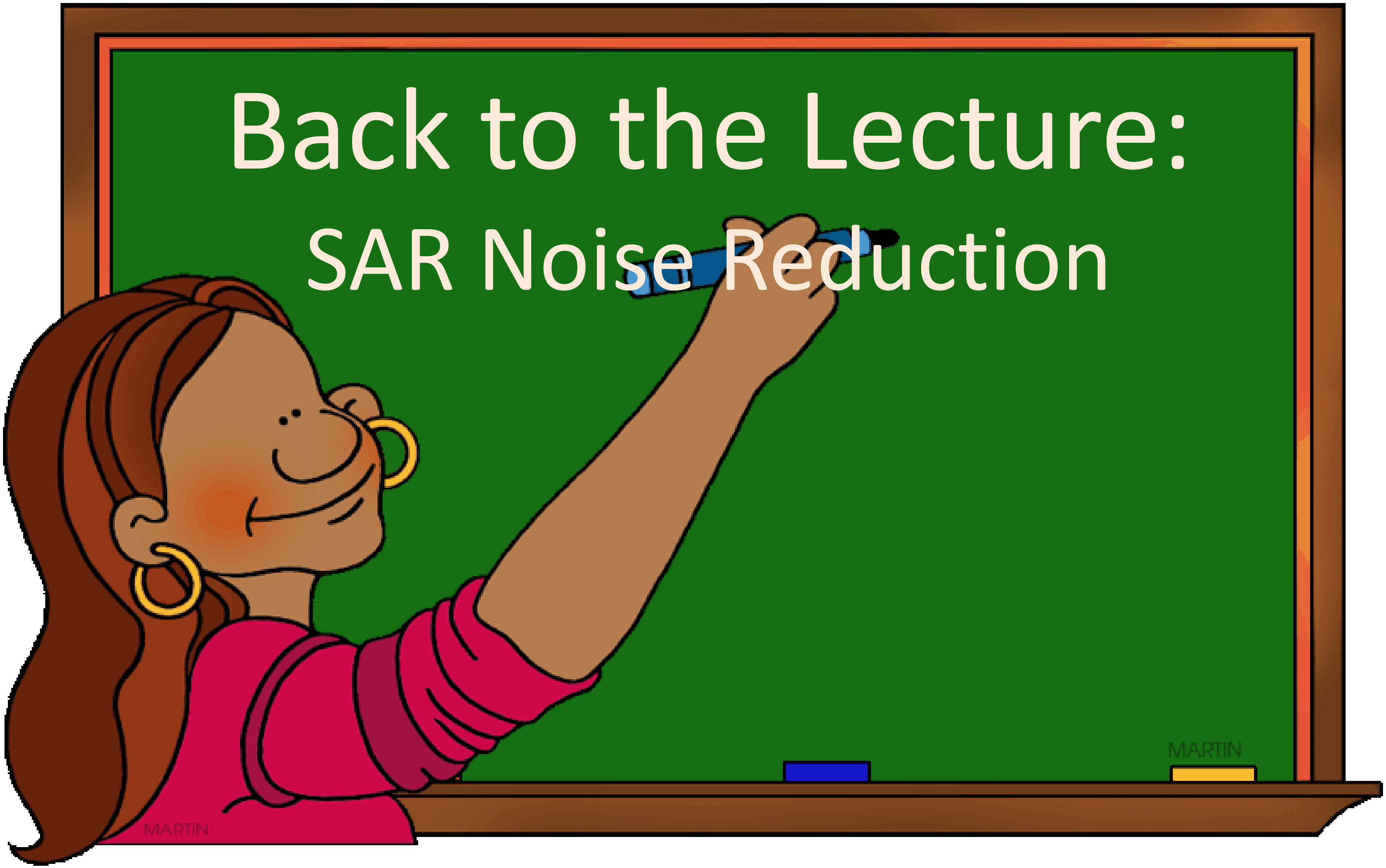


Convert Digital Number to Radar Backscatter



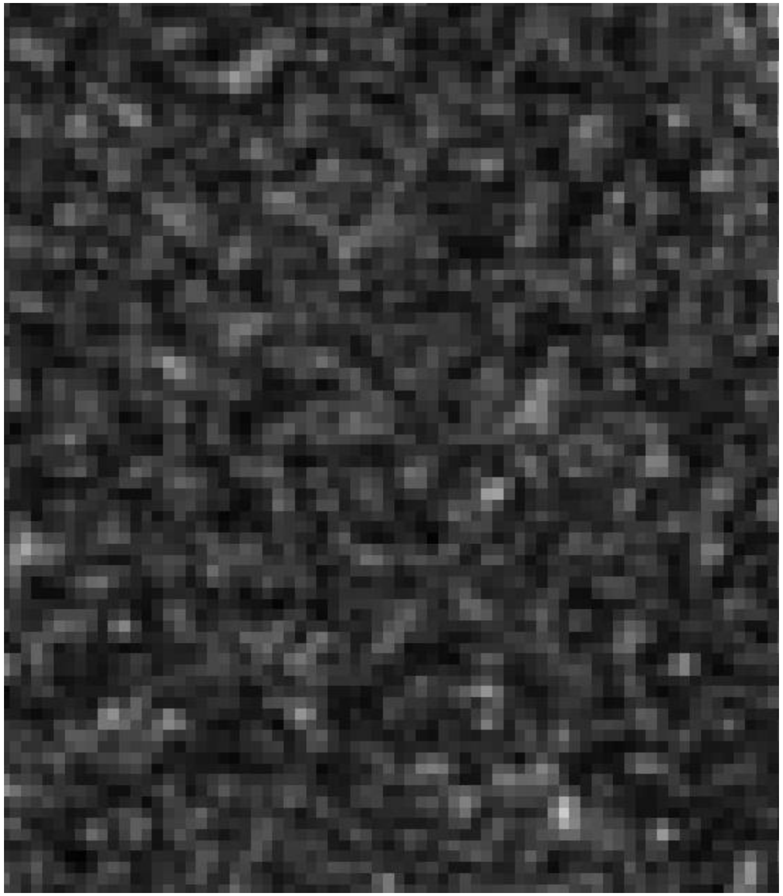
Back to the Lecture:

SAR Noise Reduction



What is Speckle?

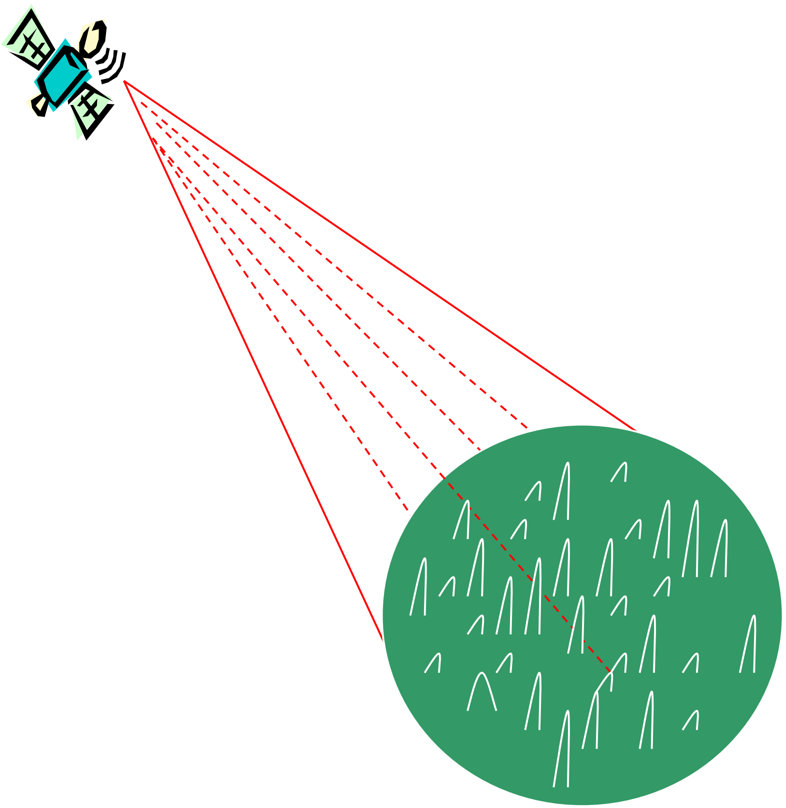
- Consider waves incident on a target of identical but randomly placed scatterers (for example, blades of grass)
- Each individual scatterer (blade of grass) within a resolution cell (“pixel”) will return a vector of constant amplitude BUT arbitrary phase



Speckle Phenomenon

Speckle Phenomenon

- The radar adds these responses coherently (amplitude and phase) to a single vector (vector sum)
- Constructive or destructive interference among the backscatter waves of individual blades of grass within one resolution cell creates speckle



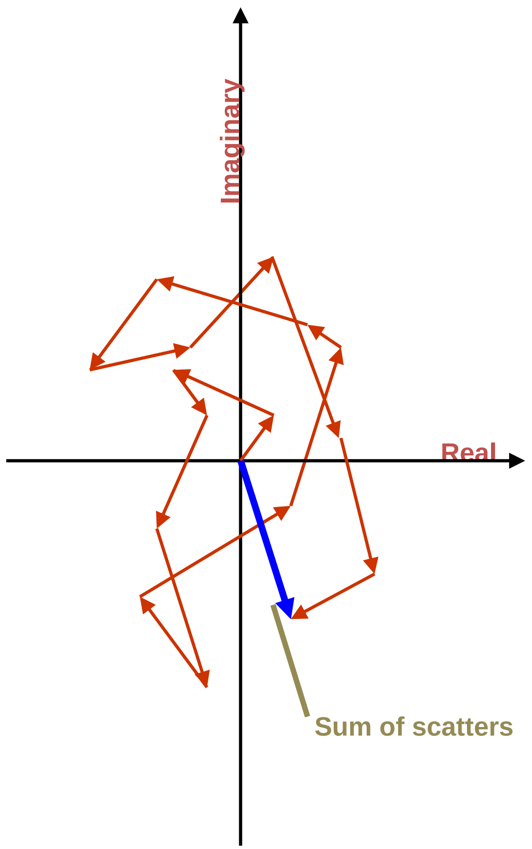
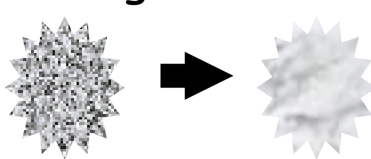


Image source: Goodman, 1976.

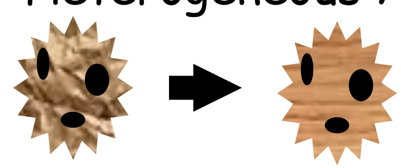
Speckle Filtering

Speckle Filtering

Homogeneous Area



Heterogeneous Area



Speckle Reduction
(Radiometric Resolution)

Details Preservation
(Spatial Resolution)

Speckle Filtering

Speckle filtering is not an exact science subjective → image dependent

Therefore, an ideal speckle filter must satisfy to the following specifications:

- Speckle Reduction
- Edge Sharpness Preservation
- Line and Point Target Contrast Preservation
- Retention of Mean Values in Homogeneous Regions
- Retention of Texture Information

Information source: Quantitative Criteria (J.S. Lee - IGARSS 98)

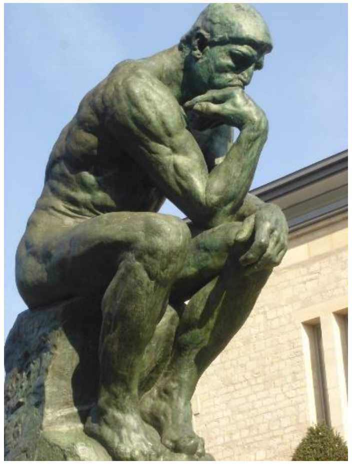


Image source: https://commons.wikimedia.org/wiki/File:ThinkingMan_Rodin.jpg

What to do?

- Multi-look processing
- Image Filtering

Image source:
https://commons.wikimedia.org/wiki/File:Neutral_density_filter_demonstration.jpg

Multi-looking

- Multi-looking is usually applied for ground range images by the Instrument Processing Facility before releasing the products

Sentinel-1 Level-1 GRD products are multi-looking images

1 look in Azimuth and 5 looks in Range

- Users have the choice to apply multi-looking processing again in order to further reduce the speckle.

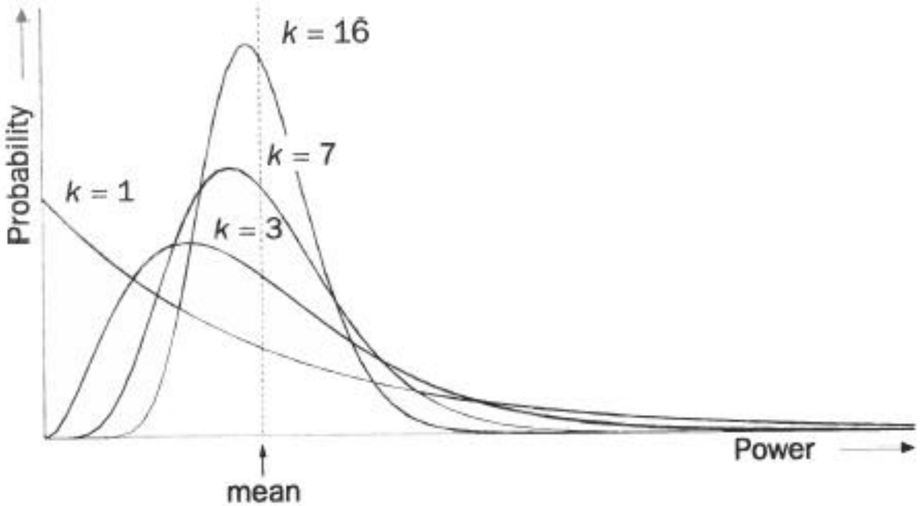
Multi-looking

Multi-looking processing for intensity images

- Averaging intensity (Not complex images) of neighboring pixels
- Good noise smoothing
- Spatial resolution loss - blurring edges - erasing thin lines
- Loss of linear or point features

Multi-looking

Impact of Multi-looking



Distribution of averaged power for 1, 3, 7 and 16 look radar images.

Image source:Van der Sanden, 1997

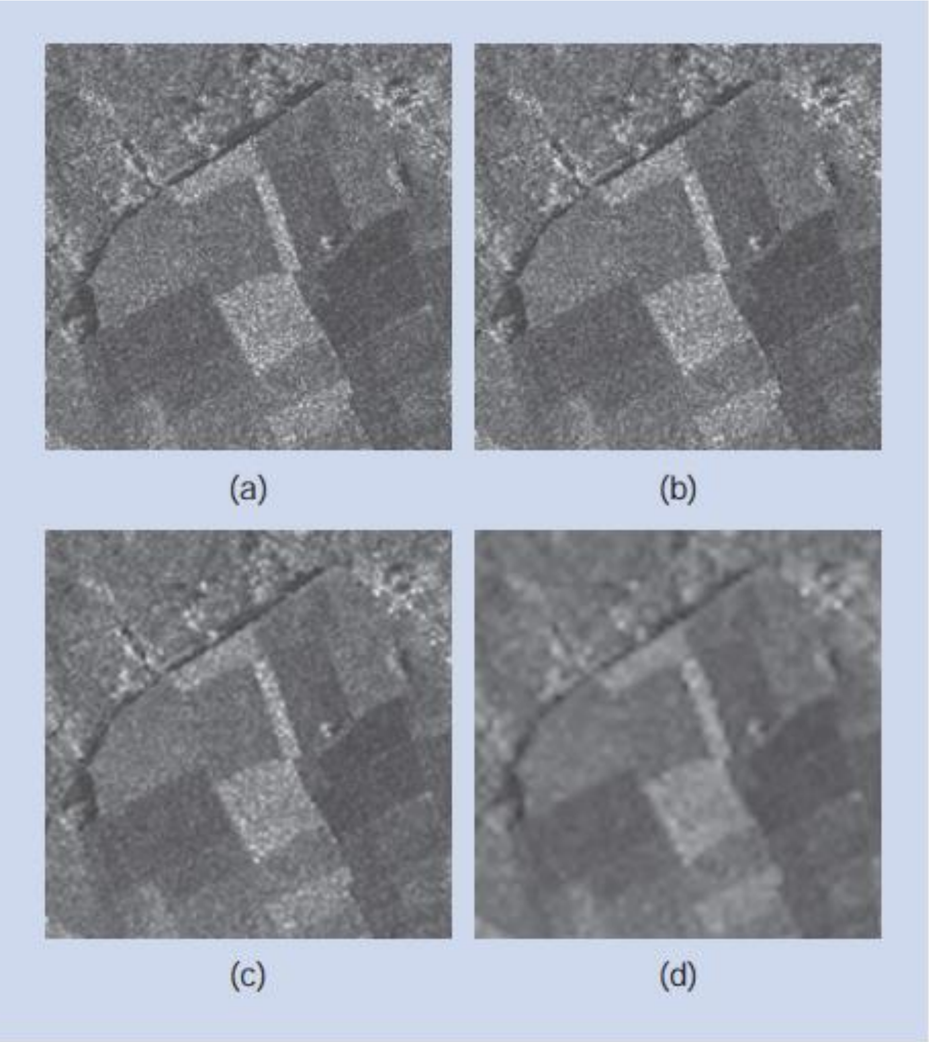


FIGURE 5. The effect of speckle can be reduced through multi-look in azimuth and range which also worsens the resolution as seen in the multi-looked SAR images above. (a) Without multi-look. (b) 2×2 multi-look. (c) 4×4 multi-look. (d) 8×8 multi-look.

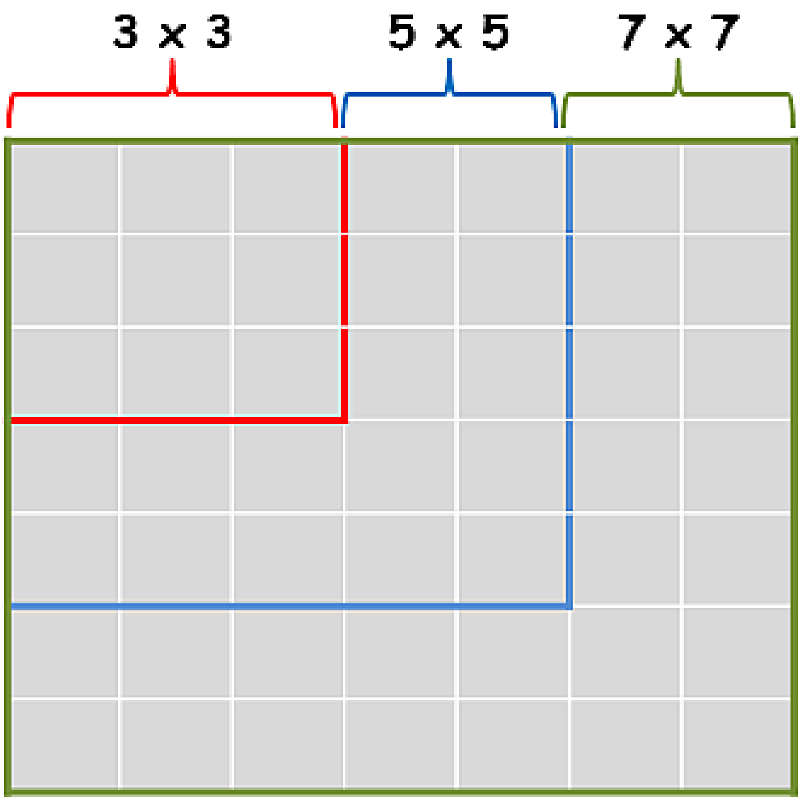
Image source: Moreira et al., 2013

Speckle Filtering

- Speckle filtering is therefore a compromise between speckle removal (radiometric resolution) and details preservation (spatial resolution)
- Good speckle removal requires the use of large processing windows
- On the contrary, good preservation of the image details like texture is needed

Age Old Question: What Filter Size?

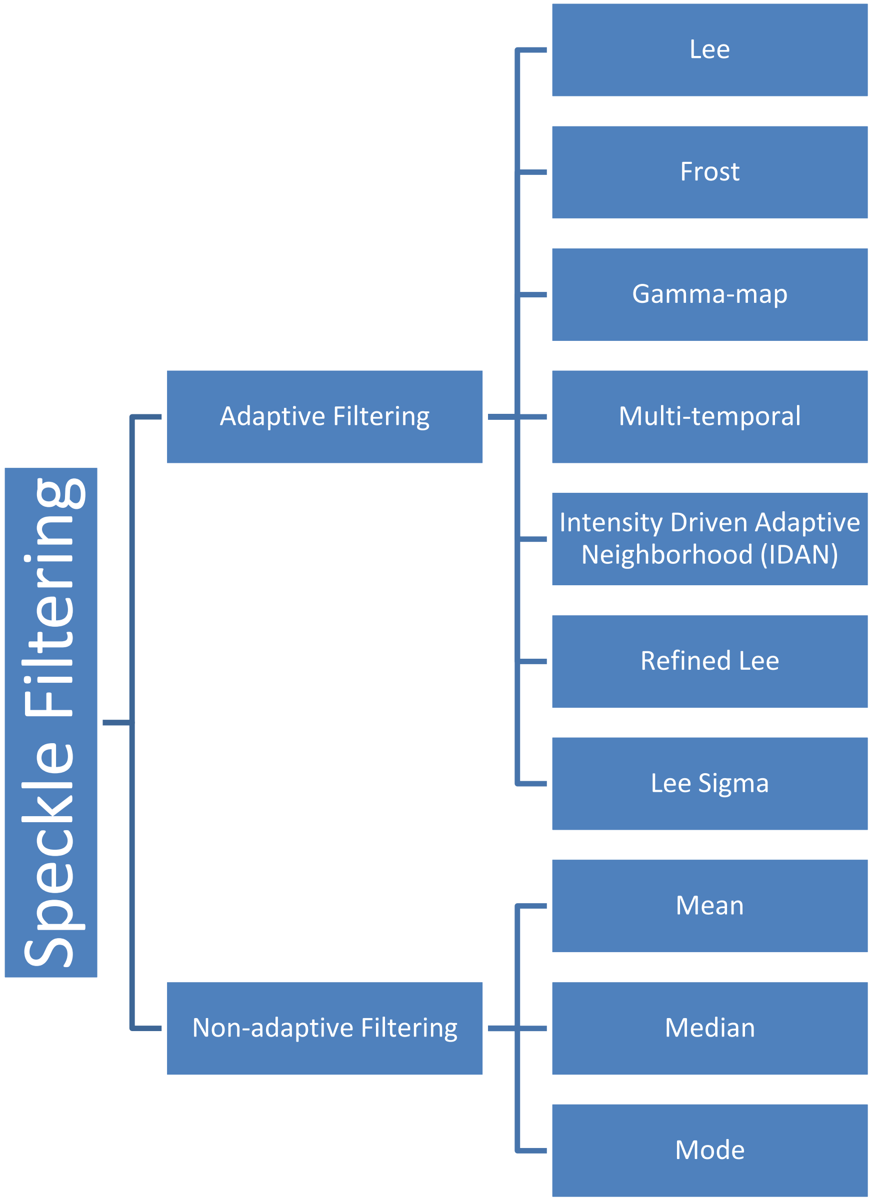
- There is **no** simple answer
- Choice depends on the targets (point target, distributed target) and the target size (for example field sizes)



What is the target?

Let the target dictate the filter size

Speckle Filtering



New methods are developing constantly

Non-Adaptive Filters

- Commonly used in remote sensing . . . **but** not for SAR processing
- Intensity of each sample in the image is replace by the mean/median/mode of pixel values in a moving window surrounding the sample

Mean

5	7	4
9	8	6
5	5	8

5+7+4+9+8+6+5+5+8 = 57
57/9 = 6.33

Mean = 6

Median

5	7	4
9	8	6
5	5	8

4,5,5,5,6,7,8,8,9

Median = 6

Mode

5	7	4
9	8	6
5	5	8

4
555
6
7
88
9

Mode = 5

Non-Adaptive Filters

Mean filter

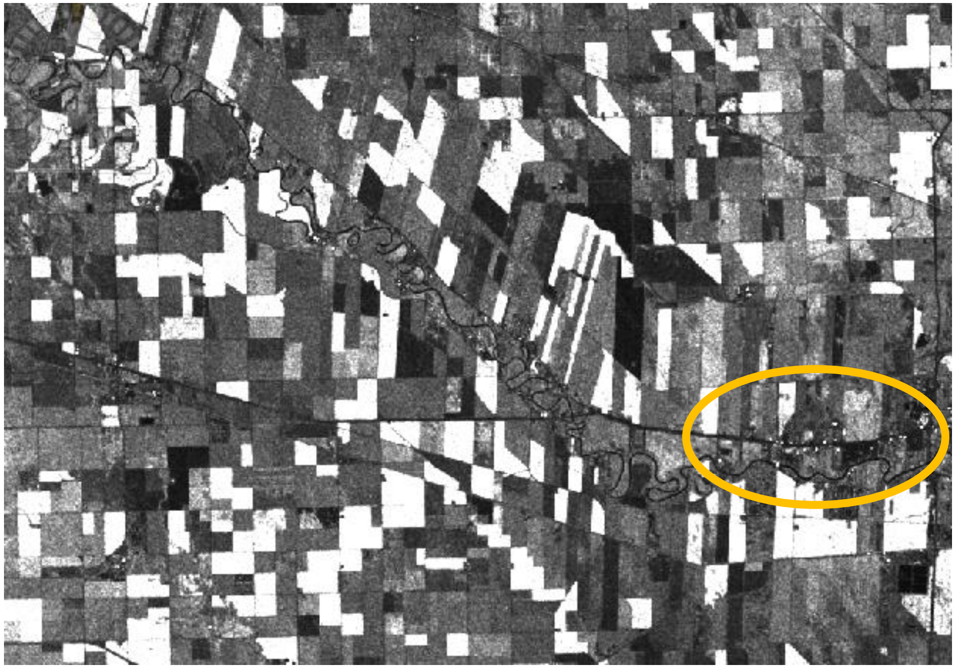
Mean filter: Not an optimal filter for SAR because dark and bright pixels within the filter window can cancel each other out. However, it produces image blur, loss of details and, eventually, loss of spatial resolution.

HV polarization multi-looked unfiltered image

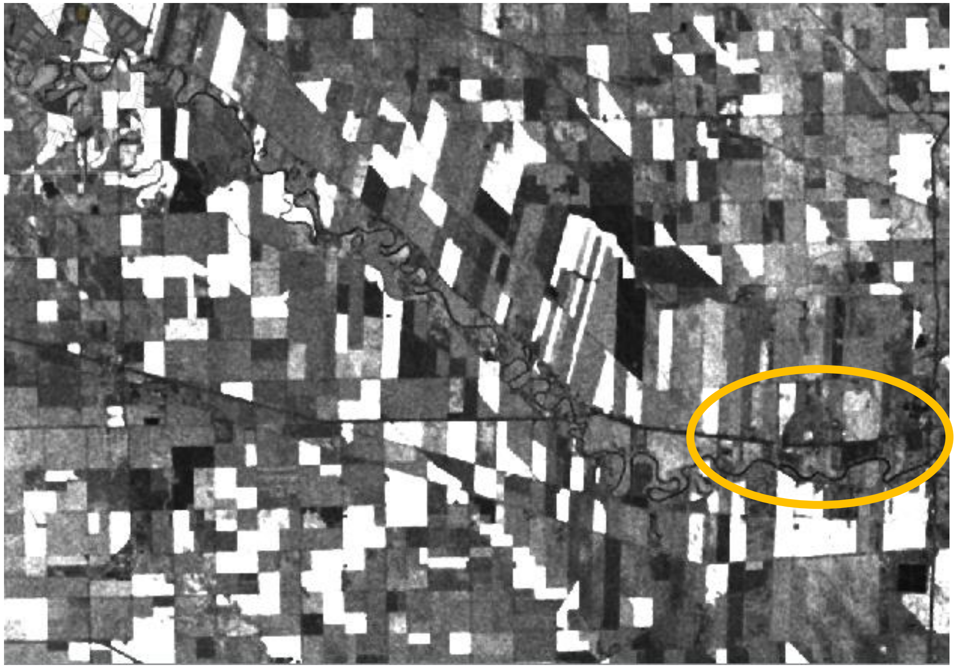
Mean filter (7 by 7 window size)

Non-Adaptive Filters

Median filter: This filter is useful for removing speckle when the noise is less than a half of the filter window. The median filter is edge preserving, although it may lead to the removing of small objects from the image.



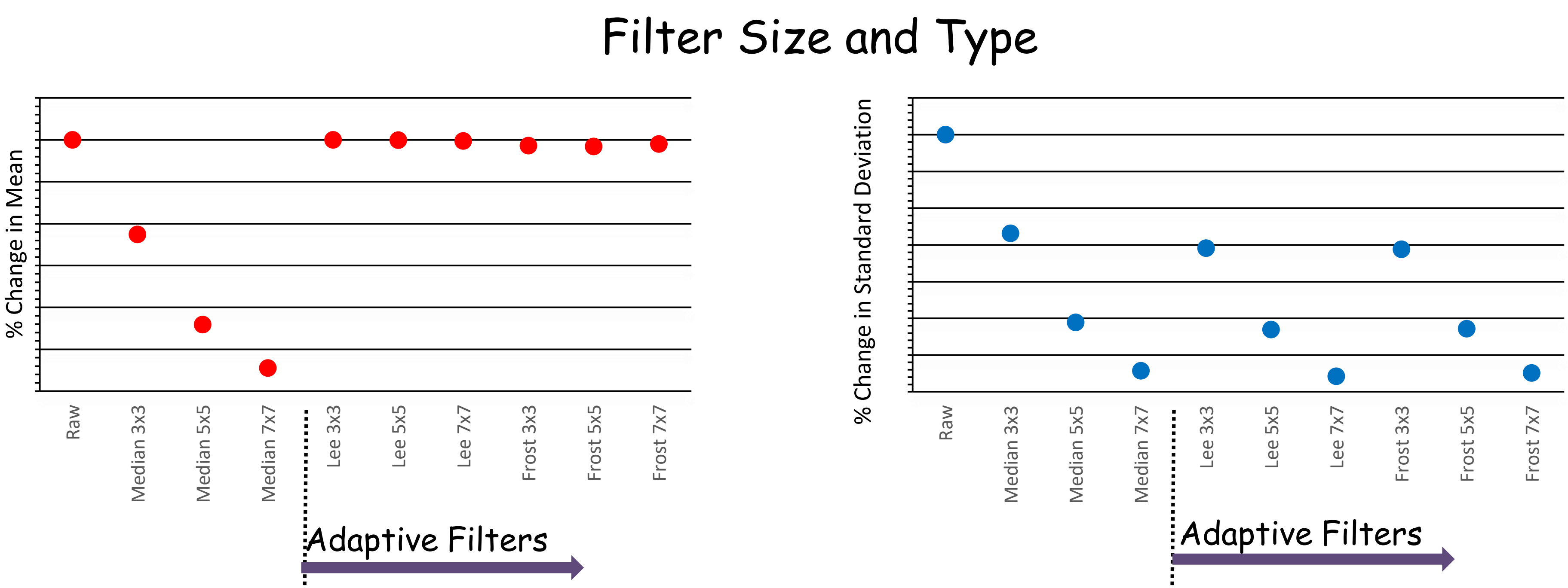
Mean filtered image



Median filter (7 by 7 window size)

Radar Adaptive Filters

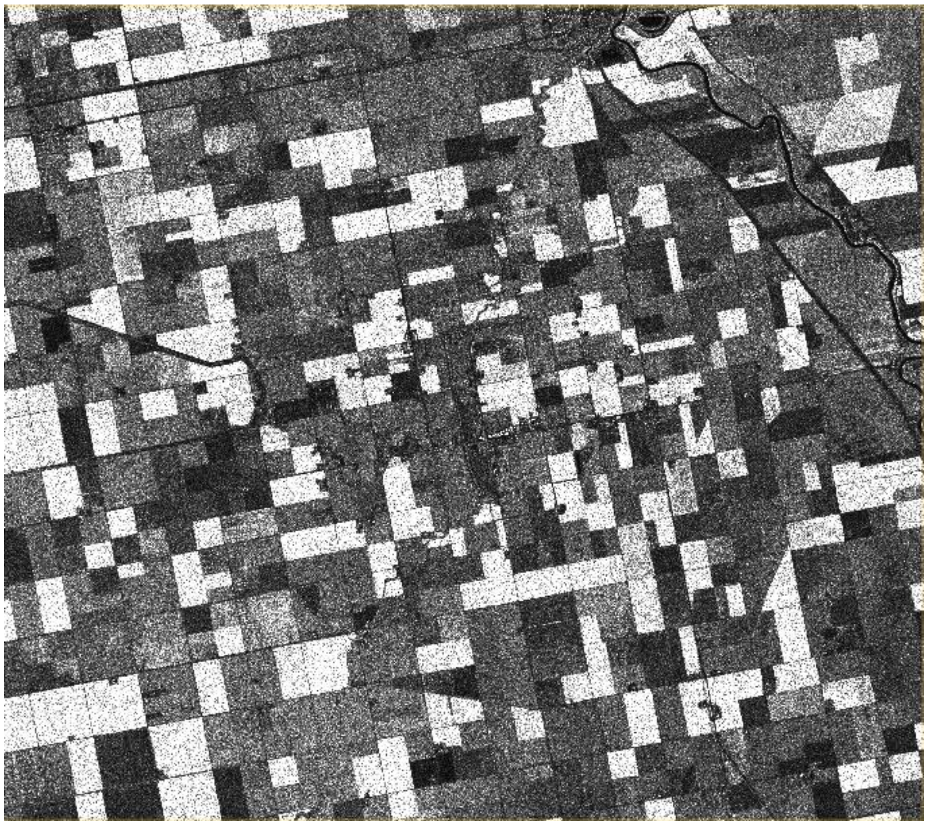
- Adaptive filters are all adaptive as a function of the local coefficient of variation.
- The filters modify the image based on appropriate scene and speckle models extracted from the local environment of each pixel



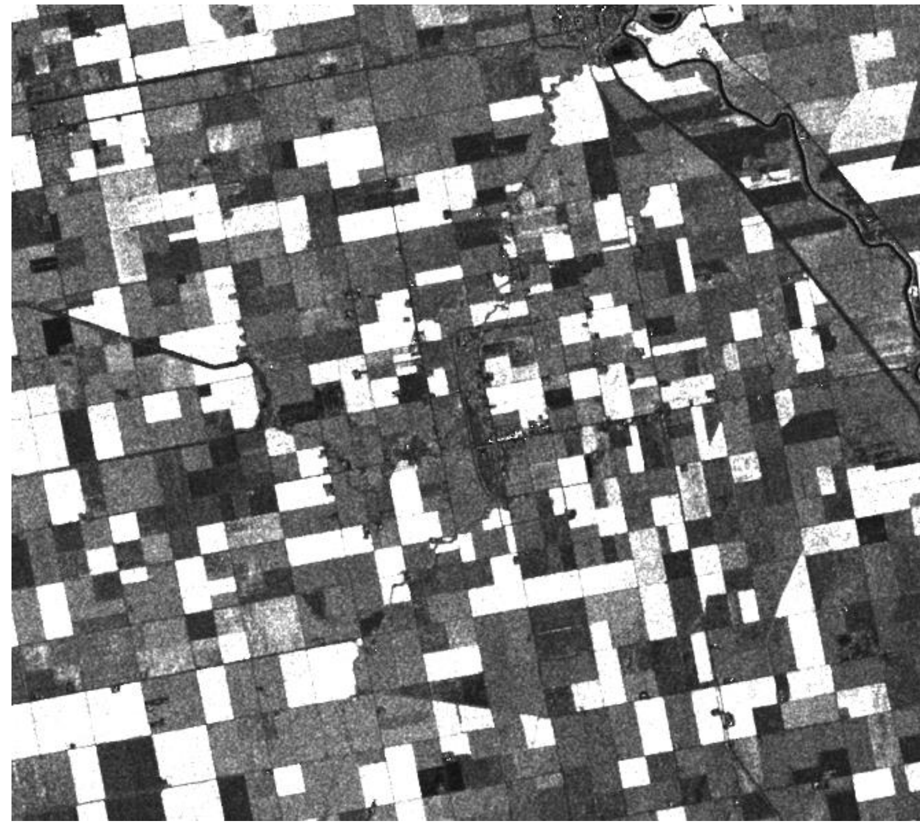
Gamma MAP Filter

- Based on the assumption that the (unspeckled) intensity of the underlying scene is Gamma distributed
- The filter minimizes the loss of texture information better than Frost or Lee filters within gamma distributed scenes
- Suitable for a wide range of gamma distributed scenes such as forested areas, agriculture areas and oceans
- The filter preserves pixel value for non-Gamma distributed scenes

Gamma Map Filter



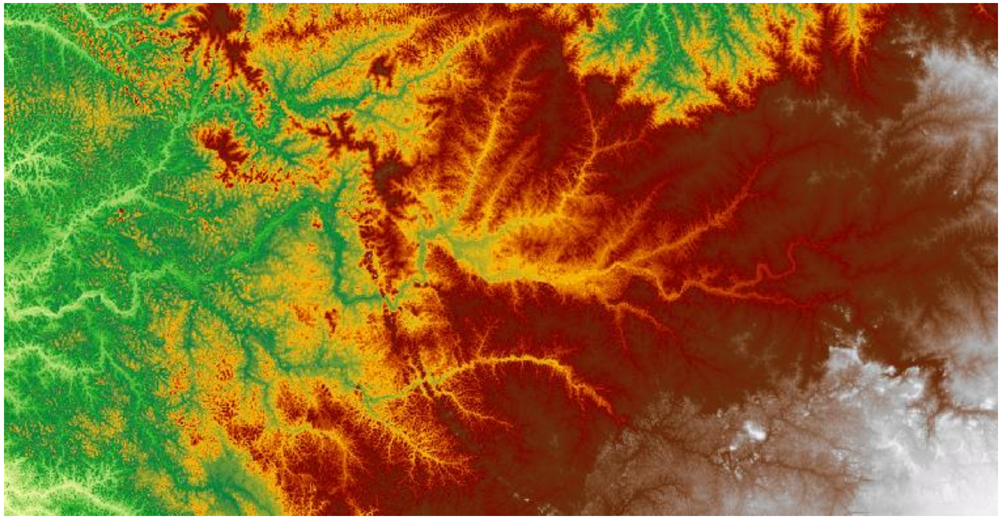
HV polarization multi-looked unfiltered image



Gamma map filter (7 by 7 window size)

Geometric Correction

- The Sentinel-1 GRDH image does not have geographic coordinates. The conversion of images (either slant or ground range geometry) into a map coordinate system is need for future applications.
- Terrain correction with the use of Digital Elevation Mode (DEM) data correct topographical distortions like foreshortening, layover or shadowing.
- The Range-Doppler approach is the most appropriate way to perform geometric correction. The method needs information about the topography (normally provided by a DEM) as well as orbit satellite information to correct the topographic distortions and derive a precise geolocation for each pixel of the image.



SRTM-90 m DEM

Image source: cgiarcsi.community/data/srtm-90m-digital-elevation-database-v4-1/

Break for Hands-On Exercise

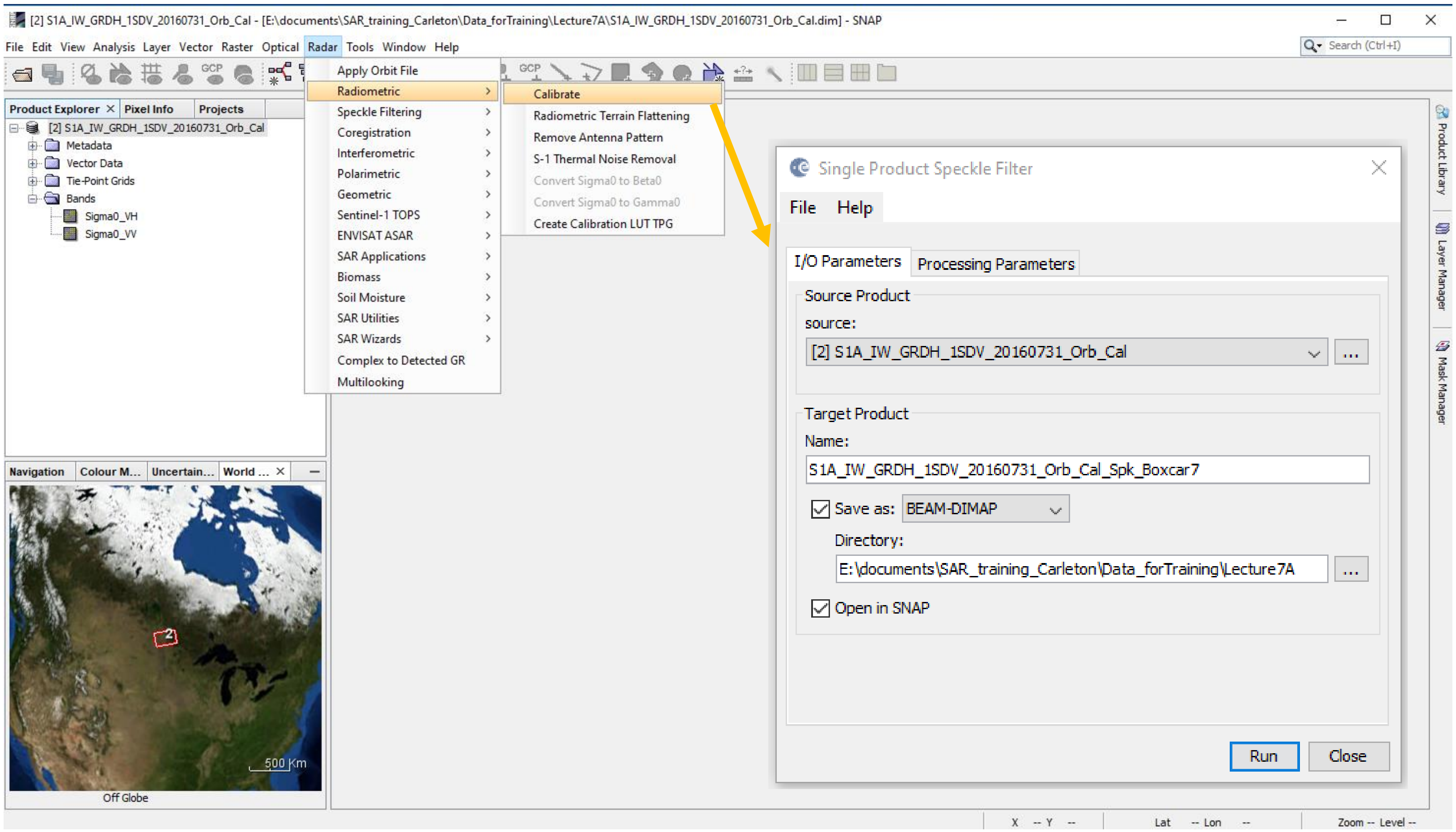
Speckle filtering and geometric correction

Image source: ttps://www.esa.int/spaceinimages/Images/2014/02/Sentinel-1

Filtering an Image

1) Go to Radar menu >> Speckle Filtering >> Single Product Speckle Filter
2) In the Single Product Speckle Filter window:
   - I/O Parameters tab: source : *S1A_IW_GRDH_1SDV_20160731_Orb_Cal*

     target product : *S1A_IW_GRDH_1SDV_20160731_Orb_Cal_Sp_kBoxcar7*



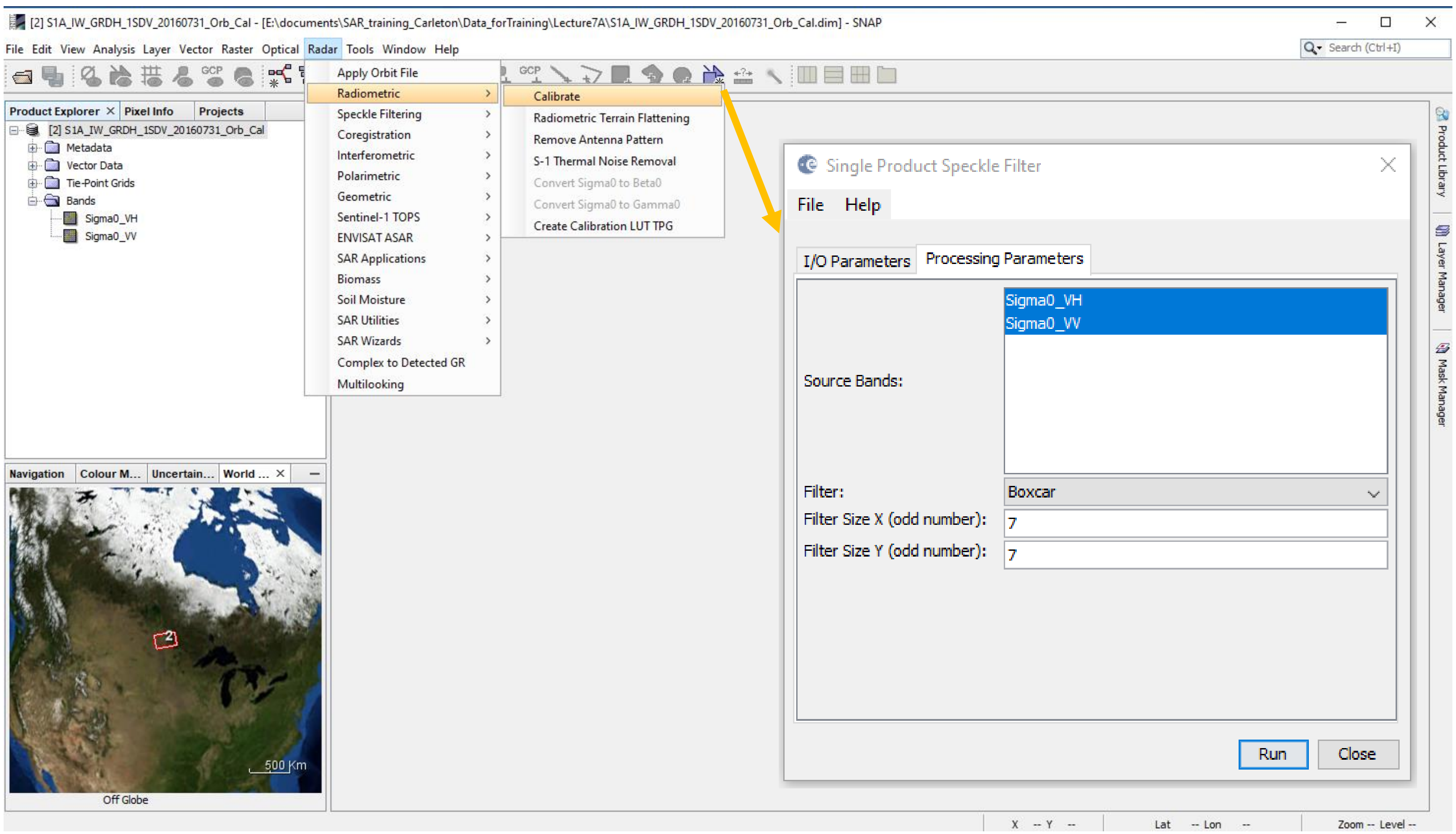
Filtering an Image

- Processing Parameters tab:

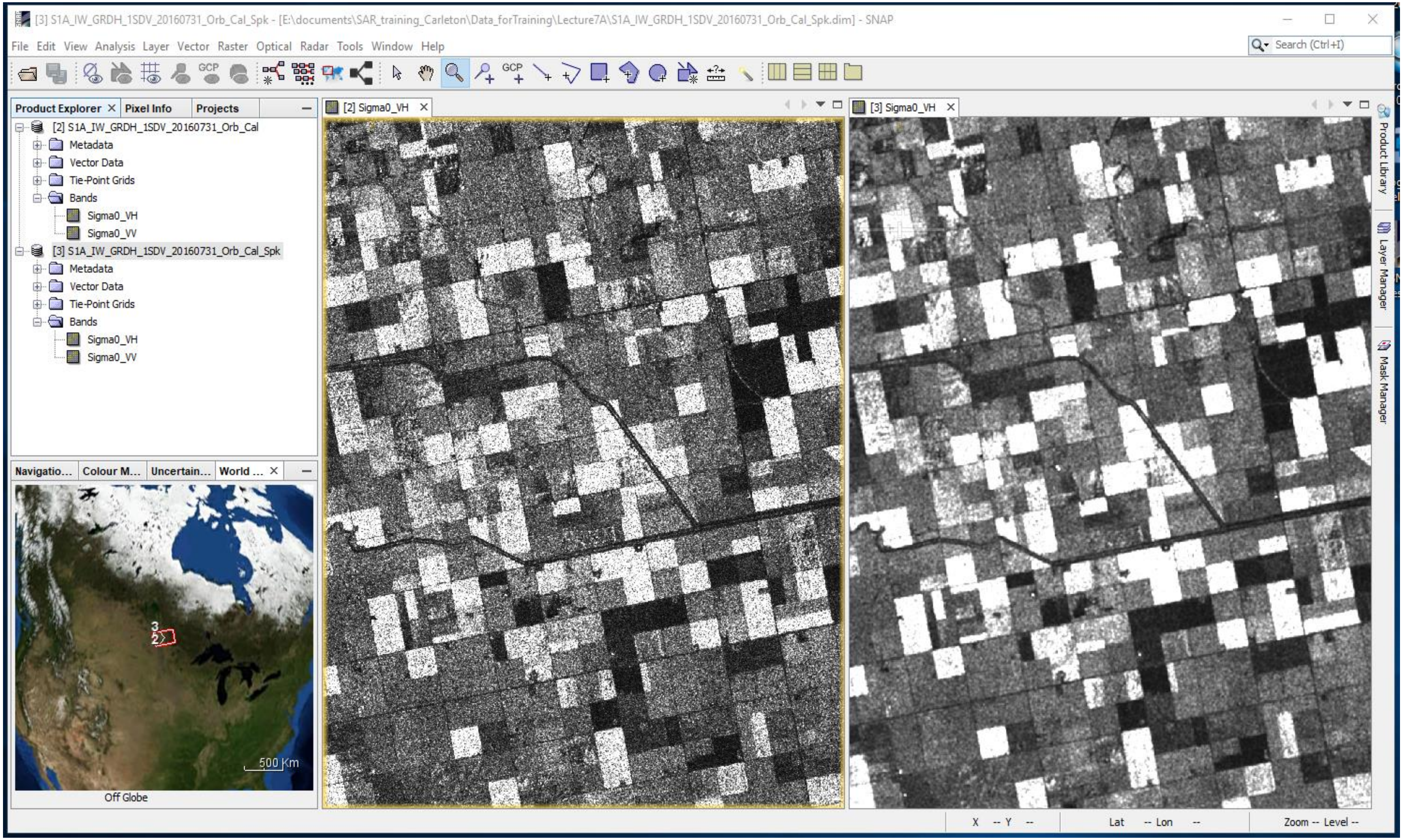
  Source bands: *sigma 0_HV and sigma0_VV*

  Filter*: Boxcar*

  Filter size: *7 by 7 window*



Filtering an Image

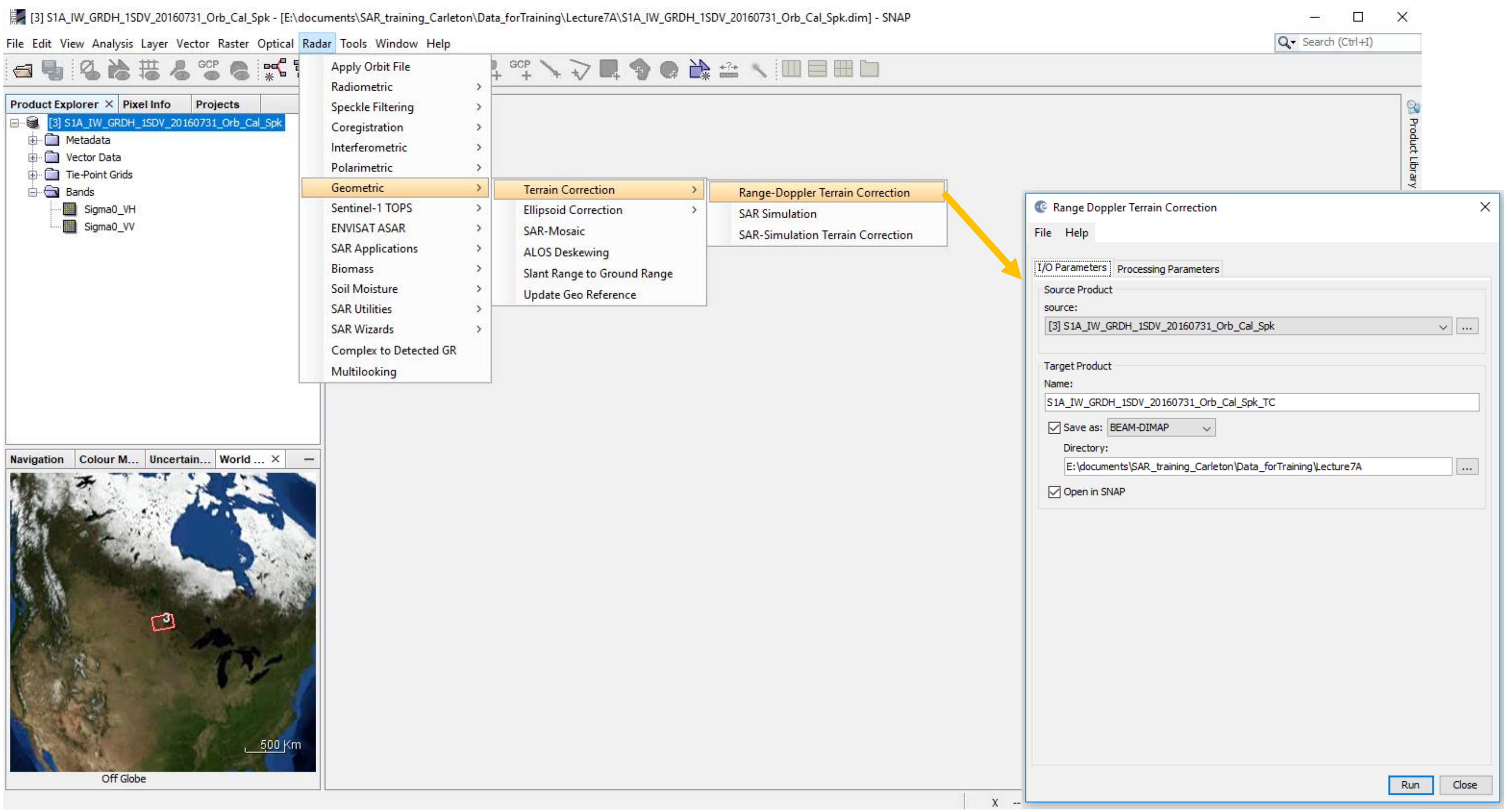


Geometric Correction of an image

1. Go to Radar Menu >> Geometric >> Terrain Correction >> Range-Doppler Terrain Correction
2. In the Range-Doppler Terrain Correction window

   I/O Parameters tab: source : *S1A_IW_GRDH_1SDV_20160731_Orb_Cal_Sp_kBoxcar7*

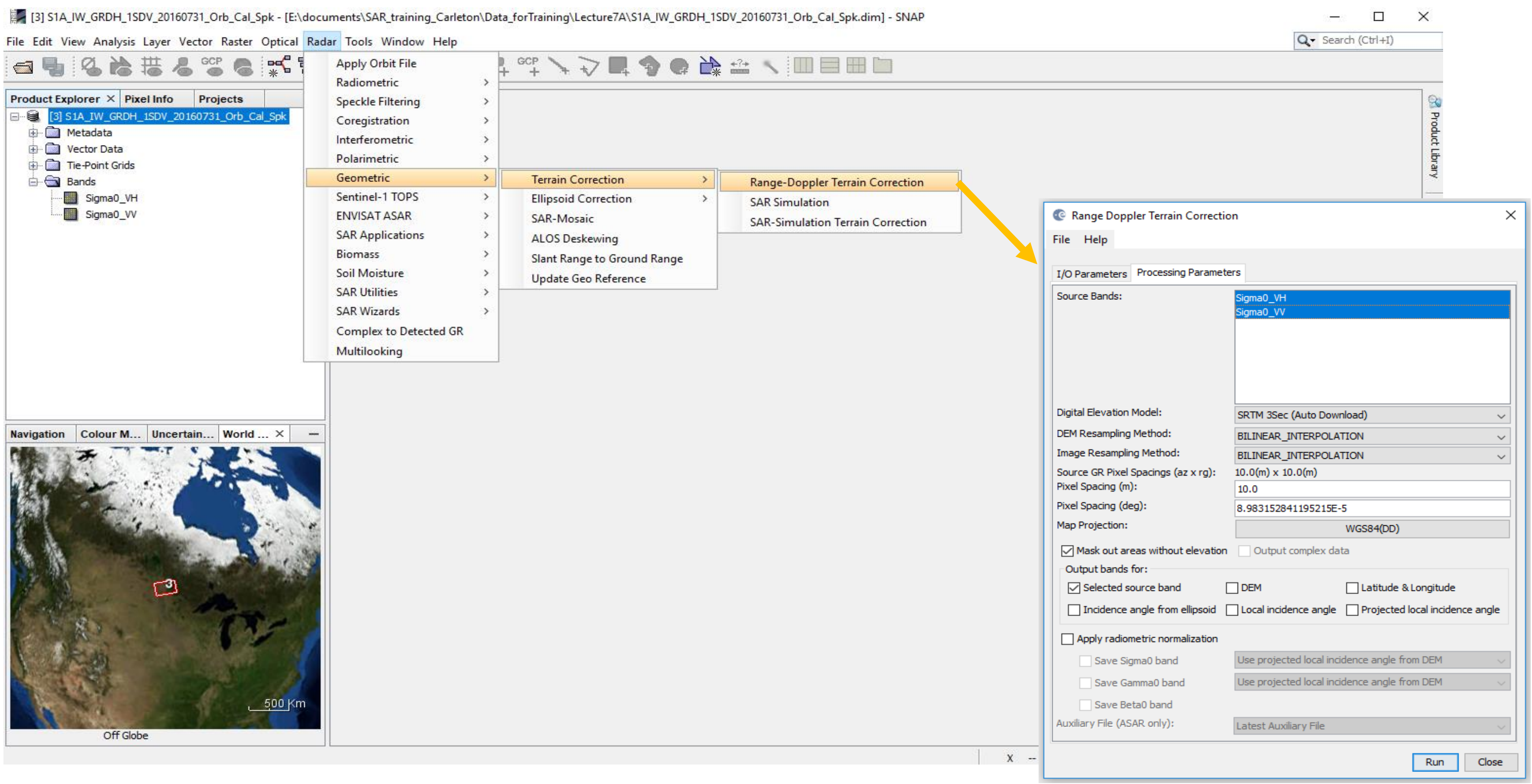
   target product : *S1A_IW_GRDH_1SDV_20160731_Orb_Cal_Spk_TC*



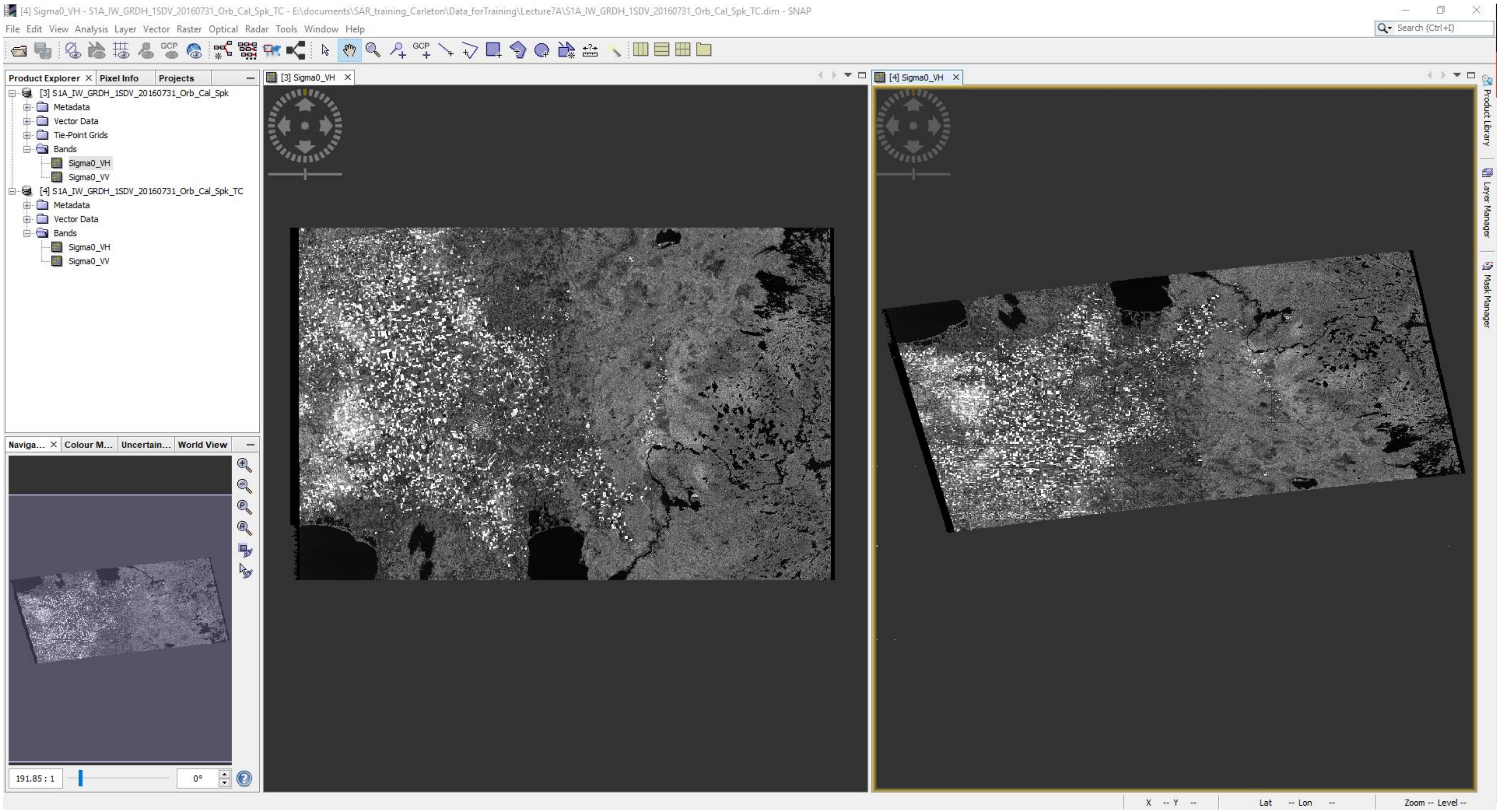
Geometric Correction of an image

- Processing Parameters tab:

  Source bands : *Sigma_VH and Sigma_VV*
  DEM: *SRTM 3Sec (Auto Download) which requires an internet connection*
  Resampling Method: *Bilinear Interpolation*
  Pixel Spacing: *10 m*
  Map Projection: *WGS84(DD)*



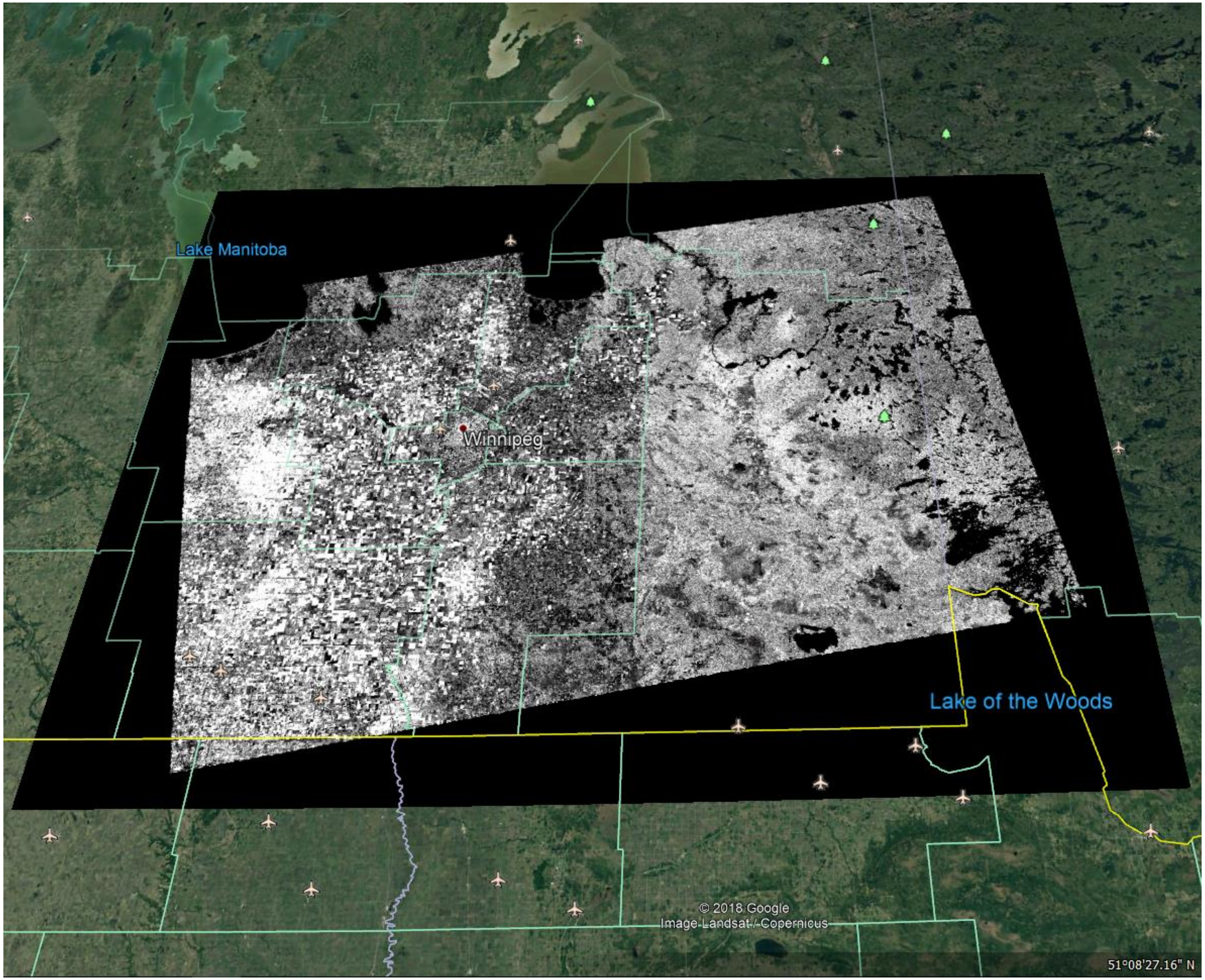
Geometric Correction of an image



Speckle filtered image

Speckle filtered image geocoded to the WGS 84 reference system

Geometric Correction of an image



Speckle filtered image geocoded to the WGS 84 reference system, display in Google Earth

Filtering an Image with Difference Window sizes

1. Apply Boxcar filter with 3 different window sizes to a radiometric converted images:
2. Subset an
   - *S1A_IW_GRDH_1SDV_20160731_Orb_Cal*

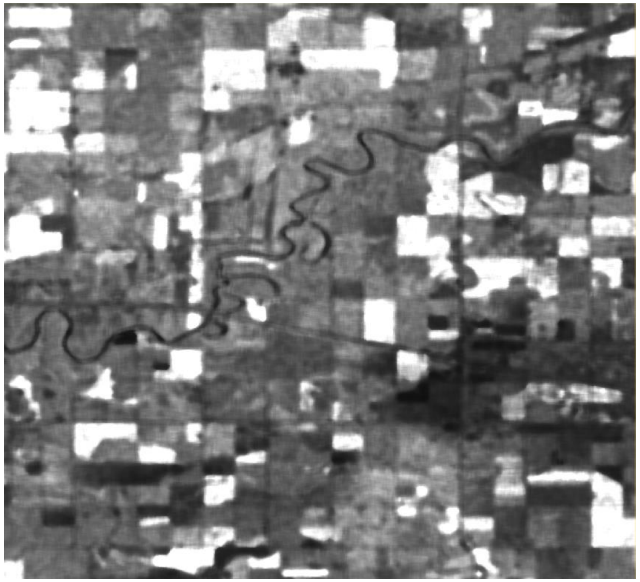
2. Apply terrain correction using Range Doppler method to the filtered images:
   - *S1A_IW_GRDH_1SDV_20160731_Orb_Cal_spk3_TC*
   - *S1A_IW_GRDH_1SDV_20160731_Orb_Cal_spk9_TC*
   - *S1A_IW_GRDH_1SDV_20160731_Orb_Cal_spk27_TC*

Filtering an Image with Difference Window sizes

Raw GRDH image

3 by 3 window size

9 by 9 window size



27 by 27 window size

References

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