Radiometric Terrain Correction for Sentinel-1A Data

GAMMA software, Linux

This data recipe is for users who wish to radiometrically terrain correct (terrain geocode) Sentinel-1A synthetic aperture radar (SAR) data using GAMMA software. GAMMA yields high-quality results. *Note: GAMMA requires purchase, a significant expense.*

In this document, you will find:

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A. Background:

Radiometric correction involves removing the misleading influence of topography on backscatter values. Terrain correction corrects geometric distortions that lead to geolocation errors. The distortions are induced by side-looking (rather than straight-down looking or nadir) imaging, and are compounded by rugged terrain. Terrain correction moves image pixels into the proper spatial relationship with each other. Radiometric terrain correction combines both corrections (Figures 1 and 2 in E) to produce a more useful product for science applications. This recipe is to support users who are comfortable working in the command line environment and have GAMMA installed on their computers.

ASF provides the perl scripts “**rtc_sentinel_recipe.pl**” and “**utm2dem_i2.pl**” to radiometrically terrain correct Sentinel-1A GRD data using GAMMA software.
This script uses a DEM file and a Sentinel-1A granule as inputs and creates terrain-corrected GeoTIFFs of each polarization, an incidence angle map, a layover/shadow map, and a clipped DEM file that matches the area of the SAR image.

B. Materials:

- Sentinel-1A GRD product (download granule of your choice from Vertex or use Sample Granule)
- Digital Elevation Model (DEM) (available from many sources, including USGS Earth Explorer and OpenTopography; choose projection in meters)
- GAMMA software package (MSP + ISP + DIF&GEO + LAT). *Note: GAMMA requires purchase, a significant expense.*
- GDAL warp (part of GDAL Utilities)
- rtc_sentinel_recipe.pl (included with this package)
- utm2dem_i2.pl (included with this package)

C. Steps:

1) Download and install in your local environment the GAMMA software package.
2) Download and install the most recent version of GDAL utilities; this will include gdalwarp. To do this for the Linux operating system Ubuntu, for example, use apt-get: (sudo apt-get install gdal-bin).
3) Put the rtc_sentinel_recipe.pl script and the utm2dem_i2.pl into a directory that is in your path. Modify your path if necessary using "export PATH=$PATH:~[desired directory]" .
4) To turn these scripts into executable files, change into the directory the scripts are saved in and enter "chmod a+x *"
5) Create a directory to house the Sentinel-1A GRD products (the .zip file).
6) Download an S1A GRD granule from ASF Vertex and move it to your GAMMA processing directory. (Sample granule available)
7) Unzip the S1A GRD file in your processing directory.
8) Download a DEM: The script will automatically download and apply an SRTMGL1 DEM file from OpenTopo, or you may use a DEM of your choice.
   Note: If you want to use your own DEM, download an external DEM and corresponding par file in GAMMA format, and place in GAMMA processing directory. The downloaded DEM must be in GAMMA format (DEM and par file).
9) The following options are available when running the script: output Output RTC file name
   -e dem (option) specify a DEM file to use (with par file)
   e.g. big.dem to specify big.dem and big.dem.par
   -r res (option) specify the output resolution (default 10m)

10) Run the script **$ perl rtc_sentinel_recipe.pl [options] <output filename>**

D) Output:

Once the script has finished running, the main output can be found in the **PRODUCT directory**. The PRODUCT directory will contain the 4 or 5 output product files – one for each polarization (e.g. VV or VV and VH), one for the incidence angle map (inc_map), one for the layover/shadow map (ls_map), and one for the clipped DEM file (dem).

Here is a sample PRODUCT directory listing:

```
$ ls -1 PRODUCT/
s1a-iw-rtc-20150513T100702-dem.tif s1a-iw-rtc-
20150513T100702-inc_map.tif s1a-iw-rtc-
20150513T100702-ls_map.tif s1a-iw-rtc-
20150513T100702-vh.tif
s1a-iw-rtc-20150513T100702-vv.tif
```

Many intermediate files are left in the current working directory as well as several sub-directories being created after the run has completed. These files can be deleted once processing of the RTC products has completed. Below is a list of the intermediate files that do not need to be archived further.

```
$ ls -1 20150513T100702.log
20150513T100702.vh.GRD
20150513T100702.vh.GRD.par
20150513T100702.vh.mgrd
20150513T100702.vh.mgrd.bmp
20150513T100702.vh.mgrd.ellipse_cal
20150513T100702.vh.mgrd.par 20150513T100702.vv.GRD
20150513T100702.vv.GRD.par
20150513T100702.vv.mgrd
20150513T100702.vv.mgrd.bmp
20150513T100702.vv.mgrd.ellipse_cal
20150513T100702.vv.mgrd.par asf_utm2dem.log
big.dem big.dem.par
dem_par.in dem.tif geo_vh
geo_vv
    PRODUCT
    S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49
    E5.SAFE
    S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49
    E5.zip
    tmpdem.tif
    utm_tmp.aux.xml
    utm_tmp.hdr
```

E) Before and After Images

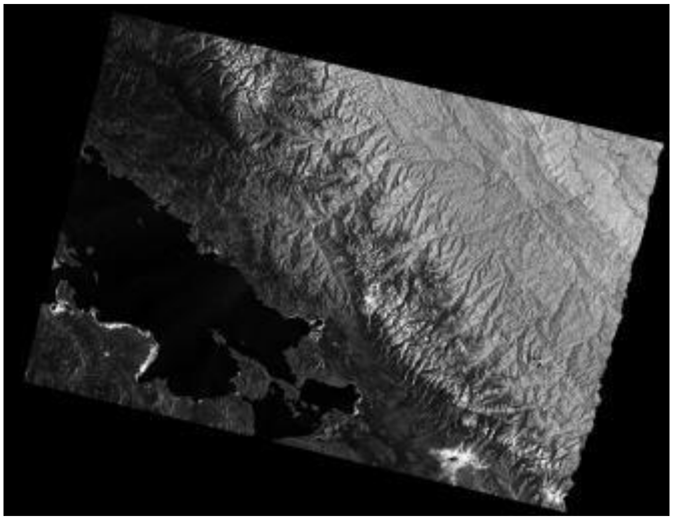

Figure 1: Sample granule prior to RTC processing.

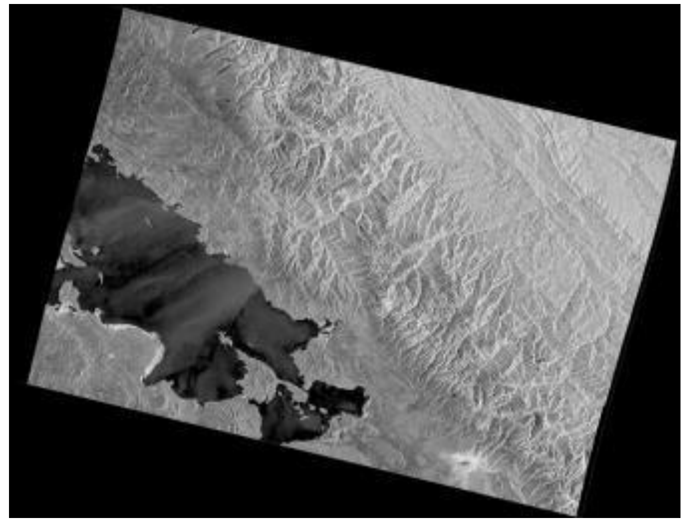

Figure 2: RTC product.

F) How the Perl Scripts Work:

Given the following:

$pol	- polarization being worked on
$output	- output name
$res	- desired output resolution
$look_fact	- calculated look factor = int($res/10+0.5)
$dem	- input DEM file

1) Ingests the data into GAMMA format to begin radiometric terrain correction of the main polarization data

par_S1_GRD */*/*$pol*.tiff */*/*$pol*.xml */*/*/calibration-*$pol*.xml */*/*/noise-*$pol*.xml $output.$pol.GRD.par $output.$pol.GRD

2) *(Optional if users use* -r res*)* Multi-looks the data to the desired resolution

multi_look_MLI $output.$pol.GRD $output.$pol.GRD.par $output.$pol.mgrd $output.$pol.mgrd.par $look_fact $look_fact

Note: Multi-looking will not be performed if $look_fact < 2.

3) Converts the data from ground range to slant range

GRD_to_SR $output.$pol.mgrd.par $output.$pol.mli.par - $output.$pol.mgrd $output.$pol.mli 1 1 2 $res $res

4) Generates initial lookup table, simulated SAR image, and DEM segment parameters; erases existing DEM segment parameters

mk_geo_radcal.pl $output.$pol.mli $output.$pol.mli.par $dem $dem.par geo_$pol/area.dem geo_$pol/area.dem_par geo_$pol image $res 0 -p -j -n 1 -q -c

Here, the options used are as follows:

- -p use pixel area program to create simulated SAR image
- -j don't use layover-shadow map in pixel area calculation
- -n 1 use a first order mapping function
- -q quiet mode – don't display intermediate results
- -c create calibrated output files

5) Measures initial offset between simulated SAR image and actual SAR image

mk_geo_radcal.pl $output.$pol.mli $output.$pol.mli.par $dem $dem.par geo_$pol/area.dem geo_$pol/area.dem_par geo_$pol image $res 1 -p -j -n 1 -q -c

6) Performs refinement of lookup table by offset measurement with respect to the simulated SAR image

mk_geo_radcal.pl $output.$pol.mli $output.$pol.mli.par $dem $dem.par geo_$pol/area.dem geo_$pol/area.dem_par geo_$pol image $res 2 -p -j -n 1 -q -c

7) Updates lookup table and produce terrain geocoded SAR image and DEM in SAR range-Doppler coordinates (RDC)

mk_geo_radcal.pl $output.$pol.mli $output.$pol.mli.par $dem $dem.par geo_$pol/area.dem geo_$pol/area.dem_par geo_$pol image $res 3 -p -j -n 1 -q -c

Note: Once the first polarization is completed, the second polarization proceeds as follows (assuming it exists):

1) Ingests the data into GAMMA format to perform terrain correction on the second polarization.

par_S1_GRD */*/*$pol*.tiff */*/*$pol*.xml */*/*/calibration-*$pol*.xml */*/*/noise-*$pol*.xml $output.$pol.GRD.par $output.$pol.GRD

2) Multi-looks the data to the desired resolution (optional step)

multi_look_MLI $output.$pol.GRD $output.$pol.GRD.par $output.$pol.mgrd $output.$pol.mgrd.par $look_fact $look_fact

Note that multi-looking will not be performed if $look_fact < 2.

3) Converts the data from ground range to slant range

GRD_to_SR $output.$pol.mgrd.par $output.$pol.mli.par - $output.$pol.mgrd $output.$pol.mli 1 1 2 $res $res

4) Performs refinement of lookup table by offset measurement with respect to the simulated SAR image.

mk_geo_radcal.pl $output.$pol2.mli $output.$pol2.mli.par $dem $dem.par geo_$pol1/area.dem geo_$pol1/area.dem_par geo_$pol2

image $res 3 -p -j -n 1 -q -c

Note: $pol2 is the cross-polarization and $pol1 is the main polarization.

G) Example Run:

User begins RTC of S1A data by unzipping the data into working directory.

$ ls
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.zip

[TEST]$ unzip *.zip
Archive:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.zip
creating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5. SAF
E/
creating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/support/
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/support/s1-level-1-calibration.xsd
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/support/s1-level-1-product.xsd
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/support/s1-object-types.xsd
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/support/s1-level-1-noise.xsd
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/support/s1-map-overlay.xsd
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/support/s1-level-1-quicklook.xsd
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/support/s1-product-preview.xsd
inflating:

S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/support/s1-level-1-measurement.xsd
creating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/measurement/
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/measurement/s1a-iw-grd-vv-20150513t100702-20150513t100727-005901-0079a1-001.tiff
inflating: S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E
5.SAF
E/measurement/s1a-iw-grd-vh-20150513t 100702-20150513t 100727-005901-0079a1-002.tiff
creating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/annotation/
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/annotation/s1a-iw-grd-vv-20150513t 100702-20150513t 100727-005901-0079a1-001.xml
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/annotation/s1a-iw-grd-vh-20150513t100702-20150513t100727-005901-0079a1-002.xml
creating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/annotation/calibration/
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/annotation/calibration/noise-s1a-i w-grd-vv-20150513t100702-20150513t100727-005901-
0079a1-001.xml
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/annotation/calibration/noise-s1a-i w-grd-vh-20150513t100702-20150513t100727-005901-
0079a1-002.xml
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/annotation/calibration/calibration-s1a-i w-grd-vv-20150513t100702-20150513t100727-
005901-0079a1-001.xml
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/annotation/calibration/calibration-s1a-i w-grd-vh-20150513t100702-20150513t100727-
005901-0079a1-002.xml
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_ 49E5.SA
FE-report-20150513T124605.pdf
inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF
E/manifest.safe

```
  creating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E   5.SAF
E/preview/
  inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T1007 27_005901_0079A1_49E 5.SAF
E/preview/quick-look.png
  inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E   5.SAF
E/preview/map-overlay.kml
  inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E   5.SAF
E/preview/product-preview.html
  creating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E   5.SAF
E/preview/icons/
  inflating:
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E   5.SAF
E/preview/icons/logo.png


$ ls
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E 5.SAF   E
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E5.zip
```

User runs the script to process the data. The first date string of the file is the output name, and the script specifies an output resolution of 30 meters.

```
$ rtc_sentinel_recipe.pl -r 30 20150513T100702
================================================================
                Sentinel RTC Program
================================================================
Processing resolution is 30 meters
file is
S1A_IW_GRDH_1SDV_20150513T100702_20150513T100727_005901_0079A1_49E5.
SAFE
Found beam mode iw
Found base resolution of 1.000000e+01
Getting a DEM file covering this SAR image
   found max latitude of -14.534316
   found min latitude of -16.87627
   found max longitude of -67.152425
   found min longitude of -70.211118
wget  -Odem.tif  "http://opentopo.sdsc.edu/otr/getdem?demtype=SRTMGL1&west=-
```

```
70.211118&south=-16.87627&east=-67.152425&north=-
14.534316&outputFormat=GTiff"
--2016-05-05 23:39:25--
http://opentopo.sdsc.edu/otr/getdem?demtype=SRTMGL1&west=-70.211118&south=-
16.87627&east=-67.152425&north=-14.534316&outputFormat=GTiff
Resolving opentopo.sdsc.edu... 198.202.90.222
Connecting to opentopo.sdsc.edu|198.202.90.222|:80... connected.
HTTP request sent, awaiting response... 302 Found
Location: http://ot-data1.sdsc.edu:9090/otr/getdem?demtype=SRTMGL1&west=-
70.211118&south=-16.87627&east=-67.152425&north=-14.534316&outputFormat=GTiff
[following]
--2016-05-05 23:39:25-- http://ot-
data1.sdsc.edu:9090/otr/getdem?demtype=SRTMGL1&west=-70.211118&south=-
16.87627&east=-67.152425&north=-14.534316&outputFormat=GTiff
Resolving ot-data1.sdsc.edu... 198.202.90.171
Connecting to ot-data1.sdsc.edu|198.202.90.171|:9090... connected.
HTTP request sent, awaiting response... 200 OK
Length: unspecified [application/octet-stream]
Saving to: “dem.tif”

   [                    <=>                    ] 185,735,316  488K/s  in
6m 0s

2016-05-05 23:45:36 (504 KB/s) - “dem.tif” saved [185735316]

gdalwarp -r cubic -t_srs '+proj=utm +zone=19 +datum=WGS84' dem.tif tmpdem.tif
utm2dem_i2.pl tmpdem.tif big.dem big.dem.par
nominal terrain altitude (m):     0.000
DEM projection (EQA, UTM, OMCH, OM, HOM, LCC, LCC2, TM, PS, SCH, PC, AEAC,
SIN): EQA :
*** enter DEM Datum, Ellipsoid, and Map Projection Parameters ***

NOTE: To search datum and ellipsoid database enter "?" for region name
NOTE: To define a new datum enter "other" as the region name
NOTE: For WGS84 datum enter "WGS84"

enter region name: number of available datums for regions: WGS84 : 1

ID:   1  DATUM:          WGS 1984   ELLIPSOID:          WGS 84
      REGION: Global Definition, WGS84, World

select DATUM ID number in the range 1 - 1:
```

selected DATUM: WGS 1984 ELLIPSOID: WGS 84 REGION: Global Definition, WGS84, World

***** DATUM and ELLIPSOID parameters *****
ellipsoid semi major axis (m): 6378137.000
ellipsoid semi-minor axis (m): 6356752.314
ellipsoid reciprocal flattening: 298.257224
ellipsoid eccentricity**2: 6.69438e-03

DATUM translation vector (x,y,z) (m): 0.0000 0.0000 0.0000
DATUM scale factor: 0.00000e+00
DATUM rotation about (x,y,z) (arc-seconds): 0.0000 0.0000 0.0000

input UTM projection parameters : proposed UTM zone number: 31 (with lon0 = 3.0
0 deg.)
UTM zone number: (31): input of false northing:false northing (northern hemisphere: 0, southern hemisphere: 10000000.): USAGE NOTE: HIT RETURN TO ACCEPT THE DEFAULT PARAMETER VALUE, OTHERWISE ENTER THE NEW VALUE!

DEM title: DEM : data format(REAL*4, INTEGER*2): REAL*4 : DEM height offset (m) (nominal=0.0): 0.0000: DEM height scale factor (nominal=1.0): 1.000000: DEM width (samples): 0: DEM height (lines): 0: posting (northing (m), easting (m)): 0.000000 0.000000 : offset of first DEM sample (northing (m), easting (m)): 0.0000 0.0000 : Found VV polarization - processing

Ingesting GRD file into Gamma format
par_S1_GRD */*/*vv*.tiff */*/*vv*.xml */*/*/calibration-*vv*.xml */*/*/noise-*vv*.xml 20150513T100702.vv.GRD.par 20150513T100702.vv.GRD
Multi-looking GRD file
multi_look_MLI 20150513T100702.vv.GRD 20150513T100702.vv.GRD.par 20150513T100702.vv.mgrd 20150513T100702.vv.mgrd.par 3 3
Running RTC process... initializing
mk_geo_radcal 20150513T100702.vv.mgrd 20150513T100702.vv.mgrd.par big.dem big.dem.par geo_vv/area.dem geo_vv/area.dem_par geo_vv image 30 0 -p -j -n 1 -q -c
Running RTC process... coarse matching
mk_geo_radcal 20150513T100702.vv.mgrd 20150513T100702.vv.mgrd.par big.dem big.dem.par geo_vv/area.dem geo_vv/area.dem_par geo_vv image 30 1 -p -j -n 1 -q -c

User hits return to accept the default parameter value or enters the new value.

scene title: DIFF_par determined from ISP image parameter files : range, azimuth offsets of image-2 relative to image-1 (samples): 0 0 : enter number of offset measurements in range, azimuth: 32 32 : search window sizes (32, 64, 128...) (range, azimuth): 256 256 : minimum matching cross-correlation (nominal: 0.2): 0.100:

Running RTC process... fine matching
mk_geo_radcal 20150513T100702.vv.mgrd 20150513T100702.vv.mgrd.par big.dem big.dem.par geo_vv/area.dem geo_vv/area.dem_par geo_vv image 30 2 -p -j -n 1 -q -c
Running RTC process... finalizing
mk_geo_radcal 20150513T100702.vv.mgrd 20150513T100702.vv.mgrd.par big.dem big.dem.par geo_vv/area.dem geo_vv/area.dem_par geo_vv image 30 3 -p -j -n 1 -q -c
data2geotiff area.dem_par image_0.ls_map 5 20150513T100702.ls_map.tif
data2geotiff area.dem_par image_0.inc_map 2 20150513T100702.inc_map.tif
data2geotiff area.dem_par area.dem 2 outdem.tif
gdal_translate -ot Int16 outdem.tif 20150513T100702.dem.tif

Found VH polarization - processing

Cross-pol is vh; Main pol is vv
Ingesting GRD file into Gamma format
par_S1_GRD */*/*vh*.tiff */*/*vh*.xml */*/*/calibration-*vh*.xml */*/*/noise-*vh*.xml 20150513T100702.vh.GRD.par 20150513T100702.vh.GRD
Multi-looking GRD file
multi_look_MLI 20150513T100702.vh.GRD 20150513T100702.vh.GRD.par 20150513T100702.vh.mgrd 20150513T100702.vh.mgrd.par 3 3
creating directory for output geocoded image products: geo_vh
Copying diff par file geo_vv/image.diff_par to geo_vh/image.diff_par
ln -f geo_vv/image_0.map_to_rdc geo_vh/image_0.map_to_rdc
ln -f geo_vv/image_0.ls_map geo_vh/image_0.ls_map
ln -f geo_vv/image_0.inc_map geo_vh/image_0.inc_map
ln -f geo_vv/image_0.sim geo_vh/image_0.sim
ln -f geo_vv/image_0.pix_map geo_vh/image_0.pix_map
mk_geo_radcal 20150513T100702.vh.mgrd 20150513T100702.vh.mgrd.par big.dem big.dem.par geo_vv/area.dem geo_vv/area.dem_par geo_vh image 30 3 -p -j -n 1 -q -c
Moving file image_cal_map.mli.tif to ../PRODUCT/s1a-iw-rtc-20150513T100702-vh.tif