

# **ERS – ASAR Integration in GAMMA IPTA Processing**

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## 1. Introduction

The purpose of this document is to describe a possible way for a relatively straight-forward and simple, yet adequate, integration of ASAR IS2 VV data with an ERS-1/2 data stack as part of an IPTA analysis.

## 2. Starting point

The starting point of the technical description is at the stage where an IPTA processing has been successfully completed for a stack of ERS scenes to a level defined in more detail below. The IPTA processing of the ERS stack is not described in this document.

### 2.1 ERS based solution

The ERS based IPTA processing is successfully completed to the following level: The ERS scenes were processed to SLC and co-registered. Point scatterer candidates were determined (resulting in the point list *pt*) and for some of these points (defined by *pmask1*) the following parameters were determined:

- uncorrected height values (*pdem*)
- corrected height values (*phgt1*)
- linear deformation values (*pdef1*)
- non-linear deformation phases (*pdef\_phase*, optional)
- atmospheric phases (*patm1*)
- baselines (typically refined, *pbase*)

This solution was consistent in the sense that the point-wise differential interferogram calculated by subtracting the phase model (sum of topographic phase, linear deformation phase, non-linear deformation phase, atmospheric phase) from the point-wise interferogram (*pint*) looks relatively smooth with values near a constant phase and a reasonably low phase noise in the spatial and the temporal dimension.

Apart from the above listed files which describe the phase model the following files are used to define or document the solution:

<i>19991104.dem</i>	<i>SLC_tab</i>	<i>bperp.ascii</i>	<i>pSLC</i>
<i>pbase</i>	<i>pdem</i>	<i>pt</i>	<i>19991104.rml.par</i>
<i>ave.rml</i>	<i>bperp_plot.gif</i>	<i>pSLC_par</i>	<i>pdef1</i>
<i>phgt1</i>	<i>19991104.rslc.par</i>	<i>ave.rml.ras</i>	<i>itab</i>
<i>patm1</i>	<i>pdef1.ras</i>	<i>pmask1</i>	<i>pdef_phase</i>

Typically, either a backup of the ERS solution is made or the files are copied to a new directory used for the integration of the ASAR data integration.

## ***2.2. Derivation of ASAR SLC which are co-registered to the ERS reference SLC***

The ASAR RAW data are processed using the GAMMA MSP. An often used selection of processing parameters is that all the scenes (ERS and ASAR) are processed to the same Doppler Centroid (or alternatively the bandwidth fraction in selected bandwidth can be selected, or alternatively each scene can be processed to its own optimal Doppler parameters).

Alternatively, ASAR SLC data processed by an ESA Pac can be used.

The registration of the ASAR SLC to the selected ERS SLC reference geometry can principally be done in the same manner, as it is done for an ERS SLC. But you have to be more careful. Because of the different azimuth sampling (different azimuth pixel size) a relatively strong linear trend in the offsets needs to be determined and corrected. In any case the offsets should be determined in an iterative manner (running `offset_pwr` and `offset_fit` more than once).

Maybe more robust and therefore better suited is the use of the novel programs (to be included in next GAMMA software distribution):

- `rdc_trans`
- `SLC_interp_lt`

The main purpose of these programs is to support the consideration of terrain height effects on the SLC resampling, but this program is also very convenient in the co-registration between data acquired by different sensors or sensor configurations. The first program calculates the transformation between the images based on the imaging geometry using SAR parameters (orbit, sensor, mode) as well as terrain heights (or an assumed constant terrain height). The transformation is stored in the form of a transformation lookup table. The second program supports the resampling using the second image to the reference geometry. The transformation lookup table can be refined based on the data itself in a similar way as used in the normal image co-registration (using `offset_pwr`, `offset_fit` for a rough but efficient refinement using multi-look intensity images and `offset_pwr`, `offset_fit` for a very accurate final refinement using the full resolution SLC data).

As a result of this step the ASAR SLC (typically denoted `.rslc`) and the related SLC parameter files (`.rslc.par`) are available in the same geometry as the ERS reference SLC. No phase correction (phase trend or similar) was applied in this step.

## **3. Update IPTA files to include ASAR scenes**

So far the IPTA files only concerned the ERS data. Some of the files need to be updated to include also the ASAR data:

The starting point of the technical description is at the stage where an IPTA processing has been successfully completed for a stack of ERS scenes to a level defined in more detail below. The IPTA processing of the ERS stack is not described in this document.

### ***3.1 SLC\_tab***

The `SLC_tab` contains the filenames of the registered SLC and the corresponding SLC parameter file. Lines have to be added to include also the ASAR scenes.

### **3.2 pSLC\_par, pSLC**

For the new SLC\_tab the stack of SLC parameter files pSLC\_par and the stack containing the SLC values for the point list, pSLC, need to be updated using the program SLC2pt. As these two files are normally not further modified during the further ipta processing the records for the ERS scenes can just be regenerated and the following command can be used:

```
SLC2pt SLC_tab pt - pSLC_par pSLC -
```

### **3.3 itab**

The itab contains the definitions of the pairs used in the IPTA processing. Lines have to be added to include also the pairs with ASAR scenes. In the simplest case with a single ERS reference which shall also be used for the ASAR scenes this is done by adding for each ASAR scene one line. Other cases are dealt with accordingly (basically not taking into account if a scene is ASAR or ERS).

Notice that the flags in the itab file can be used. It is for example possible to have the itab with the ASAR scenes from the beginning but just to set the flag to 0 for the pairs with ASAR scenes for the initial “ERS-only” IPTA processing.

### **3.4 Baselines**

The baseline file, pbase contains all the individual baseline files (\*.base) of the interferometric pairs selected in the itab file. Records have to be added for the new lines in the itab, respectively for the ERS – ASAR (and if selected ASAR – ASAR ) pairs.

It is important to be aware that precision baselines are probably already determined for the ERS pairs. Therefore, the program base\_orbit\_pt should not be run for the entire stack but only individually for the new records. For security reasons it is recommended to save a copy of the “ERS only” baselines file. The new baselines are added using commands such as:

```
base_orbit_pt pSLC_par itab_ASAR 57 pbase_ASAR
base_orbit_pt pSLC_par itab_ASAR 58 pbase_ASAR
...
base_orbit_pt pSLC_par itab_ASAR 66 pbase_ASAR
```

After this step the baseline file contains precision baselines for the ERS pairs and initial orbit based baseline estimates for the pairs with an ASAR scene. The program base\_par\_pt can be used to copy the precision baselines to the initial baseline parameters:

```
base_par_pt tmp pbase_ASAR - 2
    (copy precision baseline to initial baseline where available)
base_par_pt - pbase_ASAR - 0
    (check if baselines available as expected)
```

After this the “currently best baseline is available as “initial baseline” for all interferometric pairs, so that the initial baseline can be used in the phase simulation and the regression analysis.

### ***3.5 Interferogram stack, pint***

The interferogram stack corresponding the itab with the ASAR pairs is generated using the program `intf_pt`:

```
intf_pt pt - itab_ASAR - pSLC pint 1
```

Notice that the program `intf_pt` has recently been updated with a modification applied to cases where the two scenes of a pair are acquired with different carrier frequencies. In this case a phase ramp is applied to the second scene to correct the phase of the second SLC such that it corresponds to the carrier frequency of the first (reference) scene.

The updated version of `intf_pt` will be included in next GAMMA software distribution.

### ***3.6 Atmospheric phase stack, patm***

The atmospheric phase stack corresponding the itab with the ASAR pairs is generated by copying additional lines with non-zero values very close to 0.0 into the additional records using the program `lin_comb_pt`:

```
lin_comb_pt pt pmask1 patm1 1 patm1 1 patm1 57 0.00001 0. 0. 2 1
lin_comb_pt pt pmask1 patm1 1 patm1 1 patm1 58 0.00001 0. 0. 2 1
...
lin_comb_pt pt pmask1 patm1 1 patm1 1 patm1 66 0.00001 0. 0. 2 1
```

### ***3.7 Non-linear deformation phase stack, pdef\_phase***

The non-linear deformation phase stack corresponding the itab with the ASAR pairs is generated by copying additional lines with non-zero values very close to 0.0 into the additional records using the program `lin_comb_pt`:

```
lin_comb_pt pt pmask1 pdef_phase 1 pdef_phase 1 pdef_phase 57 0.00001 0. 0. 2 1
lin_comb_pt pt pmask1 pdef_phase 1 pdef_phase 1 pdef_phase 58 0.00001 0. 0. 2 1
...
lin_comb_pt pt pmask1 pdef_phase 1 pdef_phase 1 pdef_phase 66 0.00001 0. 0. 2 1
```

## **4. Generate ASAR differential interferograms using “ERS-only” based model**

Next the differential interferogram stack is calculated. The phase model derived beforehand using the ERS data pairs only is used as model (i.e. `phgt1`, `pdef1`, `patm1`, `pdef_phase`) is used for this purpose. In the following example commands record 47 is the reference SLC. The itab contains all pairs with the reference SLC (single reference case), line 47 in the itab is for the autointerferogram (47 – 47) and therefore `patm1` record 47 contains the atmosphere of the reference SLC.

The atmosphere of the reference SLC is subtracted from each record to derive the atmospheres for the interferometric pairs (also from the near zero values for the ASAR pairs to compensate the influence of the atmosphere in the reference ERS acquisition).

```
lin_comb_pt pt pmask1 patm1 - patm1 47 patm1x - 0.0 1.0 -1.0 2 1
```

Then the phase model (psim\_unw0) considering the linear deformation rate (pdefl) and the point heights (phgt1) is calculated

```
phase_sim_pt pt pmask1 pSLC_par - itab_ASAR - pbase_ASAR phgt1 psim_unw0 pdefl 0 0
```

and subtracted from the point interferogram stack:

```
sub_phase_pt pt pmask1 pint - psim_unw0 ptmp0 1 0
```

Then, the atmospheric phases (patm1x) and the non-linear deformation phases (pdef\_phase) are subtracted:

```
sub_phase_pt pt pmask1 ptmp0 - patm1x ptmp1 1 0
sub_phase_pt pt pmask1 ptmp1 - pdef_phase pdiff0 1 0
```

Resulting in the (complex valued) differential interferogram stack pdiff0. Displaying pdiff0 is achieved using:

```
prasmph_pwr24 pt pmask1 19991104.rslc.par pdiff0 - 19991104.rmli.par ave.rmli 1
```

and shows the following:

For the “ERS-only” pairs (in our example these are the pairs 1-56) the differential phase looks spatially smooth, with only a slight noise around an almost constant value. This is the result of the previous ipta processing for the ERS-only scenes.

The pairs between the ERS reference (scene 47) and the ASAR scenes (i.e. records 57-66 in our example) look noisy.

The reason for this phase noise is the following: In the interferogram calculation a phase correction was applied to compensate the ASAR phases for the slightly different ASAR carrier frequency (i.e. 5.331 GHz instead of 5.300 GHz). This phase correction corresponds to the addition of a phase ramp in range direction. The slope of this phase ramp is:

$$phase\_slope = \frac{4\pi(f_{ASAR} - f_{ERS})}{c} = 1.3 \frac{rad}{m}$$

which results in a phase correction per slant range pixel of:

$$phase\_per\_slant\_range\_pixel = phase\_slope \cdot dr = 10.4rad$$

This phase correction is applied assuming that the phase center for a SLC resolution cell is located at the geometric center of the pixel. This is appropriate for a distributed scatterer (e.g. a rough bare soil), nevertheless this assumption is not correct for a point like scatterer. The scattering phase center of a point like scatterer is located at one specific location within the SLC pixel. The correction applied is not correct in this case. In fact the error of the correction is distributed over the interval  $-5.2$  rad to  $+5.2$  rad (i.e. more than an entire phase cycle) which results in the very noisy appearance observed for the differential point interferograms.

If pairs between two ASAR scenes are included then these look relatively smooth. The phase corresponds to:

- a baseline related phase trend
- atmospheric phase
- non-linear deformation phase

## **5. Determine ERS - ASAR point wise phase offset: `ph_offset0`**

In the previous step we noted, that the phase correction applied in the interferogram generation was wrong by a certain offset because of the deviation of the position of the phase center of the point like scatterer from the center of the resolution cell. The correction applied and the related error for the point like scatterers is the same for all ERS – ASAR pairs (constant ERS and ASAR carrier frequencies and constant scatterer position).

From a mathematical point of view this means that for each point one distinct phase correction needs to be determined. No spatial correlation of this phase correction is expected (position of point scatterer phase center within the resolution cell is random).

A very straightforward and simple way to determine this phase offset is to assume that one of the ERS – ASAR differential interferograms directly corresponds to this phase correction. Ideally, a pair with an ASAR scene with low atmospheric errors is selected (for an explanation why see error discussion below). Furthermore, the selection of a pair with a relatively short baseline is preferred as higher phase noise is expected for pairs with long baselines. If non-linear deformation is important an ASAR scene acquired close to an ERS scene (time-wise) should be selected to minimize errors related to non-linear deformation.

The differential interferogram corresponds to the difference between the currently best available model and interferogram. Based on the ERS scenes some knowledge on the accuracy of the accuracy of this model is available.

Apart from the point wise ERS – ASAR phase offset (which is the target parameter) the differential interferogram contains terms related to model errors and noise. In particular the atmosphere of the ASAR scene and is not included in the model (respectively assumed to be a constant value near 0.0). Similarly, no non-linear deformation phase (or at most an interpolated estimate) was considered. Furthermore, no refined baseline was considered.

Practical examples showed that the point wise ERS – ASAR phase correction determined with this approach was good enough to continue the processing and integrate the ASAR scenes to the ERS series.

Technically, using the IPTA software this step is done as follows. First a file with values close to 0.0 is generated, to be used later on for the conversion of the complex interferogram values to real valued phases:

```
lin_comb_pt pt pmask1 psim_unw0 - psim_unw0 - phase_0 - 0.00001 0. 0. 2 1
```

Then the (real valued) phase of the complex valued differential interferogram is determined such that it is between  $-\pi$  and  $+\pi$ . The phase correction will be applied to complex valued interferograms only and therefore no unwrapping of the phase correction is necessary. The complex values to phase conversion is done by unwrapping using 0-phase as reference:

```
unw_model_pt pt pmask1 pdiff0 - phase_0 ph_offset0 7436
```

This phase offset (record 64; i.e. using the itab pair 64 to determine the correction) can be displayed using:

```
pdisdt_pwr24 pt pmask1 19991104.rslc.par ph_offset0 64 19991104.rmli.par ave.rmli 6.3 1
```

The phase correction looks random (as previously the related differential interferogram).

In a next step this point wise ERS – ASAR phase correction is copied to a data stack for a convenient application of this phase correction. All records corresponding to ERS-only (or ASAR-only) pairs have non-zero phase correction values very close to 0.0 (in our example records 1-56). All records corresponding to ERS – ASAR pairs (in our example records 57 - 66) contain the point-wise ERS-ASAR phase offset.

Technically this is achieved by first generating a stack (EA\_phase) with a small non-zero value for each point in each record:

```
lin_comb_pt pt pmask1 psim_unw0 - psim_unw0 - EA_phase - 0.00001 0. 0. 2 1
```

Then the point-wise ERS-ASAR phase offset is copied to the records corresponding to ERS – ASAR pairs:

```
lin_comb_pt pt pmask1 ph_offset0 64 ph_offset0 64 EA_phase 57 0.0 0. 1. 2 0
lin_comb_pt pt pmask1 ph_offset0 64 ph_offset0 64 EA_phase 58 0.0 0. 1. 2 0
...
lin_comb_pt pt pmask1 ph_offset0 64 ph_offset0 64 EA_phase 66 0.0 0. 1. 2 0
```

## 6. Apply point wise ERS – ASAR phase offset

Now, the point-wise ERS-ASAR phase offset can be subtracted from the differential interferograms:

```
sub_phase_pt pt pmask1 pdiff0 - EA_phase pdiff1 1 0
```

The corrected differential interferograms are displayed using:

```
prasmph_pwr24 pt pmask1 19991104.rslc.par pdiff1 - 19991104.rmli.par ave.rmli 1
```

Now all the ERS – ASAR point wise differential interferograms look smooth! For these differential interferograms it should be possible to unwrap and interpret the phase.

The differential interferogram record 64 (selected ASAR reference) the phase is a constant, near-zero value.

## 7. Unwrapping of differential interferometric phases for ASAR scenes

Probably the most straightforward approach for the unwrapping is to do spatial phase unwrapping for the pairs with at least one ASAR scene. This can be done with or without application of a slight spatial filtering. In difficult cases not a single method may be ideal for



all the records but only an adaptation of the processing parameters for the individual case may lead to the result. In any case a careful quality control (visualizing and checking the temporal and spatial consistency of the unwrapped phases) is very essential.

In the following one possible approach which includes a slight spatial filtering of the complex valued differential interferogram is indicated:

```
spf_pt pt pmask1 19991104.rslc.par pdiff1 pdiff1_spf - 0 5 0 -
mcf_pt pt pmask1 pdiff1_spf - - - pdiff1_spf.unw 20 4 7359 0
prasdt_pwr24 pt pmask1 19991104.rslc.par pdiff1_spf.unw - 19991104.rml.par ave.rml 12.6
2
unw_model_pt pt pmask1 pdiff1 - pdiff1_spf.unw pdiff1.unw 7359
prasdt_pwr24 pt pmask1 19991104.rslc.par pdiff1.unw - 19991104.rml.par ave.rml 12.6 2
```

In this example the unwrapping was also repeated for the ERS-only pairs and this result was used as it looked fully reliable. Nevertheless, the already existing unwrapped phases should be used in the case of any difficulty with the unwrapping for the ERS-only pairs.

The unwrapping needs to be repeated for individual pairs until a solution which appears reliable is found. Possibilities to come to this solution also include the estimation and subtraction of an atmospheric phase or the refinement of the baseline.

The unwrapped phase of the differential interferogram is then used to calculate the unwrapped phase of the original point-wise interferogram:

```
/bin/rm ptmp0 ptmp1
sub_phase_pt pt pmask1 pdiff1.unw - psim_unw0 ptmp0 0 1
sub_phase_pt pt pmask1 ptmp0 - patm1x ptmp1 0 1
sub_phase_pt pt pmask1 ptmp1 - pdef_phase pint_unw 0 1
```

Here we did not add back the ERS – ASAR phase offset, EA\_phase. So we have to keep in mind that this phase was already subtracted from pint\_unw.

## **8. Refine ASAR baselines and update differential interferogram**

Once the unwrapped phases are available for the pairs with the ASAR scenes the related baselines can be refined using base\_ls\_pt. For this refinement we only consider points with a very low linear deformation rate (masking other points). Notice that we use the original heights and not the corrected heights. This is done individually for the records corresponding to pairs with an ASAR scene using the steps:

```
/bin/cp pmask1 pdef1_mask
thres_msk_pt pt pdef1_mask pdef1 1 -0.002 0.002
base_ls_pt pt pdef1_mask pSLC_par - itab_ASAR 57 pint_unw pdem pbase_ASAR 0 1 1 1 1
1.
base_ls_pt pt pdef1_mask pSLC_par - itab_ASAR 58 pint_unw pdem pbase_ASAR 0 1 1 1 1
1.
...
base_ls_pt pt pdef1_mask pSLC_par - itab_ASAR 66 pint_unw pdem pbase_ASAR 0 1 1 1 1
1.
```

At this stage the baseline file `pbase_ASAR` contains refined ERS-only pair baselines in the parameters for the original baseline parameters (first two lines) and for the ASAR pairs orbit based baselines in the parameters for the original baseline parameters (first two lines) and refined baselines in the parameters for the refined baseline parameters (third and fourth lines). After making a backup copy of this baseline stack file we copy all precision baselines to the initial baseline:

```
cp pbase_ASAR pbase_ASAR.bu
base_par_pt tmp pbase_ASAR - 2
    (copy precision baseline to initial baseline where available)
base_par_pt - pbase_ASAR - 0
    (check if baselines available as expected)
```

The difference between the “old phase model” using the original orbit based baseline and the “new phase model” can be calculated as the different between the related simulated phase images. `psim_unw0`, calculated in step 4, with the orbit based baseline represents the old phase model, `psim_unw1` calculated below the new phase model (with the refined baselines for the pairs with ASAR scenes (using identical `phgt1` and `pdef1` as used to calculate `psim_unw0`))

```
phase_sim_pt pt pmask1 pSLC_par - itab_ASAR - pbase_ASAR phgt1 psim_unw1 pdef1 0 0
lin_comb_pt pt pmask1 psim_unw0 - psim_unw1 - tmp0 - 0.00001 -1.0 1.0 2 1
```

For the pairs with ASAR scenes `ptmp0` contains the difference between the simulated phase using the refined and the original baselines, for the ERS-only pairs it contains 0.00001.

This phase correction `ptmp0` can now be subtracted from the differential interferogram `pdiff1` and the unwrapped differential interferogram `pdiff1.unw`:

```
sub_phase_pt pt pmask1 pdiff1 - tmp0 pdiff2 1 0
sub_phase_pt pt pmask1 pdiff1.unw - tmp0 pdiff2.unw 0 0
```

Notice that this approach is without unwrapping the phases again. This may be a significant advantage in all the cases where the unwrapping was only achieved after a significant effort. Unwrapping the new differential interferogram `pdiff2` may make sense as the unwrapping problems may be reduced using a better baseline model (this possible iteration is not described here).

The differential with the refined baselines are displayed using:

```
prasdt_pwr24 pt pmask1 19991104.rslc.par pdiff2.unw - 19991104.rmli.par ave.rmli 12.6 2
```

## 9. Regression analysis

Only now the ASAR data also enter a regression analysis. This can be done “at different levels”. We recommend to rather do it without redoing too much the entire analysis from scratch. One possible approach is to use the unwrapped differential interferogram and the program with a single spatial reference point (not the complex valued files and processing using multiple patches):

```
def_mod_pt pt pmask1 pSLC_par - itab_ASAR pbase_ASAR 0 pdiff2.unw 0 7359 pres1
pdh1 pddef1 punw1 psigma1 pmask2 5. 0.03 5.0 2 pdh_err pdef_err ppc_err
```

Here a high phase standard deviation is allowed in order not to exclude points at this stage. Using the additional pairs with the ASAR data height corrections to the point heights (pdh1) and the linear deformation rate (pddef1) are determined. It is expected that these corrections are rather small. The various terms are displayed using commands such as

```
pdisdt_pwr24 pt pmask1 19991104.rslc.par pdh1 1 19991104.rmlt.par ave.rmlt 3.0 1
pdisdt_pwr24 pt pmask1 19991104.rslc.par pddef1 1 19991104.rmlt.par ave.rmlt 0.005 1
pdisdt_pwr24 pt pmask1 19991104.rslc.par psigma1 1 19991104.rmlt.par ave.rmlt 1.5 1
pdisdt_pwr24 pt pmask1 19991104.rslc.par pdh_err 1 19991104.rmlt.par ave.rmlt 3.0 1
pdisdt_pwr24 pt pmask1 19991104.rslc.par pdef_err 1 19991104.rmlt.par ave.rmlt 0.005 1
pdisdt_pwr24 pt pmask1 19991104.rslc.par ppc_err 1 19991104.rmlt.par ave.rmlt 1.5 1
```

It is also recommended to check pres1 for unwrapping errors:

```
prasd_t_pwr24 pt pmask1 19991104.rslc.par pres1 - 19991104.rmlt.par ave.rmlt 12.6 1
```

Next, the residual phase is used (1) to update the atmospheric phase estimate for the ERS-only pairs and (2) to estimate a first atmospheric phase for the pairs with ASAR data. This is typically done by spatial filtering of the residual phase (unless a non-linear deformation term is estimated first):

```
spf_pt pt pmask1 19991104.rslc.par pres1 pres1_spf - 2 25 0 -
prasd_t_pwr24 pt pmask1 19991104.rslc.par pres1_spf - 19991104.rmlt.par ave.rmlt 6.3 1
```

## 10. Model update

In a next step the model is updated for the terms determined in the regression analysis. Here the naming convention used is such that the new names correspond again to the old names (to reduce the total number of files used).

Update point heights:

```
/bin/cp phgt1 phgt0
lin_comb_pt pt pmask1 phgt0 1 pdh1 1 phgt1 1 -0. 1. 1. 2 0
```

Update linear deformation rates:

```
/bin/cp pdef1 pdef0
lin_comb_pt pt pmask1 pdef0 1 pddef1 1 pdef1 1 -0. 1. 1. 2 0
```

Atmospheric phases:

```
/bin/cp patm1 patm0
lin_comb_pt pt pmask1 patm0 - pres1_spf - patm1 - -0. 1. 1. 2 0
```

Non-linear deformation phase:

In the case a non-linear deformation term was estimated from the residual phases it is used to update the stack of non-linear deformation phases in the same way as the atmospheric phases are updated.

## 11. Iteration

### 11.1. Regression analysis

The model updating can now be iterated by applying the new model (i.e. subtracting the new model from the unwrapped interferogram), running the regression analysis on the updated differential interferogram, estimating again non-linear deformation and atmospheric phase corrections, and updating again the phase model.

Unless there are clear indications for phase unwrapping errors it is not recommended to redo the phase unwrapping as this may destabilize the iteration (for a few points).

### 11.2. ERS-ASAR phase offset estimation

At this stage it is also possible to re-estimate the ERS-ASAR phase offsets. Previously, this was done based on a single (but well suited) ASAR scene with the limitation that the phase offsets contain components related to the inaccuracy of the assumed phase model, such as the atmospheric phase and the non-linear deformation phase for this selected ASAR scene, as well as its phase noise.

Now, that unwrapped phases are available for all the ERS-ASAR scenes and more advanced models (e.g. the related atmospheric and non-linear deformation phases are estimated) it is possible to improve the ERS-ASAR phase offset estimation based on all the ERS-ASAR pairs. This is simply done by averaging (point wise) of the non-models terms (corresponding to the unfiltered residual phases of the regression analysis).

One advantage of this improvement is that the previously selected “reference” ASAR scene is won back as an independent observation. Previously, its differential phase was by definition set to zero (respectively a very small non-zero value) which did not permit to determine its atmosphere or non-linear phase. When using an average estimate based on all the ERS-ASAR pairs it will deviate from this estimate. This deviation will be related to its atmospheric and non-linear deformation phase.

## 12. Calculate and visualize displacement series

After the end of the iteration the displacement time series is calculated by first calculating the total displacement phases and by converting these to displacements.

What is typically used as “the total displacement phase” consists not only of the linear phase model and the non-linear phase but also of the residual phase error which could not be included in the model terms. Consequently, not only the deformation phase terms but also the residual phase of the last regression have to be added to calculate the total deformation phase:

```
/bin/rm ptmp1 ptmp2
phase_sim_pt pt pmask1 pSLC_par - itab_ASAR - pbase_ASAR - ptmp1 pdef1 1 0
lin_comb_pt pt pmask1 ptmp1 - pdef_phase1 - ptmp2 - 0.00001 1. 1. 2 0
lin_comb_pt pt pmask1 ptmp2 - pres1 - pdef_phase_tot - 0.00001 1. 1. 2 0
dispmap_pt pt pmask1 pSLC_par itab_ASAR pdef_phase_tot phgt1 pdisp1 0
prasdt_pwr24 pt pmask1 19991104.rslc.par pdisp1 66 19991104.rmli.par ave.rmli 0.05 2
```

For an interactive access to the displacement series the program `vu_disp` is used:

```
vu_disp pt pmask1 pSLC_par itab_ASAR pdisp1 pdef1 phgt1 psigma2 pdh_err pdef_err -
pdisp1.ras
```

At this stage an often used step is to restrict the visualization to the points with qualities above a certain criteria, e.g. with a phase standard deviation below a given threshold. This is done using:

```
/bin/cp pmask1 pmask_sigma1
thres_msk_pt pt pmask_sigma1 psigma1 1 0.01 1.0
```

Then the mask file `pmask_sigma1` can be used to restrict the visualization to the points with qualities above a certain criteria:

```
prasdt_pwr24 pt pmask_sigma1 19991104.rslc.par pdisp1 66 19991104.rml.par ave.rml 0.05
2
vu_disp pt pmask_sigma1 pSLC_par itab_ASAR pdisp1 pdef1 phgt1 psigma1 pdh_err
pdef_err - pdisp1.ras
```

### 13. Visualization in map geometry

So far all the displays were done in the multi-look slant range geometry. The IPTA also supports the display of the results in the map geometry. The strategy used here is that for each point the related map coordinate is calculated and kept in a vector data structure of `fcomplex` values. The map coordinate of a point can be calculate under consideration of (1) a refinement necessary to adjust for offsets between the calculated map coordinates and a reference data set representing these coordinates (e.g. a backscatter image simulate based on a DEM) and (2) the individual point heights determined in the IPTA analysis.

A possible sequence to prepare the file containing the point locations (pixel numbers relative to map section defined in a DEM parameter file), `pt_map`, and the file with the related map coordinates, `pmap`, is the following:

```
gc_map 19991104.rml.par - Luxemburg.utm.dem_par Luxemburg.utm.dem
Luxemburg.utm.dem_par.tmp - 19991104.lt 1 1 19991104.sim
geocode 19991104.lt 19991104.sim 840 19991104.sar_sim 400 1500 0 0
create_diff_par 19991104.rml.par - 19991104.diff_par 1
offset_pwr 19991104.sar_sim ave.rml 19991104.diff_par 19991104.off 19991104.snr 256
256 offsets 2 16 16 7.0
offset_fitm 19991104.off 19991104.snr 19991104.diff_par coeffs coeffsets 7.0 3
offset_pwr 19991104.sar_sim ave.rml 19991104.diff_par 19991104.off 19991104.snr 128
128 offsets 2 32 32 7.0
offset_fitm 19991104.off 19991104.snr 19991104.diff_par coeffs coeffsets 7.0 3
```

Here the screen output contains information on the quality of the geocoding refinement determined – this can look such as:

```
final solution: 264 offset estimates accepted out of 1024 samples
final range offset poly. coeff.: -6.968e+00 2.813e-03 9.840e-04
final range offset poly. coeff. errors: 6.214e-03 2.798e-05 3.286e-05
final azimuth offset poly. coeff.: 2.183e+00 -1.088e-04 -4.695e-03
final azimuth offset poly. coeff. errors: 6.273e-03 2.825e-05 3.317e-05
```

final model fit std. dev. (samples) range: 0.1808 azimuth: 0.1825

Then the geocoding refinement is applied to refine the lookup table:

```
gc_map_fine 19991104.lt 840 19991104.diff_par 19991104.lt_fine 1
```

Using the refined lookup table it is possible to geocode raster data sets such as the average intensity image:

```
geocode_back ave.rml 400 19991104.lt_fine ave.utm.rml 840 760 2 0
dispwr ave.utm.rml 840
ras_dB ave.utm.rml 840 1 0 1 1 -22. 3.5 0. 1
```

Furthermore, the point coordinates can be calculated under the consideration of the refinement and the IPTA point heights using

```
pt2geo pt pmask1 pSLC_par - itab_ASAR phgt1 Luxemburg.utm.dem_par 19991104.diff_par
1 5 pt_map pmap
```

allowing then to visualize point data in map geometry (raster format); e.g. for the linear deformation rate:

```
prasdt_pwr24_map pt_map pmask_sigma1 Luxemburg.utm.dem_par pdef1 1 ave.utm.rml
0.005 1
mv pdef1.ras pdef1.utm.ras
```

or to generate a visualization of the point locations:

```
ras_pt pt_map pmask_sigma1 ave.utm.rml.ras pt.utm.ras 1 1 255 0 0 2
```

which can then be used with

```
disras_dem_par pt.utm.ras Luxemburg.utm.dem_par
```

to get the map coordinates at the cursor location.

And the deformation histories can be visualized in map geometry using:

```
vu_disp pt_map pmask_sigma1 pSLC_par itab_ASAR pdisp1 pdef1 phgt1 psigma1 pdh_err
pdef_err pmap pdef1.utm.ras
```

## 14. Generation of ASCII files of results

An ASCII file of the result of an IPTA processing can be generated using:

```
disp_prt pt_map pmask_sigma1 - pSLC_par itab_ASAR pmap phgt1 pdef1 psigma1 pdh_err
pdef_err pdisp1 7359 items.txt disp_tab.txt
```

The file, items.txt, contains a list of the column definitions used in the ASCII format result file disp\_tab.txt.