GAMMA REMOTE SENSING

Processing of SENTINEL-1 GRD Time Series with ISP/DIFF&GEO/LAT

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SENTINEL-1

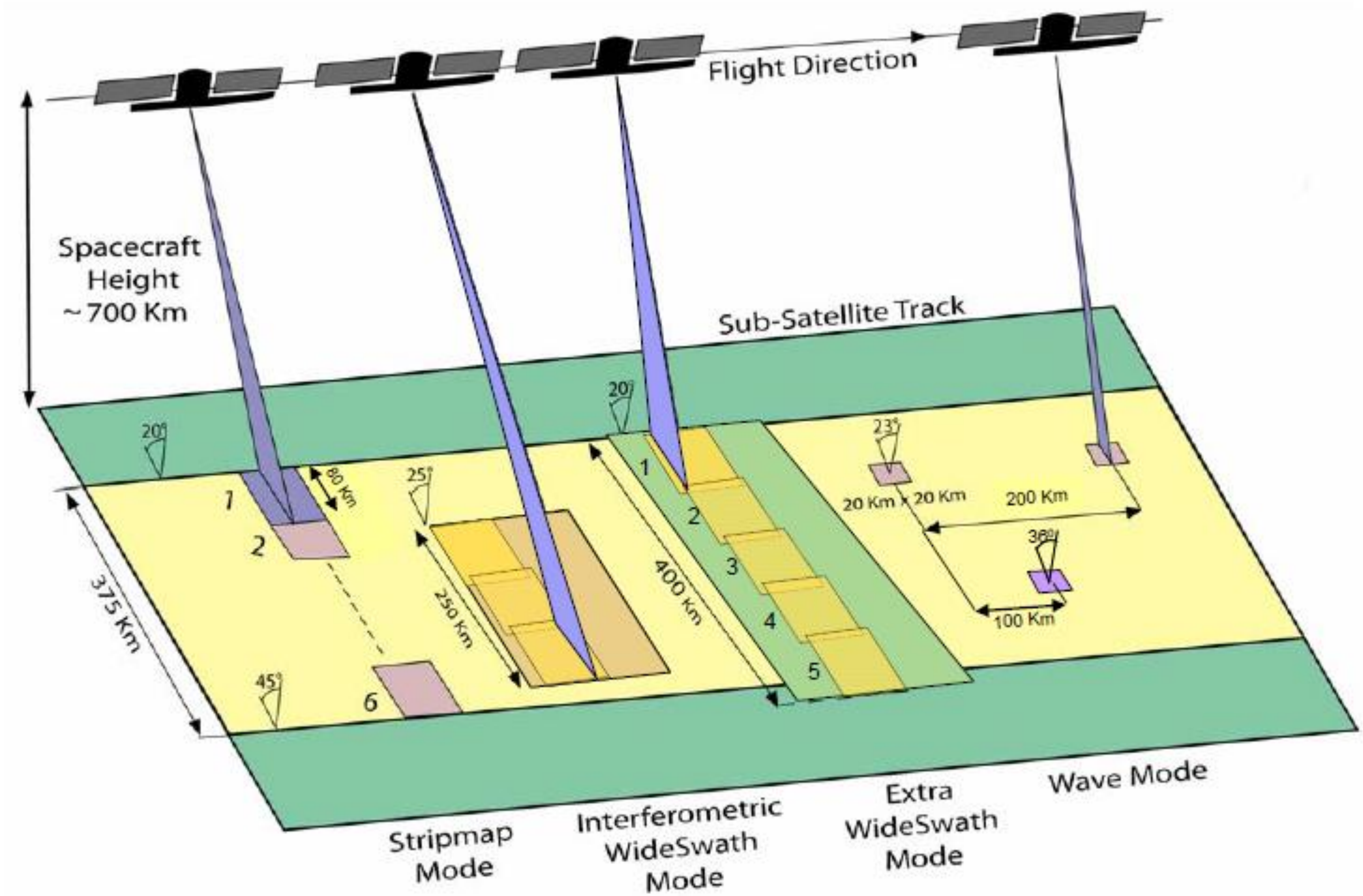
Launch Dates:
Sentinel-1A - 03 April 2014
Sentinel-1B - Scheduled for 2016
Operational lifespan: 7 years (With consumables for 12)

Mission Objectives:
Land monitoring of forests, water, soil and agriculture
Emergency mapping support in the event of natural disasters
Marine monitoring of the maritime environment
Sea ice observations and iceberg monitoring
Production of high resolution ice charts
Forecasting ice conditions at sea
Mapping oil spills
Sea vessel detection
Climate change monitoring

Mission Orbit:
Orbit Type: Sun-synchronous, near-polar, circular
Orbit Height: 693 km
Inclination: 98.18°
Repeat Cycle: 175 orbits in 12 days

Payload:
C-SAR (C-band Synthetic Aperture Radar)
Resolution and Swath Width (Four modes):
Strip Map Mode: 80 km Swath, 5 x 5 m spatial resolution
Interferometric Wide Swath: 250 km Swath, 5x20 m spatial resolution
Extra-Wide Swath Mode: 400 km Swath, 25 x 100 m spatial resolution
Wave-Mode: 20 km x 20 km, 5 x 20 m spatial resolution

SENTINEL-1



https://sentinel.esa.int/

Ls

```
S1A_IW_GRDH_1SDV_20160104T052528_20160104T052553_009340_00D80F_124D_vh_ml.mli
S1A_IW_GRDH_1SDV_20160104T052528_20160104T052553_009340_00D80F_124D_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160116T052528_20160116T052553_009515_00DD0D_67D8_vh_ml.mli
S1A_IW_GRDH_1SDV_20160116T052528_20160116T052553_009515_00DD0D_67D8_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160128T052527_20160128T052552_009690_00E237_E032_vh_ml.mli
S1A_IW_GRDH_1SDV_20160128T052527_20160128T052552_009690_00E237_E032_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160209T052527_20160209T052552_009865_00E736_BFA2_vh_ml.mli
S1A_IW_GRDH_1SDV_20160209T052527_20160209T052552_009865_00E736_BFA2_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160221T052527_20160221T052552_010040_00EC72_C493_vh_ml.mli
S1A_IW_GRDH_1SDV_20160221T052527_20160221T052552_010040_00EC72_C493_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160304T052527_20160304T052552_010215_00F15A_B5A2_vh_ml.mli
S1A_IW_GRDH_1SDV_20160304T052527_20160304T052552_010215_00F15A_B5A2_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160316T052527_20160316T052552_010390_00F654_14C5_vh_ml.mli
S1A_IW_GRDH_1SDV_20160316T052527_20160316T052552_010390_00F654_14C5_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160409T052528_20160409T052553_010740_01007E_1778_vh_ml.mli
S1A_IW_GRDH_1SDV_20160409T052528_20160409T052553_010740_01007E_1778_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160503T052529_20160503T052554_011090_010B55_C010_vh_ml.mli
S1A_IW_GRDH_1SDV_20160503T052529_20160503T052554_011090_010B55_C010_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160714T052524_20160714T052549_012140_012CF8_8F0D_vh_ml.mli
S1A_IW_GRDH_1SDV_20160714T052524_20160714T052549_012140_012CF8_8F0D_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160726T052525_20160726T052550_012315_0132A1_54F5_vh_ml.mli
S1A_IW_GRDH_1SDV_20160726T052525_20160726T052550_012315_0132A1_54F5_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160807T052526_20160807T052551_012490_013882_969B_vh_ml.mli
S1A_IW_GRDH_1SDV_20160807T052526_20160807T052551_012490_013882_969B_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160819T052527_20160819T052552_012665_013E40_E96D_vh_ml.mli
S1A_IW_GRDH_1SDV_20160819T052527_20160819T052552_012665_013E40_E96D_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160831T052527_20160831T052552_012840_014434_9ADB_vh_ml.mli
S1A_IW_GRDH_1SDV_20160831T052527_20160831T052552_012840_014434_9ADB_vh_ml.mli_par
S1A_IW_GRDH_1SDV_20160912T052527_20160912T052552_013015_0149CC_F1E5_vh_ml.mli
S1A_IW_GRDH_1SDV_20160912T052527_20160912T052552_013015_0149CC_F1E5_vh_ml.mli_par
srtm
srtm.par
```

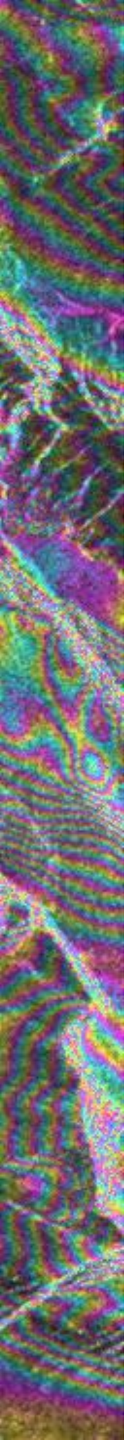
Import of GRDs: (already done)

par_S1_GRD
*** Generate MLI and GRD images and parameter files from a Sentinel-1 GRD product ***
*** Copyright 2016, Gamma Remote Sensing, v2.8 17-Aug-2016 awi/clw/ts ***

usage: par_S1_GRD <GeoTIFF> <annotation_XML> <calibration_XML> <noise_XML> <MLI_par> <MLI> [GRD_par] [GRD] [eflg] [rps] [noise_pwr]

input parameters:
  GeoTIFF (input) image data file in GeoTIFF format (*.tiff)
  annotation_XML (input) Sentinel-1 L1 XML annotation file
  calibration_XML (input) Sentinel-1 L1 radiometric calibration XML file (enter - for no radiometric calibration)
  noise_XML (input) Sentinel-1 L1 noise XML file (enter - to not add back thermal noise)
    NOTE: The L1 GRD product has thermal noise subtracted, enter noise_XML to add back thermal noise
  MLI_par (output) MLI parameter file (example: yyyymmdd_pp.mli.par)
  MLI (output) MLI data file in slant range geometry (example: yyyymmdd_pp.mli)
  GRD_par (output) GRD parameter file (example: yyyymmdd_pp.grd.par, enter - for none)
  GRD (output) GRD data file (example: yyyymmdd_pp.grd, enter - for none)
  eflg GR-SR grid extrapolation flag:
    0: no extrapolation of the GR-SR grid beyond the grid boundaries
    1: permit extrapolation of the GR-SR grid to cover the entire image (default)
    NOTE: extrapolation of the GR-SR grid may introduce geocoding errors
  rps slant range pixel spacing (m) (enter - for default: calculated from ground-range parameters)
  noise_pwr noise intensity for each MLI sample in slant range using data from noise_XML
    NOTE: when the noise_pwr file is specified, noise power correction will NOT be applied to the MLI data values

→ par_SLC_GRD already applies absolute calibration to sigma nought !!!



more S1A_IW_GRDH_1SDV_20160104T052528_20160104T052553_009340_00D80F_124D_vh_ml.mli_par

Gamma Interferometric SAR Processor (ISP) - Image Parameter File

```
title:     s1a-iw-grd-vh-20160104t052528-20160104t052553-009340-00d80f-002.tiff S1A-IW-IW-VH-9340 (software: Sentinel
002.60)
sensor:    S1A
date:      2016 1 4 5 25 28.5934
start_time:             19528.596362   s
center_time:            19541.092287   s
end_time:               19553.588212   s
azimuth_line_time:     7.4825898e-03   s
line_header_size:                  0
range_samples:                  6433
azimuth_lines:                  3341
range_looks:                      25
azimuth_looks:                     5
image_format:               FLOAT
image_geometry:             SLANT_RANGE
range_scale_factor:     1.0000000e+00
azimuth_scale_factor:   1.0000000e+00
center_latitude:         50.6050916   degrees
center_longitude:        11.5504814   degrees
heading:               -164.9024248   degrees
range_pixel_spacing:       25.000000   m
azimuth_pixel_spacing:     50.000000   m
near_range_slc:          800238.1166  m
center_range_slc:        880638.1166  m
far_range_slc:           961038.1166  m
first_slant_range_polynomial:        0.00000      0.00000  0.00000e+00  0.00000e+00  0.00000e+00  0.00000e+00  s m 1 m^-
3
```

Define reference image for co-registration

ref=S1A_IW_GRDH_1SDV_20160104T052528_20160104T052553_009340_00D80F_124D_vh_ml.mli

Create geocoding lookup table for reference image

```
gc_map ${ref}_par - srtm.par srtm gcdem.par gcdem
geo2rdc 0.5 0.5 - - - inc - - ls_map – 2
```

2 arcsec resolution of final products

```
# map dimensions

mli_width=`awk '$1 == "range_samples:" {print $2}'
${ref}_par`
mli_lines=`awk '$1 == "azimuth_lines:" {print $2}' ${ref}_par`
dem_width=`awk '$1 == "width:" {print $2}' gcdem.par`
```

Estimate pixel scattering area based on DEM and ellipsoid

pixel_area ${ref}_par gcdem.par gcdem geo2rdc ls_map inc pix_dem - - - pix

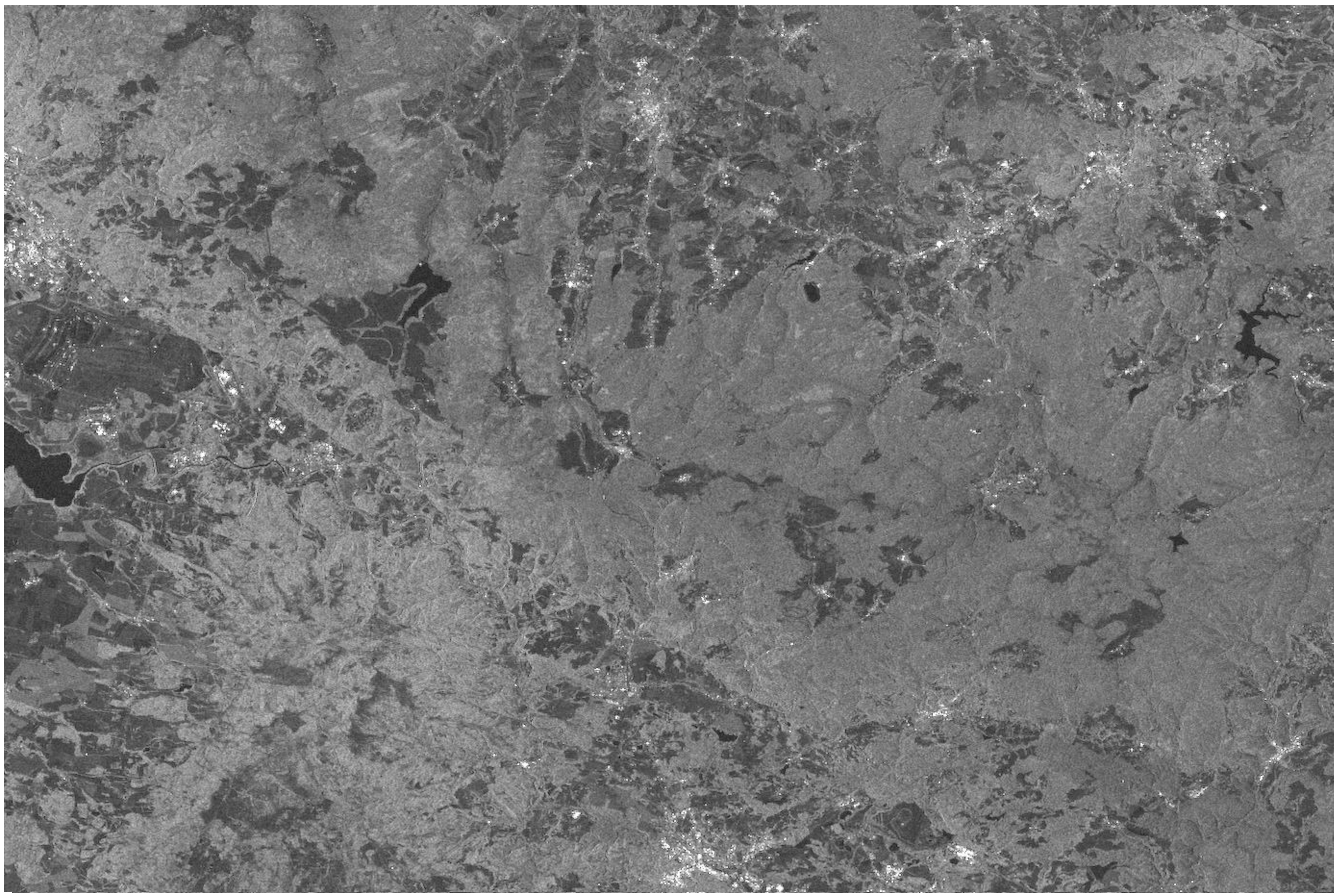
```
# Refinement of geocoding lookup table

create_diff_par ${ref}_par - diff_par 1 0

offset_pwrm pix_dem ${ref} diff_par offs snr 128 64 offsets 2
64 24 0.2

offset_fitm offs snr diff_par coffs coffsets 0.2 4

# Updating of the look-up table
gc_map_fine geo2rdc $dem_width diff_par geo2rdc.fine 1
/bin/mv geo2rdc.fine geo2rdc

# Reproduce pixel area estimate
pixel_area ${ref}_par gcdem.par gcdem geo2rdc ls_map inc
pix_dem - - - pix
```

```
# Co-registration of all MLIs to selected refernce image

# Resample dem to rdc geometry
geocode geo2rdc gcdem $dem_width gcdem.rdc $mli_width $mli_lines 0 0

i=S1A_IW_GRDH_1SDV_20160128T052527_20160128T052552_009690_00E237_E032
_vh_ml.mli

# Pixel dimensions of image to be coregistered
mli_width_t=`awk '$1 == "range_samples:" {print $2}' ${i}_par`
mli_lines_t=`awk '$1 == "azimuth_lines:" {print $2}' ${i}_par`

rdc_trans ${ref}_par gcdem.rdc ${i}_par ${i}.lt
geocode ${i}.lt ${ref} $mli_width ${i}.sim $mli_width_t $mli_lines_t 0 0

create_diff_par ${i}_par - ${i}.diff_par 1 0
offset_pwrm ${i}.sim ${i} ${i}.diff_par ${i}.offs ${i}.snr 128 128 ${i}.offsets 2 12 12 0.2
offset_fitm ${i}.offs ${i}.snr ${i}.diff_par ${i}.coffs ${i}.coffsets 0.2 1

→ final model fit std. dev. (samples) range: 0.0488   azimuth: 0.0524

gc_map_fine ${i}.lt $mli_width ${i}.diff_par ${i}.lt_fine 1

MLI_interp_lt ${i} ${ref}_par ${i}_par ${i}.lt_fine ${ref}_par ${i}_par ${i}.diff_par
$(basename ${i} mli)rmli $(basename ${i} mli)rmli_par

dis2pwr $ref $(basename ${i} mli)rmli $mli_width $mli_width     # After coregistration
```

```
# Co-registration of all MLIs to selected refernce image



for i in $(ls *ml.mli); do
    if [ ${i} != ${ref} ]; then
        # Pixel dimensions of image to be coregistered
        mli_width_t=`awk '$1 == "range_samples:" {print $2}' ${i}_par`
        mli_lines_t=`awk '$1 == "azimuth_lines:" {print $2}' ${i}_par`

        rdc_trans ${ref}_par gcdem.rdc ${i}_par ${i}.lt
        geocode ${i}.lt ${ref} $mli_width ${i}.sim $mli_width_t $mli_lines_t 0 0

        create_diff_par ${i}_par - ${i}.diff_par 1 0
        offset_pwrm ${i}.sim ${i} ${i}.diff_par ${i}.offs ${i}.snr 128 128 ${i}.offsets 2 12 12 0.2
        offset_fitm ${i}.offs ${i}.snr ${i}.diff_par ${i}.coffs ${i}.coffsets 0.2 1
        gc_map_fine ${i}.lt $mli_width ${i}.diff_par ${i}.lt_fine 1

        MLI_interp_lt ${i} ${ref}_par ${i}_par ${i}.lt_fine ${ref}_par ${i}_par ${i}.diff_par
$(basename ${i} mli)rmli $(basename ${i} mli)rmli_par
    fi
done
```

```
# Compensate pwr images for pixel area variations

product ${ref} pix $(basename ${ref} mli)s0 $mli_width 1 1 0
for i in $(ls *rmli); do
    product ${i} pix $(basename ${i} rmli)s0 $mli_width 1 1 0
done
```

```
dis2pwr S1A_IW_GRDH_1SDV_20160409T052528_20160409T052553_010740_01007E_1778_vh_ml.s0 S1A_IW_GRDH_1SDV_20160409T052528_20160409T052553_010740_01007E_1778_vh_ml.rmli $mli_width $mli_width
```

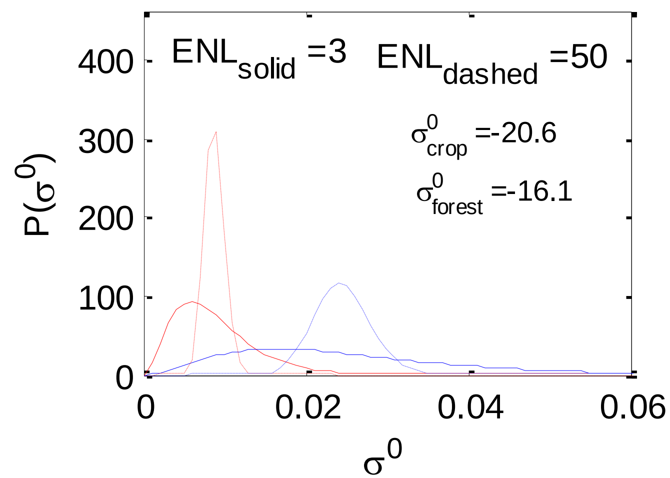


Why Filtering?

Gamma distributed speckle:

$$p(I) = \frac{1}{\Gamma(L)}\left(\frac{L}{\sigma}\right)^{L} I^{L-1} e^{\frac{-LI}{\sigma}}$$

L (or ENL) = Equivalent Number of Looks



Multichannel Filtering

Linear Combination of k channels increases ENL with reduced cost of resolution (Quegan & Yu, 2001):

$$J_k = \sum_{i=1}^{M} A_{ki} I_i \qquad A_{ki} = \langle I_k \rangle \frac{C_I^{-1}\sigma}{\sigma^t C_I^{-1}\sigma}$$

A=weighting coefficient,C=covariance matrix, σ=mean vector (spatial estimate), J=filtered image

When ignoring ENL differences & correlation between channels :

$$J_k = \frac{\sigma_k^{\ 0}}{M} \sum_{i=1}^{M} \frac{I_i}{\sigma_i^{\ 0}}$$

Spatial estimate of RCS required:

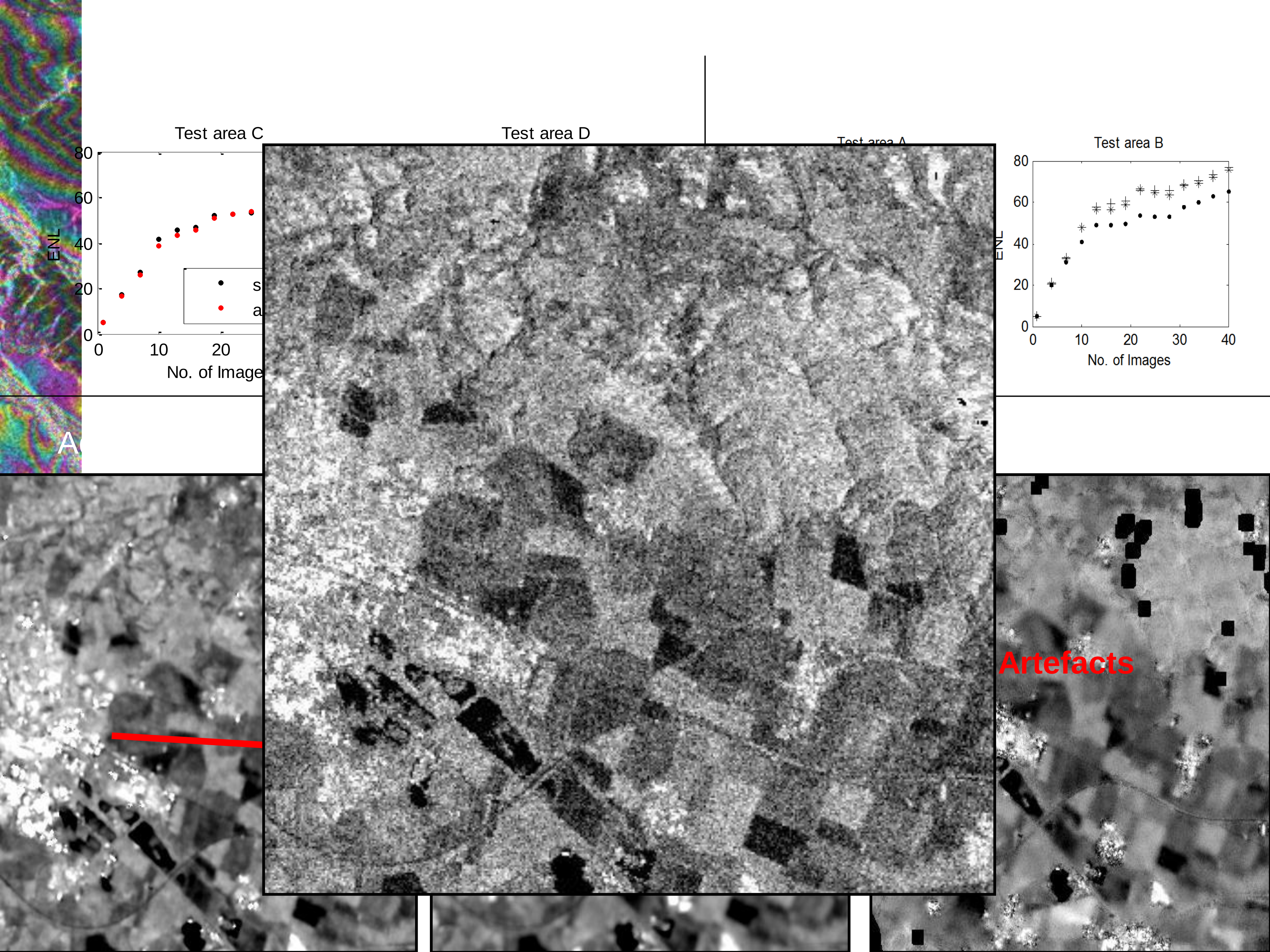
Tested: Spatial average vs. Adaptive Frost RCS reconstruction

Expected increase of ENL with M images and N samples used for spatial estimate of σ^0 (L=initial ENL):

$$ENL = \frac{MNL}{M + N - 1}$$

$$N' = \frac{N}{\left(1 + 2\rho_{I,a}[1] + 2\rho_{I,r}[1] + 4\rho_{I,a}[1]\rho_{I,r}[1]\right)}$$

ρ=spatial correlation at lag [.]


Test area C
80
60
40
20
0
ENL
0
10
20
No. of Image
Test area D
Test area B
80
60
40
20
0
ENL
0
10
20
30
40
No. of Images
Artefacts

Filtering

temp_filt

ANSI-C programs: temp_filt.c and temp_filt_ad.c

NAME
temp_filt - Multi-temporal filtering of co-registered data sets of format float.
temp_filt_ad - Multi-temporal filtering of co-registered data sets of format float using adaptive spatial mean estimate.

SYNOPSIS
```
temp_filt <data_tab> <width> [waz] [wr] [wt_flag] [zero_flag] [loffset] [nlines]
```

<data_tab>	(input) two column list of the names of input and output data files (float) input file 1 output file 1 input file 2 output file 2 ... ...
<width>	number of samples/row
[waz]	spatial averaging filter width in azimuth pixels (default=1.0)
[wr]	spatial averaging filter width in range pixels (default=1.0)
[wt_flag]	weighting function flag (default=0: uniform; 1: linear; 2: gaussian)
[zero_flag]	default: zero_flag=0 => 0.0 interpreted as missing value zero_flag=1 => 0.0 interpreted as valid data value
[loffset]	number of lines offset to starting line (default=0)
[nlines]	number of lines to process (default: 0=entire file)

```
# Apply multi-temporal filter

for i in $(ls *s0); do
    echo "$i $(basename $i .s0)_mtfil.s0" >> optfile_filt
done
temp_filt optfile_filt $mli_width 5 5

dis2pwr
S1A_IW_GRDH_1SDV_20160316T052527_20160316T052552_010390_00F654_
14C5_vh_ml_mtfil.s0
S1A_IW_GRDH_1SDV_20160316T052527_20160316T052552_010390_00F654_
14C5_vh_ml.s0 $mli_width $mli_width
```

Multi-temporal metrics

```
temp_lin_var
*** Land Application Tools : Program  temp_lin_var ***
*** Copyright 2012 Gamma Remote Sensing, v4.0 8-Mar-2013 clw/uw ***

*** Calculation of temporal mean and variability (defined as stdev/pow(mean, norm_pow) of multiple data sets ***

usage: temp_lin_var <data_tab> <mean> <stdev> <width> [waz] [wr] [wt_flag] [zero_flag] [loff] [nlines] [norm_pow]

input parameters:
  data_tab   (input) single column list of the names of input data files (float)
  mean       (output) temporal mean (linear scale) (float)
  stdev      (output) temporal variability (stdev/pow(mean,norm_pow))(float)
  width      number of samples/row
  waz        spatial averaging filter width in azimuth pixels (default = 1.0)
  wr         spatial averaging filter width in range pixels (default = 1.0)
  wt_flag    weighting function
             0: uniform (default)
             1: linear
             2: gaussian)
  zero_flag  zero_flag
             0: data value 0.0 interpreted as missing data (default))
             1: data interpreted
  loff       offset to starting line (default = 0)
  nlines     number of lines to process (0:entire file (default))
  norm_pow   temporal stdev is normalized with POW(mean,norm_pow)
             0.0: normalized with 1.0
             1.0: normalized with backscatter intensity (default)
```

Calculate multitemporal metrics

```
ls *_mtfil.s0 > optfile_mt
temp_lin_var optfile_mt mtmean mtstdev $mli_width

dis2pwr mtmean $mli_width

dis_linear mtstdev $mli_width
```

Geocode intensity images

```
####################################################################################
#########
for i in $(ls *mtfil.s0); do
    geocode_back ${i} $mli_width geo2rdc $(basename ${i} .s0)_geo.s0 $dem_width
done
geocode_back mtmean $mli_width geo2rdc mtmean_geo.s0 $dem_width
geocode_back mtstdev $mli_width geo2rdc mtstdev_geo.s0 $dem_width

####################################################################################
#########
#  Sigma to gamma conversion --> reduces incidence angle dependence of backscatter
####################################################################################
#########
for i in $(ls S*geo.s0); do
    sigma2gamma ${i} inc $(basename ${i} s0)g0 $dem_width
done
```

```
#################################################################################
###################
# Convert images to GeoTiff
#################################################################################
###################
data2geotiff gcdem.par inc 2 inc.tif
data2geotiff gcdem.par ls_map 5 ls_map.tif
data2geotiff gcdem.par mtmean_geo.s0 2 mtmean_geo_s0.tif 0
data2geotiff gcdem.par mtstdev_geo.s0 2 mtstdev_geo_s0.tif 0
for i in $(ls S*g0); do
    data2geotiff gcdem.par $i 2 ${i}.tif 0
done
```

Summary:

We have learned how to calculate:

- a differential repeat-pass interferogram
- displacement
- coherence
- backscatter intensity

from a 12-day repeat-pass pair of S1 TOPS IW SLCs

Note: S1 imagery can also be downloaded in detected ground range format, in which case no interferometry is possible. The sequence of programs needed to process GRDs is:

par_S1_GRD

multilook

gc_map_grd

pixel_area

geocode_back