DEM generation with the ips

```
Command line: ips delta.config
Program: ips

    Data type: STF
    Processing mode: DEM
```

[Ingest]

```
Command line: asf_import -format STF -log delta.log -quiet -lat 63.500000
64.200000 e2_3919.000 a

Command line: asf_import -format STF -log delta.log -quiet -lat 63.500000
64.200000 e1_23592.000 b
```

Both images are ingested as STF format with the same latitude constraint to focus on the area in Delta Junction where the ASF corner reflectors are deployed.

[Doppler]

```
Command line: avg_in_dop -log delta.log a b reg/avedop
Program: avg_in_dop

    Average: 2.096312e-01 -2.809000e-06 0.000000e+00
```

This program averages the Doppler polynomials in the processing parameter files of the master and slave images.

[Coregister first patch]

```
Command line: ardop -log delta.log -quiet -p 1 -v 3300 -l 0 -debug 1 -c a.dop a
reg/a_p1

Command line: ardop -log delta.log -quiet -p 1 -v 3300 -l 0 -debug 1 -c b.dop b
reg/b_p1
```

The first patch of the master and the slave image are processed using the average Doppler values.

```
Command line: coregister_coarse -log delta.log -quiet reg/a_p1 reg/b_p1 base.00
reg/ctrl1

    Baseline: Bn = -60.680820, dBn = 3.959511, Bp = 19.325935, dBp = -1.459707,
Btemp = -1.000020
    Offset slave image: dx = -2.875183, dy = -37.051548
    Certainty: 59.477118%
    Complex image offset is -185 rows, -2 columns
```

The first estimate for the offset is derived from the state vectors. This offset is then refined using a correlation match in the frequency domain. A first estimate of the baseline is stored as well as a parameter file used for the fine coregistration.

[Coregister last patch]

```
Command line: ardop -log delta.log -quiet -p 1 -v 3300 -l 16461 -debug 1 -c
a.dop a reg/a_pL

Command line: ardop -log delta.log -quiet -p 1 -v 3300 -l 16461 -debug 1 -c
b.dop b reg/b_pL

Command line: coregister_coarse -log delta.log -quiet reg/a_pL reg/b_pL base.00
reg/ctrlL

   Baseline: Bn = -60.680820, dBn = 3.959511, Bp = 19.325935, dBp = -1.459707,
Btemp = -1.000020
   Offset slave image: dx = -2.814972, dy = -37.055672
   Certainty: 69.128597%
   Complex image offset is -185 rows, -2 columns
```

The same procedure as for coregistering the first patch is applied over here.

[ardop - Master image]

```
Command line: coregister_fine -log delta.log -quiet -g 20 -f reg/a_p1 reg/b_p1
reg/ctrl1 reg/fico1
Program: coregister_fine

   Using Complex FFT instead of coherence for matching
   coregister_fine attempted 400 correlations, 376 succeeded.
```

The correlation technique uses by default an approach based on the coherence values. The quality of the offset points is evaluated by comparing forward and backward correlation. The grid size of the correlation points can be increased. This will lead to a better defined offset grid at the expense of processing time. Empirical studies show that a complex FFT approach for the correlation generally leads to a significant improvement in the coherence level.

```
Command line: coregister_fine -log delta.log -quiet -g 20 -f reg/a_pL reg/b_pL
reg/ctrlL reg/ficoL
Program: coregister_fine

   Using Complex FFT instead of coherence for matching
   coregister_fine attempted 400 correlations, 377 succeeded.
```

The fine coregistration is performed on both the first and the last patch.

```
Command line: fit_line -log delta.log -quiet reg/fico1 reg/line1
Program: fit_line

   Fit_line with 376 points:
   <img 2>.x=<img 1>.x+  0.0001440237249546*<img 1>.x+  2.5474446693804804
   <img 2>.y=<img 1>.y+  0.0002295734311467*<img 1>.x+185.1400117169461339

   x linear, x offset, y linear, y offset:
     0.0001340049717504   2.5836781231447490   0.0002244494772772
185.1628024106335886 301
```

This program performs a least-squares regression on the offset grid points calculated during the forward and backward correlation in the fine coregistration. From the weighted linear first-order least-squares fit a regression line is stored that serves as input to the creation of an offset file for SAR image processing.

```
Command line: fit_line -log delta.log -quiet reg/ficoL reg/lineL
Stopwatch started on date: Tue Jun 28 15:00:43 2005
Program: fit_line

   Fit_line with 377 points:
   <img 2>.x=<img 1>.x+  0.0001604277038263*<img 1>.x+  2.3673973103340575
   <img 2>.y=<img 1>.y+  0.0002304019004998*<img 1>.x+185.1183467629651034

   x linear, x offset, y linear, y offset:
     0.0001489173666843   2.4077702272425725   0.0002254558304249
185.1352615899909608 302
```

The same procedure is carried out for the last patch.

```
Command line: ardop -log delta.log -quiet -p 6 -v 3300 -l 0 -debug 1 -c a.dop -
power a a

   Calculating power image
```

The whole master image is processed in the average Doppler geometry. No other transformations are applied. The master image remains unchanged during the entire coregistration process.

[ardop - Slave image]

```
Command line: calc_deltas reg/line1 reg/lineL 16461 reg/deltas
```

The linear regression coefficients are converted to an offset file that can be used as an input for the SAR image processing.

```
Command line: ardop -log delta.log -quiet -p 6 -v 3300 -l 0 -o reg/deltas -debug
1 -c b.dop -power b b_corr

   Calculating power image
```

The slave image is processed applying the offsets determined by the linear regression. This approach eliminates an otherwise required resampling step outside the SAR processor.

[Interferogram/coherence]

```
Command line: igram -log delta.log a_cpx.img b_corr_cpx.img delta_igram
```

The generation of an interferogram is the result of the complex multiplication of the master and the slave image, i.e. the master image is multiplied with the complex conjugate of the slave image. The resulting interferogram is not deramped yet. Therefore, the phase values are still not corrected for earth curvature. For the interferogram an amplitude image as well as a phase image is created.

```
Command line: coh -log delta.log a_cpx.img b_corr_cpx.img coh.img
Program: coh

   Coherence      :  Occurances  :  Percent
   ---------------------------------------
    0.00 -> 0.10 :   00039713       0.209
    0.10 -> 0.20 :   00114789       0.604
    0.20 -> 0.30 :   00225746       1.188
    0.30 -> 0.40 :   00400386       2.106
    0.40 -> 0.50 :   00688465       3.622
    0.50 -> 0.60 :   01177413       6.194
    0.60 -> 0.70 :   02187634       11.509
    0.70 -> 0.80 :   04907175       25.816
    0.80 -> 0.90 :   08261494       43.463
    0.90 -> 1.00 :   01005185       5.288
   Maximum Coherence: 0.995
   Average Coherence: 0.750  (14264888.2 / 19008000) 100.000000
```

The coherence image is calculated for the two coregistered SAR images. It reads the number of looks from the metadata file unless another step interval or window size is given. The default look area is 5x1 and default step area is 15x3.

```
Command line: multilook -log delta.log -meta a_cpx.meta delta_igram
delta_igram_ml

   Input is 19800 lines by 4800 samples
   Ouput is 3960 lines by 4800 samples
```

The interferogram is multilooked using coherent summation. The multilooking of an interferogram results in an output that has square pixels. An RGB representation of the interferometric phase with the amplitude as background is created as well.

[Offset matching]

```
Command line: asf_check_geolocation -log delta.log delta_igram_ml_amp.img
delta_fixed.img offset dem_sim.img dem_slant.img
   Detected slant range SAR image
   Generating 30x30 DEM grid ...
   Fitting order 5 polynomial to DEM ...
   Maximum error in polynomial fit: 0.00268944.
   Clipping DEM to 3960x5200 LxS using polynomial fit ...
   Generating slant range DEM and simulating amplitude image ...
```

This program creates a mapping grid which can be used to extract a portion of a DEM to fit a given SAR image. The mapping grid points are used to fit a fifth-order polynomial. A subset of the reference DEM is created covering a slightly larger area than the SAR image. An additional 400 sample wide buffer is applied to ensure the complete mapping of the map projected image into slant range geometry.The program remaps a ground range elevation model into a slant range elevation model and creates a slant range simulated amplitude.

[Simulated phase]

```
Command line: dem2phase -log delta.log dem_slant.img delta.base.00
out_dem_phase.img
```

The phase image is derived from the slant range elevation using the image geometry and baseline.

```
Command line: dem2seeds -log delta.log dem_slant.img delta_igram_ml_amp.img
delta.seeds
Program: dem2seeds

   Potential seed points: 10000
   Final number of seed points: 3034

   Seed point distribution:

            X    X
       X X    X   XX
   X     XX  XX   XX
     X    XXXXXXXXX
     XX       XXXXXX
    X X XXXXXXXXXX
       XXXXXXXXXXXX
       XXXXXXXXXXXX
```

```
   XX    XXXXXXXXX
    XXXXXXXXXXXXX
   XXXXXXXXXXXXXX
   XXXXXXXXXXXXXX
   XXXXXXXXX   XXXX
   X XXXXXX    XXXX
   XX XXX X     XXX
```

This program searches for good seed point locations in a slant range digital elevation model. The algorithm first uses a dense regular grid of points to calculate the local slope. The points are sorted by local slope and the list is searched for the best points in a less dense grid to ensure a good spatial distribution. These seed point locations are used for refining the interferometric baseline. Good seed points are defined as those having minimal local slope.

[Deramp/multilook]

```
Command line: deramp -log delta.log delta_igram delta.base.00 igramd
   Baseline:   Normal: -60.680820, delta: 3.959511
               Parallel: 19.325935, delta: -1.459707
               Temporal: -1.000020 days
```

The interferogram is corrected for the earth curvature by removing the baseline induced phase shift.

```
Command line: multilook -log delta.log -meta a_cpx.meta igramd ml
Program: multilook

   Input is 19800 lines by 4800 samples
   Ouput is 3960 lines by 4800 samples
```

The deramped interferogram is multilooked to have phase values for square pixels.

[Phase unwrapping]

```
Command line: raster_calc -log delta.log ml_dem_phase.img '(a-b)%6.2831853-
3.14159265' ml_phase.img out_dem_phase.img
```

In order to simplify the phase unwrapping problem the topographic phase part derived the slant range DEM is subtracted from the multilooked interferogram.

```
Command line: phase_filter -log delta.log ml_dem_phase.img 1.6 filtered_phase
```

In this step, the Goldstein phase filter is applied to the interferogram. The filter raises the fast Fourier transformed phase in the frequency domain to some power and transforms the scaled image back into the time domain. This way the signal (topography or motion) in a phase image is preferentially amplified over the noise (decorrelation).

```
Command line: zeroify -log delta.log filtered_phase ml_phase.img
escher_in_phase.img
```

This program is used to set the phase values in the filtered phase image to zero that are zero in the phase simulated from the reference DEM.

```
Command line: escher -log delta.log escher_in_phase.img unwrap_dem
```

This program uses the Goldstein branch-cut phase unwrapping algorithm to unwrap the given [-π,π) input file into the phase unwrapped output file.

```
Command line: raster_calc -log delta.log unwrap_phase.img '(a+b)*(a/a)*(b/b)'
unwrap_dem.img out_dem_phase.img
```

The topographic phase that had been removed to simplify the phase unwrapping problem needs now to be added in again.

```
Command line: convert2ppm -mask unwrap_dem_phase.mask unwrap_mask.ppm
```

A phase unwrapping mask is created that contains detailed information about the phase unwrapping process.

```
Command line: deramp -log delta.log -backward unwrap delta.base.00 unwrap_nod
   Baseline:   Normal: -60.680820, delta:  3.959511
               Parallel: 19.325935, delta: -1.459707
               Temporal: -1.000020 days
```

In order to do the baseline refinement the unwrapped phase needs to be reramped, i.e. the flat earth phase term is added again.

[Baseline refinement]

```
Command line: refine_base -log delta.log -quiet unwrap_nod_phase.img delta.seeds
delta.base.00 delta.base.01

   Baseline:    Normal: -60.680820, delta: 3.959511
                Parallel: 19.325935, delta: -1.459707
                Temporal: -1.000020 days

   New Baseline:  Normal: -60.383602, delta: 4.371972
                  Parallel: 19.308496, delta: -1.759689


Command line: refine_base -log delta.log -quiet unwrap_nod_phase.img delta.seeds
delta.base.01 delta.base.02

   Baseline:    Normal: -60.383602, delta: 4.371972
                Parallel: 19.308497, delta: -1.759689
                Temporal: 1.000000 days

   New Baseline:  Normal: -60.381916, delta: 4.374791
                  Parallel: 19.308531, delta: -1.758919


Command line: refine_base -log delta.log -quiet unwrap_nod_phase.img delta.seeds
delta.base.02 delta.base.03

   Baseline:    Normal: -60.381916, delta: 4.374791
                Parallel: 19.308531, delta: -1.758919
                Temporal: 1.000000 days

   New Baseline:  Normal: -60.381912, delta: 4.374810
                  Parallel: 19.308533, delta: -1.758914
```

The baseline is refined in an iterative fashion using the reramped unwrapped phase and the seeds file derived the reference slant range DEM. The iteration usually converges in three steps.

```
Command line: deramp -log delta.log delta_igram delta.base.03 igramd
   Baseline:    Normal: -60.381912, delta: 4.374810
                Parallel: 19.308533, delta: -1.758914
                Temporal: 1.000000 days
```

The newly refined baseline is now applied to the original interferogram, removing the baseline induced phase shift.

```
Command line: multilook -log delta.log -meta a_cpx.meta igramd delta_igram_ml
Program: multilook

   Input is 19800 lines by 4800 samples
   Ouput is 3960 lines by 4800 samples
```

The resulting interferogram is multilooked again. This multilooked interferogram can now be analyzed to verify that there are no residual phase shifts are present that are caused by the baseline.

[Elevation]

```
Command line: deramp -log delta.log unwrap_nod delta.base.03 unwrap
   Baseline:   Normal: -60.381912, delta: 4.374810
               Parallel: 19.308533, delta: -1.758914
               Temporal: 1.000000 days
```

In order to convert the unwrapped phase into elevation it needs to be deramped with the refined baseline.

```
Command line: elev -log delta.log -quiet unwrap_phase.img delta.base.03
delta_ht.img delta.seeds
```

In this step the unwrapped phase is finally converted into a digital elevation model in slant range geometry.

```
Command line: eleverr -log delta.log -mask unwrap_dem_phase.mask coh.img
delta.base.03 delta_err_ht.img
```

A slant range DEM error map is generated from the phase unwrapping mask, coherence image and baseline information.

[Ground range DEM]

```
Command line: deskew_dem -log delta.log delta_ht.img elevation.img
Date: Program: deskew_dem

   DEM in slant range, but will be corrected.
   Correcting DEM geometrically.
```

The slant range DEM is converted to ground range and interpolates across areas that could not be unwrapped. This is done using a first order linear approximation to map slant ranges to ground ranges.

```
Command line: deskew_dem -i a_amp.img 1 elevation.img amplitude.img
```

```
Command line: deskew_dem -i delta_err_ht.img 1 elevation.img error.img

Command line: deskew_dem -i coh.img 0 elevation.img coh_gr.img
```

The amplitude, error map and coherence image are converted to ground range as well.

[Geocoding]

```
Command line: asf_geocode -read-proj-file
/share/asf_tools/projections/utm/utm.proj -resample-method bilinear -pixel-size
20.0 -log delta.log -quiet elevation delta_dem

Determining input image extent in projection coordinate space... done.

Performing analytical projection of a spatially distributed
subset of input image pixels... done.

For the differences between spline model values and projected values
for the analytically projected control points:
Mean: 0.0415724
Standard deviation: 0.0373593
Maximum (Worst observed error in pixel index distance): 0.210217
Maximum x error (worst observed error in x pixel index): 0.167267
Maximum y error (worst observed error in y pixel index): -0.176808
Upper left x corner error: 0.054716
Upper left y corner error: 0.113214
Lower right x corner error: 0.004211
Lower right y corner error: 0.002705

Resampling input image into output image coordinate space...

Storing geocoded image...


Command line: asf_geocode -read-proj-file
/share/asf_tools/projections/utm/utm.proj -resample-method bilinear -pixel-size
20.0 -log delta.log -quiet amplitude delta_amp

Command line: asf_geocode -read-proj-file
/share/asf_tools/projections/utm/utm.proj -resample-method bilinear -pixel-size
20.0 -log delta.log -quiet error delta_error

Command line: asf_geocode -read-proj-file
/share/asf_tools/projections/utm/utm.proj -resample-method bilinear -pixel-size
20.0 -log delta.log -quiet coh_gr delta_coh
```

In a final step the newly generated digital elevation model, the amplitude image, the error map and the coherence image are geocoded to a map projection. This is the link from the SAR geometry to the real world as it allows the use of the DEM in other application such as GIS etc.

[Export]

```
Command line: asf_export -format geotiff -log delta.log -quiet delta_dem
delta_dem

Command line: asf_export -format geotiff -log delta.log -quiet delta_amp
delta_amp

Command line: asf_export -format geotiff -log delta.log -quiet delta_error
delta_error

Command line: asf_export -format geotiff -log delta.log -quiet delta_coh
delta_coh
```

In order to use the results outside the ASF software tool environment all final results are exported to GeoTIFF format. This ensures that all the common commercial remote sensing and image processing packages can handle the results and keep the reference frame defined by the map projection.