PALSAR-2 ScanSAR Interferometry

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1. INTRODUCTION

In this document a new processing sequence for interferometry with PALSAR-2 ScanSAR data is described.

Previously, interferometry with PALSAR-2 ScanSAR SLCs processed with the full aperture processor and provided in CEOS format was already supported, as described in the PALSAR-2 users guide (see Section 9 of the document PALSAR2_Support_in_GAMMA_150630.pdf). In this data format separated SLC files are provided per sub-swath. As no common grid is used for the SLC data of the different sub-swaths, separate differential interferograms are generated in the slant range geometry, geocoded, and then mosaiced into one combined (full-swath) geocoded differential interferomgram. Using the orbit based phase simulation this resulted in consistent phases between the sub-swaths, permitting further processing as phase unwrapping, and and the estimation of line-of-sight displacements.

Certain steps, such as the band-pass filtering used in the estimation of ionospheric path delays or the spectral diversity approach used to determine persistent scatterer candidates need to be done in the slant range geometry. So we implemented an approach that permits to resample and mosaic the SLC data of the different sub-swaths in the slant range geometry. This was done such, that the sub-swath SLCs can be handled as “burst SLCs” with an SLC_tab, a burst SLC file, the corresponding burst SLC parameter file and a “TOPS_par” file with the information on the bursts. Because of the processing with the full aperture processor the data of a sub-swath corresponds to a single burst. Thanks to this approach the ScanSAR functionality can then be used to mosaic the burst SLCs, generate multi-look intensity mosaics, and co-register multiple burst SLCs to a common reference. The resulting co-registered PALSAR-2 ScanSAR SLC stacks can be used for time series analyses with the IPTA module.

2. NEW PALSAR-2 SCANSAR SLC READER

In the mid 2022 release a new PLSAR-2 ScanSAR SLC reader was added to the GAMMA software (*PALSAR_import_SLC_from_zipfile.py*). This reader imports the selected subswaths of a PALSAR-2 ScanSAR SLC (from full-aperture processor, provided in CEOS format). The SLC data are resampled onto a common grid. Optionally, a positional refinement is determined based on the burst overlaps. Besides the slc data files and the slc_par files tops_par files and an SLC_tab are generated, so that ScanSAR programs can be used. In this step the data is reduced to the selected sub-swaths and polarizations. Reducing the coverage in the along-track direction is supported by the program *SLC_copy_PALSAR_ScanSAR.py*.

Because of the full-aperture processing, each sub-swath is treated as a single burst. The spectrum of the burst differs in that it includes several (typically 5) small sub-bands of the azimuth spectrum – corresponding to the actual bursts of the acquisition – instead of on larger azimuth band. In combination these sub-bands cover about 20% of the azimuth bandwidth, so the data is strongly oversampled in the azimuth direction. The spectra can be displayed at *using dismph_fft*.

3. MULTI-LOOK INTENSITY IMAGE AND GEOCODING

Based on the "ScanSAR burst SLC format" PALSAR-2 data we can then generate a (mosaic) multi-look intensity image using the program *multi_look_ScanSAR*. In this step we also determine the location of the cuts between the subswaths. Only pixels of one sub-swath will be averaged into one multi-look pixel. And in the overlap region only one sub-swath is considered to avoid having different statistics than in the regions with just one sub-swath.

Geocoding of the multi-look intensity image (MLI) is then done using the normal sequence (as for stripmap mode data), e.g. using the script *geocoding.py*. Besides the refined geocoding lookup table quality information on the refinement is generated. In addition the backscatter image is transformed into the map geometry and the DEM heights from the map geometry into the MLI slant range geometry.

4. CO-REGISTRATION

The PALSAR-2 "ScanSAR burst SLC" data can be coregistered using the program *ScanSAR_coreg.py*. Only the intensity matching method is applied. The spectral diversity method is not applicable and is not applied (the program detects that there is only a single burst). The "*no_check*" option should be applied as the parameters used for the checking are not fully applicable for the full-aperture processor SLC. Besides the co-registered burst SLC the program also determines a quality file with information on the matching statistics and the refinement offset determined. Furthermore, the differential interferogram between the reference and the second image is calculated.

5. EXTRACT CO-REGISTERED MOSAIC SLC STACK

Based on the co-registered burst SLCs a stack of co-registered mosaic SLCs in slant range geometry can be generated – this also for a reduced area, e.g. only including small sections of two adjacent sub-swaths. This is done using the programs *SLC_mosaic_ScanSAR* (to generate the mosaic) and *SLC_copy* (to extract a sub-section; in this step the indicated offsets and number of lines and cols need to respect the multi-looking applied). This mosaic SLC stack can be used in the same way as a "normal" strip map mode SLC stack (except for the fact that the location of the cuts between the sub-swaths need to match with the multi-looking applied). An example of a mosaic over Svalbard, SLC that includes all the 5 sub-swaths, is shown in Figure 1.

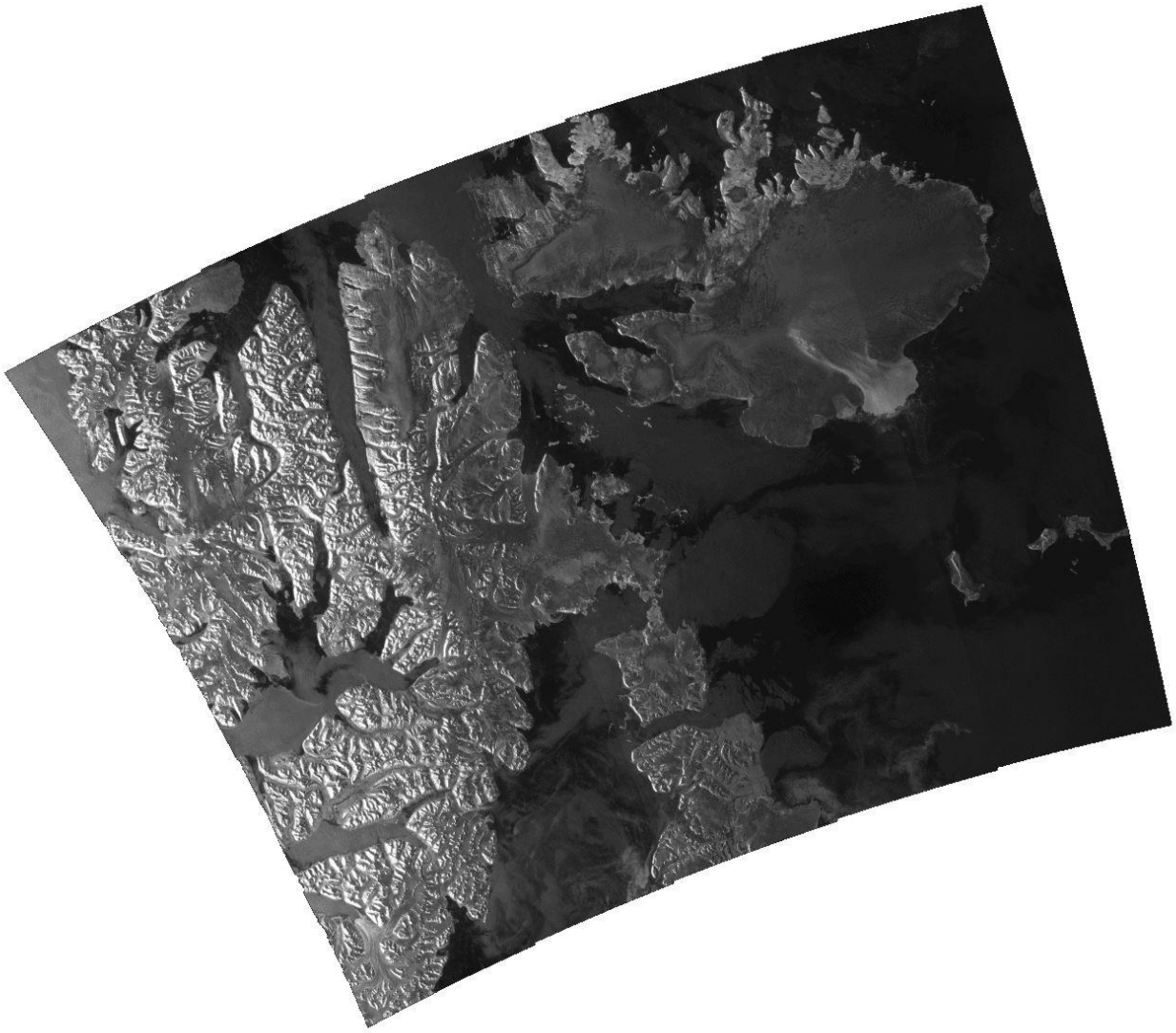


Figure 1. Example of PALSAR-2 ScanSAR SLC mosaic (shhjown after multi-looking and geocoding) over Svalbard. In the swath overlap region only one swath is considered.

6. GENERATION OF DIFFERENTIAL INTERFEROGRAM

For the co-registered mosaic RSLCs the normal sequence can be used to generate differential interferograms. In this no azimuth common band filtering should be applied, as the information on the azimuth spectra is not available in the parameter files. An example of the commands is listed below:

create_offset 20160721.rslc.par 20160623.rslc.par 20160721_20160623.off 1 4 24 0

phase_sim_orb 20160721.rslc.par 20160623.rslc.par 20160721_20160623.off 20160721.hgt 20160721_20160623.sim_unw 20160721.rslc.par - - 1 1

SLC_diff_intf 20160721.rslc 20160623.rslc 20160721.rslc.par 20160623.rslc.par 20160721_20160623.off 20160721_20160623.sim_unw 20160721_20160623.diff 4 24 1 0 0.2 1 1

rasmph_pwr 20160721_20160623.diff 20160721.rmli 2969 - - - - rmg.cm 20160721_20160623.diff.bmp 1. .35 24

For PALSAR-2 ScanSAR acquisitions in 2014 the timing of the bursts between repeat observations is often not synchronized. The azimuth spectra don't owerlap, the interferograms are not coherent. Then from very early 2015 the PALSAR-2 ScanSAR acquisitions are typically synchronized. The azimuth spectra almost perfectly overlap, the interferograms show coherence. Common band filtering considering the special ScanSAR azimuth spectra can be done using the program *SLC_adf*. Usually, the synchronization is excellent so that this is not necessary.

Many interferograms that include one or both acquisitions from 2015 (or 2016) show a significant linear phase trend across the scene. Our interpretation is that this is related to the raw data processing. The trend can be estimated from the unwrapped phase using *quad_fit* (using model 3) and subtracted using *quad_sub*.

An example of a co-seismic PALSAR-2 ScanSAR differential interferogram is shown in Figure 2.

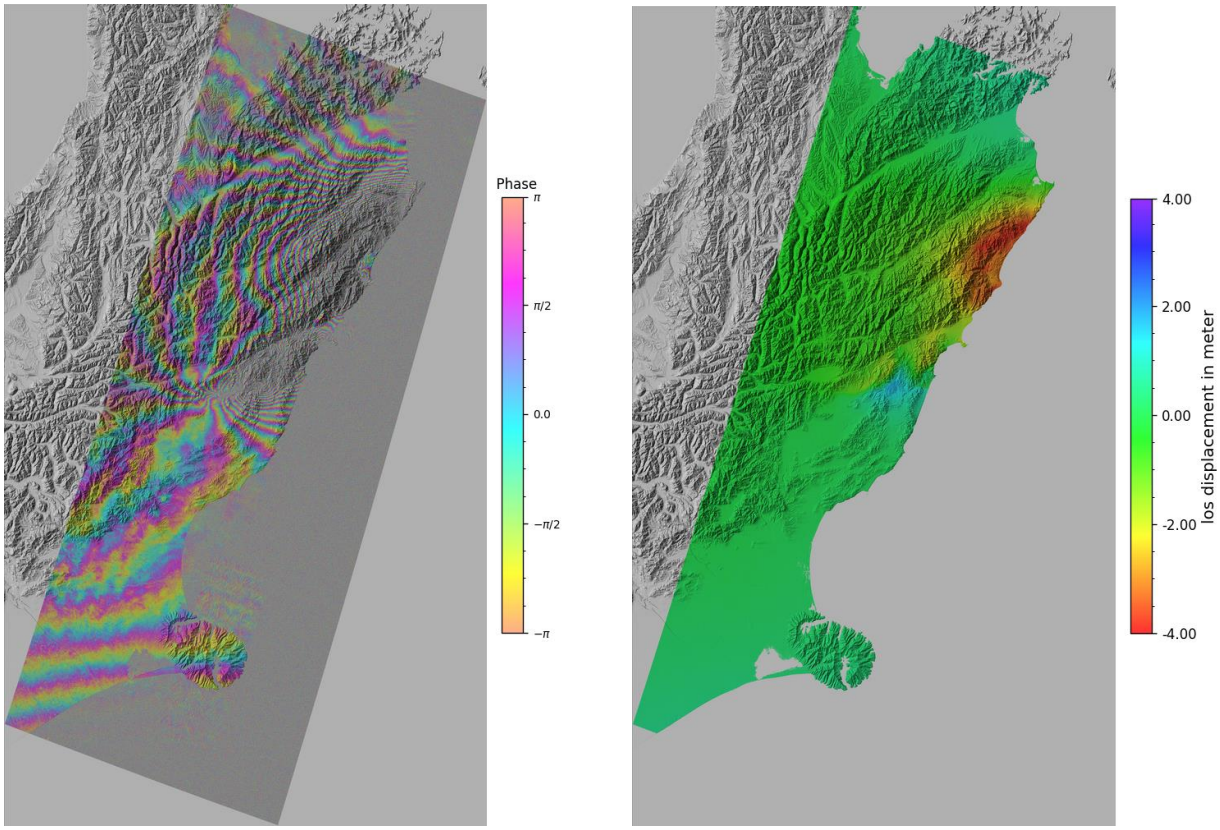


Figure 2. Co-seismic PALSAR-2 ScanSAR differential interferogram (20161018_20161115) for the New Zealand Earthquake in 2016, using sub-swaths F4 and F5. The image to the left shows the geocoded differential interferogram, the image to the right the derived line-of-sight displacement. An interative phase unwrapping procedure was used.

7. OFFSET TRACKING

The co-registered mosaic RSLCs can also be used for offset tracking. The azimuth sampling is smaller than the range sampling, e.g. 3m versus 8.5m. Nevertheless, the azimuth resolution is significantly lower as the azimuth spectral bands only cover a small fraction of the sampling bandwidth (< 20%). In the range direction the processing bandwidth is about 2/3 of the sampling rate. For the quality of the estimated offsets the actual resolution (in both directions about 15m) is the relevant parameter. So PALSAR-2 ScanSAR data is suited to estimate meter scale offsets as caused by ice motion, and very strong earthquakes. Furthermore, ionospheric path delay variation can cause significant azimuth positional offsets (Figure 3).

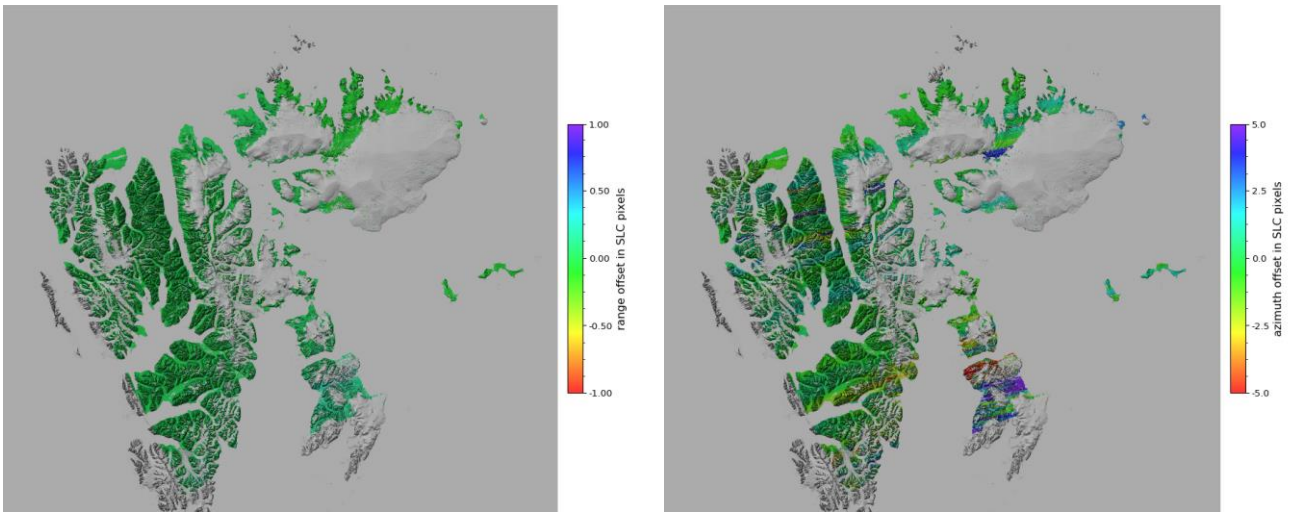


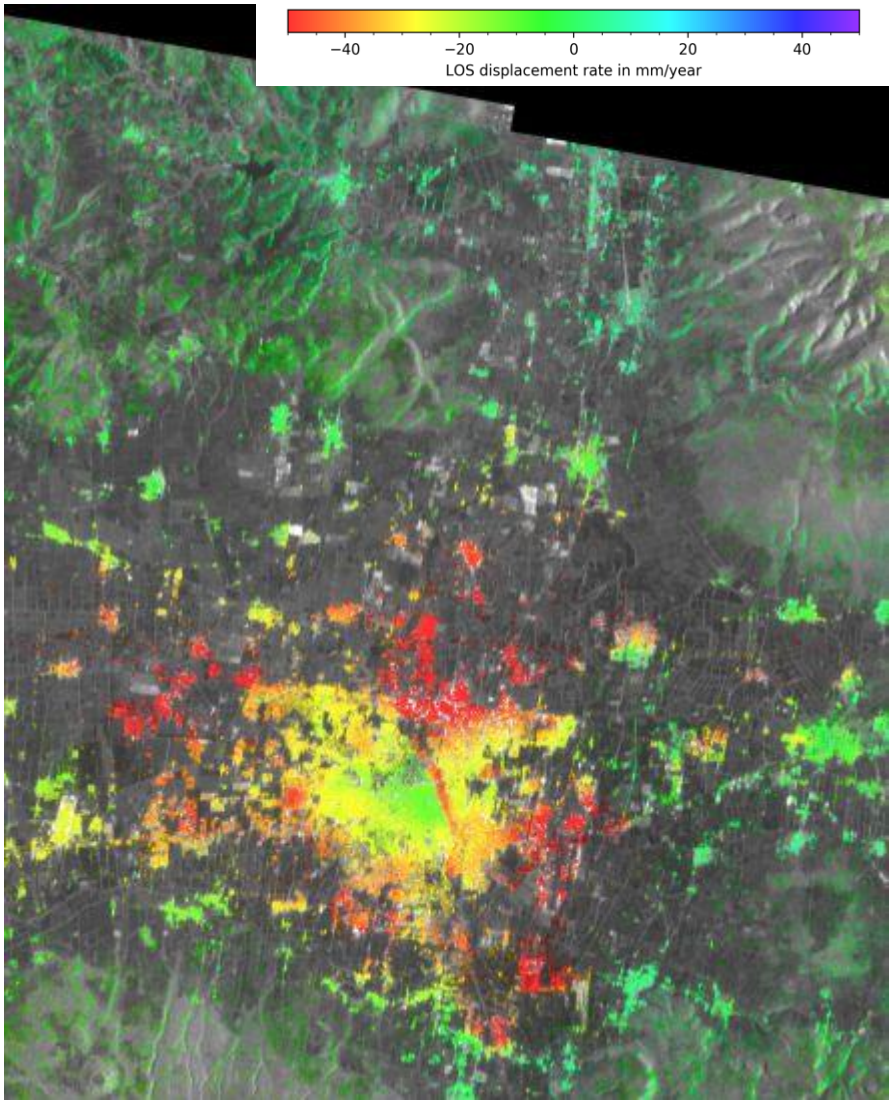
Figure 3. Range (left) and azimuth (right) offsets between the two PALSAR-2 ScanSAR SLCs acquired on 16. And 30. Aug. 2015. Azimuth offsets of more than 10m (several azimuth SLC pixels) are observed. The azimuth offsets are most likely related to strong along-track gradients in the ionospheric path delay.

8. PERSISTENT SCATTERER INTERFEROMETRY

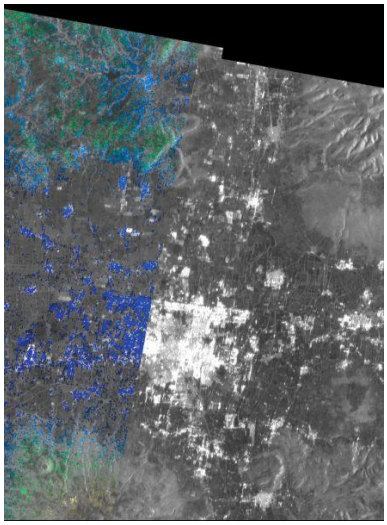
The co-registered mosaic RSLCs can also be used for persistent scatterer interferometry. Persistent scatterer candidates can be determined using the spectral diversity (program *sp_stat*) and low temporal backscatter variability (program *pwr_stat*) criteria. The determnined candidate lists look very reasonable in that solutions are found for many of the candidates.

Because of the L-band frequency used the phase noise, the atmospheric path delay variation, and the sensitivity to height errors and displacements are all relatively low. As a result the technique works well and is well suited for rather fast movements. The displacement rate precision achieved depends strongly on the total time period covered, the number of acquisitions available for that period, and the thresholds used in the processing.

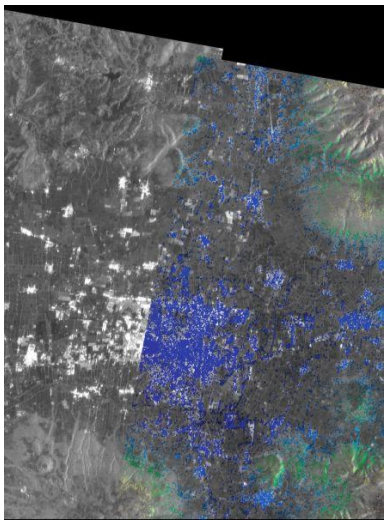
Using the co-registered mosaic SLC stack as input has the advantage that the sequence used fully corresponds to the one used for strip-map mode data stacks. But the analysis can also be done using the sub-swath SLC stacks, as demonstrated in the IPTA demo example for Celaya, Mexico (see Figure 4).



Celaya, Mexico, line-of-sight displacement rate



sub-swath F5 data (phgt)



sub-swath F4 data (phgt)

Figure 4. PALSAR-2 ScanSAR data based Persistent Scatterer Interferometry over Celaya, Mexico. Two adjacent sub-swaths were used in the processing. The image to the right shows the terrain height for the points in sub-swath F5 (top) and sub-swath F4 (bottom). The processing can either be done based on separate stacks per sub-swath (as demonstrated in the corresponding GAMMA demo example), or using the co-registered mosaic SLC stack. In both approaches terms as the overall phase trends and the atmospheric path delay phase are preferably estimated in map geometry for the combined data set.

9. ASSESSMENT OF PALSAR-2 SCANSAR MOSAIC SLCS

In this section we do an assessment of using PALSAR-2 ScanSAR mosaic SLCs versus using the separate sub-swath SLCs.

Using PALSAR-2 ScanSAR mosaic SLCs	**Using PALSAR-2 ScanSAR sub-swath SLCs**
data import	
Importing a data set using the new method (*PALSAR_import_SLC_from_zipfile.py*) that resamples the sub-swath SLCs to a common grid resuls in more or less the same files (per sub-swath) and similar file sizes as the convetional reading. Besides the resampling to the common grid the main difference is that "tops_par" files and and SLC_tab file are generated, so that the combined data set can be treated as ScanSAR data set. This makes a significant number of ScanSAR data tools applicable.	Importing a data set using the old method (par_EORC_*PALSAR*) results in separate SLCs per sub-swath. Different azimuth sampling are used for the different sub-swaths – the sub-swath SLCs are not on a common grid. No "ScanSAR" files ("tops_par" files and SLC_tab) are generated. Programs for ScanSAR data cannot be used.
file sizes	
An original PALSAR-2 ScanSAR data set of the full-aperture processor, provided as a zip has typically a size of about 30 GByte per polarization. The mosaic SLC (in FCOMPLEX format) has a similar size as the original data (~30 GByte). So file sizes and number of pixels in a data set (e.g. 26'000 x 150'000 pixels) are substantial. When working with a stack at least the burst SLC should be kept for the reference and the co-registered burst SLCs for the other scenes.	No (very large) mosaic SLC file is generated, but the total size of the sub-swaths SLCs is about the same. For each sub-swath the reference SLC and the co-registered SLC of the other scenes should be kept.
geocoding, co-registration	
Geocoding and co-registration of repeat-pass SLCs is done using the available ScanSAR tools.	Each sub-swath is individually geocoded and co-registered. The geocoded sub-swath data (e.g. backscatter or interferogram are then mosaiced in map geometry).

DInSAR	
Multi-look differential interferograms are generated based on the mosaic SLCs in slant range geometry. The differential interferograms can then be further processed (filtered, unwrapped etc.) in slant range or map geometry.	Multi-look differential interferograms are generated per sub-swath in slant range geometry, then geocoded and combined into one large geocoded differential interferogram. Using the orbit based phase simulation (*phase_sim_orb*) the phases match between sub-swaths. The differential interferograms can then be further processed (filtered, unwrapped etc.) in map geometry, only.
spectral filtering	
SAR data have specific (slant) range and azimuth spectra. Certain SAR processing tools use spatial filtering. Examples are band-pass filtering as used for split-beam and split-spectrum interferometry and the spectral filtering used in *sp_stat* to identify point like scatterers (as persistent scatterer candidates, in the IPTA). Such filtering has to be done in slant range geometry, so mosaic SLCs have the advantage that it can be done more consistently.	Spectral filtering has to be done in the slant range geometry. Accordingly, it is necessary to do it per sub-swath and then to geocode and combine the results. Filtering done on an interferogram (e.g. using *adf*) is not affected and can be done in slant-range of map geometry.
IPTA processing	
Stacks of co-registered PALSAR-2 ScanSAR SLC mosaic sections can be used as stripmap mode data for IPTA processing.	The point target identification needs to be done in slant range geometry – and therefore separately for the separate sub-swath sections. For the condidates both the slant range and map positions are known. Using the same map section for the different subswaths permits combining the point lists and related values (e.g. SLC values, interferogram values) and to apply the IPTA processing steps in map geometry. The GAMMA Software demo example *PALSAR2_ScanSAR_Mexico* demonstrates how this can be done.
Overall assessment	
Results in very large files, but the procedures are somewhat more straight forward.	More processes are done separately per sub-swath and accordingly more intermediate files are generated (lookup tables, interferograms etc.). But it works and the quality of the results corresponds to those of the new procedure.