InSAR Time Series Analysis of Sentinel-1 data Using GMTSAR and iGPS

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https://github.com/igps-ftk/iGPS
https://www.ngs.noaa.gov/gps-toolbox/Tian.htm
https://sourceforge.net/projects/igps/

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PREPARE INPUT DATA

Input Data

Create a root directory (e.g., /g4d/esa.data) to hold all input data.
Set the environmental variable esa_data to this directory, e.g. in C-shell:

setenv esa_unzip /g4d/esa.data

- **Sentinel-1 C-band SAR SLC data** (e.g., S1A_IW_SLC__1S *.zip)
  - ${esa_data}/ s1/ Files can be stored anywhere, linked to here.

- **Sentinel-1 Orbits** (*.EOF)
  - ${esa_data}/aux_poeorb POE Orbits
    - 2019
    - 2020
  - ${esa_data}/aux_resorb Rapid Orbits
    - 2019
    - 2020

- **DEM**
  - ${esa_data}/ topo/strm3/

Obtain Sentinel-1 Data

- ESA website
  - https://scihub.copernicus.eu/dhus/#/home
- ASF website (recommended)
  - https://search.asf.alaska.edu/

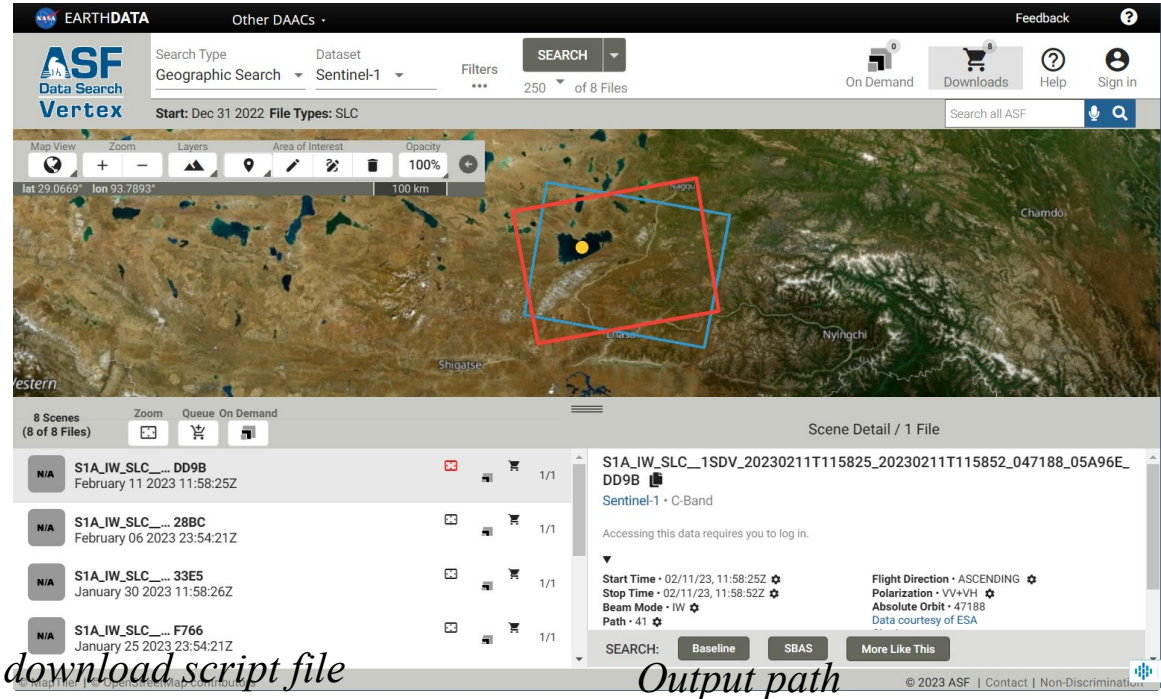
First, create a free account of those websites. The username and password will be required upon downloading request.

The downloaded zip files can be stored anywhere, but linked to ${esa_data}/s1/ directory.

Obtain Sentinel-1 Data

Get the list of data using ASF Vertex interface.

Save the download python script (*.py) to the data directory.



iGPS provides a shell script to download the files listed in the python script, e.g.

ASF Python download script file

Output path

sh_asf_s1_get_slc_py ***-file download-all-2023-02-11_12-16-04.py*** ***-opath `pwd`***
-aria2_conf your_login_name_password_file

sh_asf_s1_get_slc_py

Uses aria2 utility to download the Sentinel-1 SLC files from ASF.

It requires three command-line options:

1. -file download-all-.py

   Python downloading script obtained from ASF. Used to extract the SLC filenames.

2. -opath your_output_path

   Output path on your hard disk.

3. -aria2_conf your_login_name_password_file

   Your login information stored in a file.

   e.g. aria2.conf:

   ```
   http-user=tian
   http-passwd=123
   ```

Get the Satellite Orbits from ESA

https://scihub.copernicus.eu/gnss/#/home

Public account:
Username: gnssguest
Pasword: gnssguest

Orbits files can be downloaded using iGPS script
sh_esa_s1_get_aux_orb_gnss

E.g., download the POE orbits in the past 60 days,
sh_esa_s1_get_aux_orb_gnss -orbit poe -ndays 60
sh_esa_s1_get_aux_orb_gnss -d 2018-12-03
sh_esa_s1_get_aux_orb_gnss -orbit res
sh_esa_s1_get_aux_orb_gnss -orbit poe -ndays 10

Get the Satellite Orbits from ASF

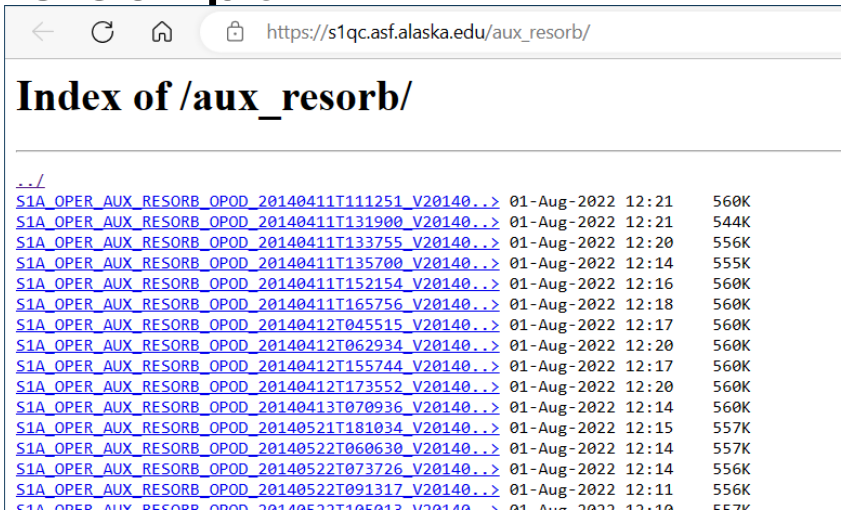
https://s1qc.asf.alaska.edu/aux_poeorb/

https://s1qc.asf.alaska.edu/aux_resorb/

All files are stored under the directory. It takes a while for listing.

Can be downloaded using iGPS script

sh_asf_s1_get_aux_orb



This script use **wget** to download files. You may store the EARTHDATA account and password in a **wget.conf** file and pass it to the script:

```
http_user=xxx
http_password=yyy
```

sh_asf_s1_get_aux_orb example

- To download the POE orbits (default) in the past 30 days,

sh_asf_s1_get_aux_orb -orb poe -n 30

- To download the RES orbits in the past 3 days,

sh_asf_s1_get_aux_orb -orb res -n 3

- To use your own EARTHDATA login information,

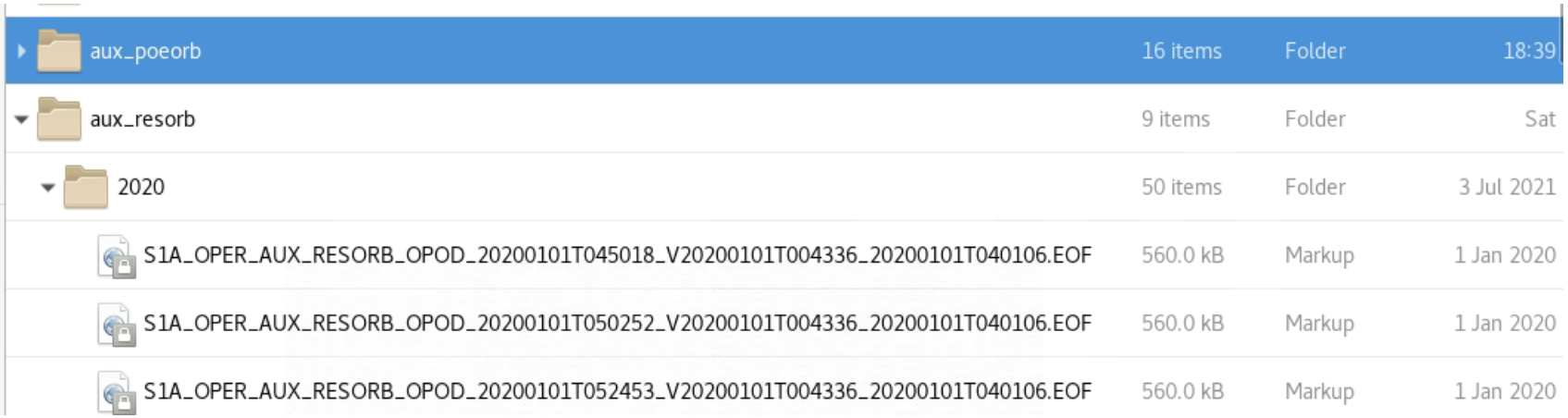
sh_asf_s1_get_aux_orb -wget_conf /your/wget/username_password_file

- Do not update page listing (if no changes in ASF server; ASF put all files in one directory, which makes it takes a while to list files):

sh_asf_s1_get_aux_orb -u n

Local Orbit Data

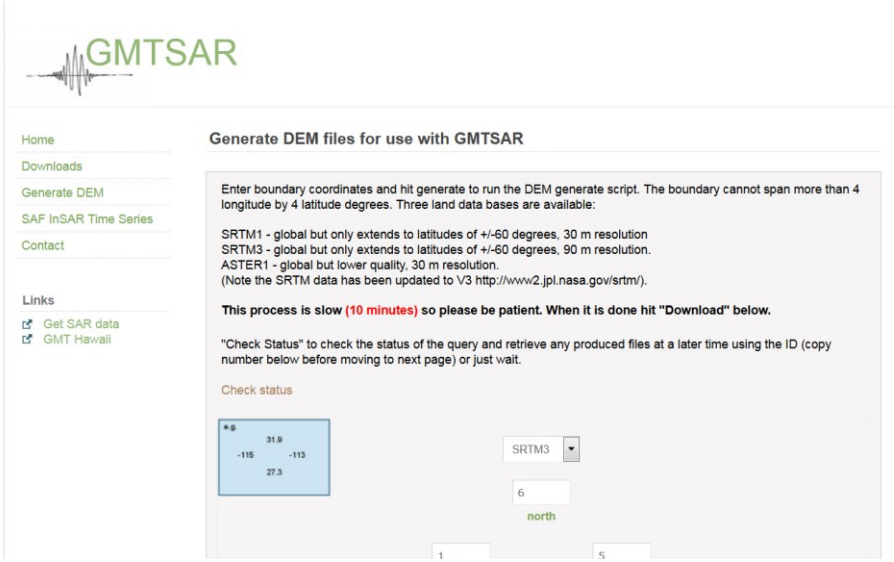
- The local orbit files are stored by year, because the search is usually too slow and sometime fails if put so many files in one directory.



Download DEM

https://topex.ucsd.edu/gmtsar/demgen/

- Maximum range for single download: 4° ×4°
- SRTM3: 90-m ground pixel size
- SRTM1/ASTER1: 30-m



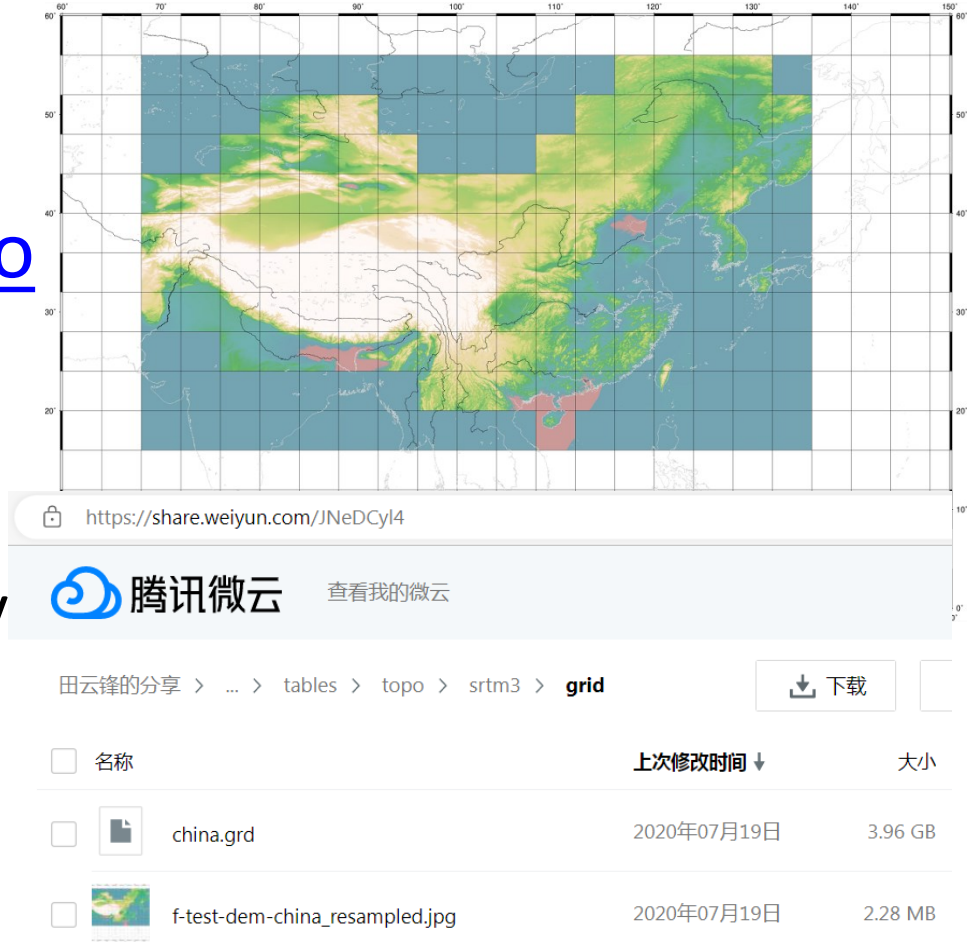
- Make sure it fully covers your area; otherwise strange fringes related to topography may appear in phase.

China Mosaic for SRTM-3

Obtain china.grd file from

- Weiyun: https://share.weiyun.com/JNeDCyl4

  – Save it to $esa_data/topo/srtm3/grid/



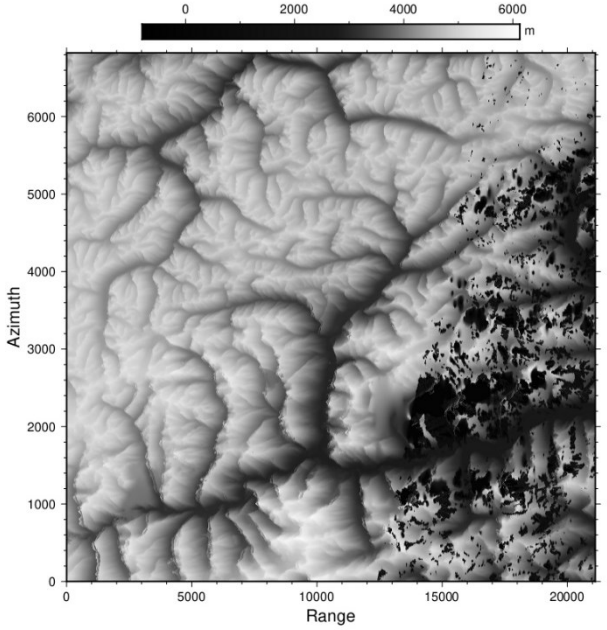
Use grdcut to clip the file for your ROI.

```
gmt grdcut china.grd -Gdem.grd -Rlon1/lon2/lat1/lat2
```

iGPS script **sh_s1_run_tsa** can perform the clipping automatically according to the frame KML files.

Verify DEM

- Old versions of SRTM may have holes.



- Check the topo_ra.pdf file in topo directory (after the first interferogram processed) and make sure it looks OK.

- GMT
- GMTSAR
- iGPS
- Dependencies

SOFTWARE INSTALLATION

Linux OS

First, you need a Linux OS system. Choose a stable release as you like.

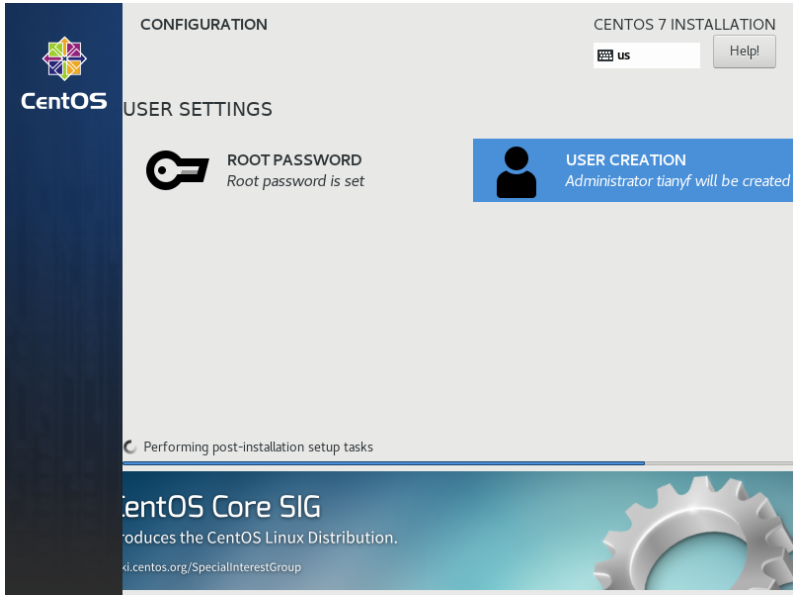
- CentOS 7,8; Rocky
- Ubuntu

Example: Centos 7

https://www.centos.org/download/

To save downloading time, get the minimum distribution ISO file, e.g. CentOS-7-x86_64-Minimal-2207-02.iso

Install the system with default settings is OK. We can add others later.



Example: CentOS 7

Install the following packages:

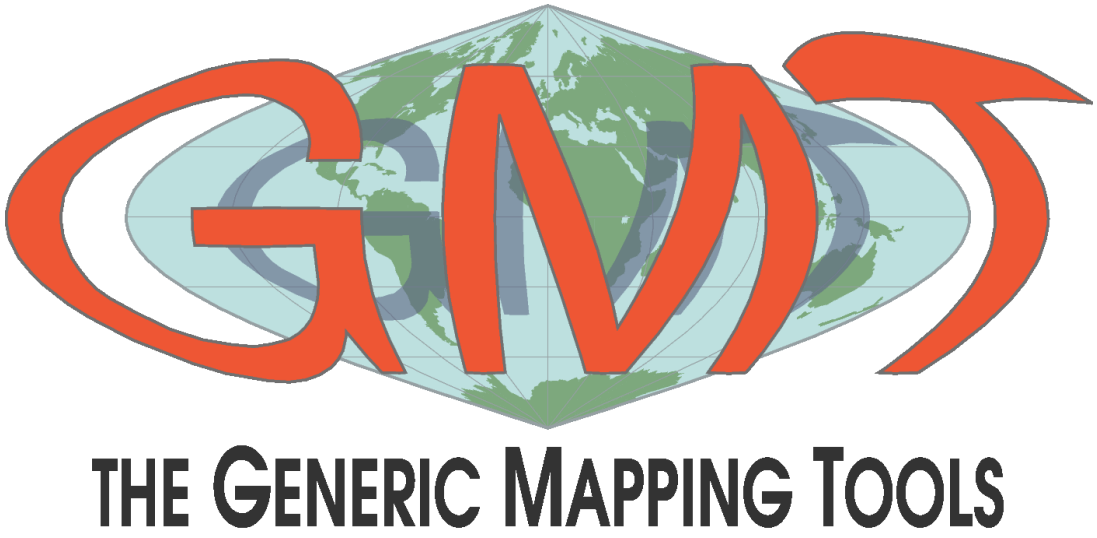
- yum groupinstall "GNOME Desktop" "Server with GUI" "Development Tools" "Compatibility Libraries"
- yum install epel-release
- yum install svn autoconf gcc-c++ libtiff-devel gmt-devel gdal.x86_64 gdal-devel cmake subversion libcurl-devel netcdf-devel pcre-devel fftw3-devel lapack-devel openblas-devel aria2 wget gv dos2unix parallel

Install GMT 6 (optional)

You can use GMT coming with OS (often a little old, e.g. GMT5 in Centos 7).

If not, install an version you like (e.g. GMT 6).

- https://www.generic-mapping-tools.org/
- Refer to the webpage for installation instructions.



e.g., GMT 6.0.0

You need:

- dcw-gmt-1.1.4.tar.gz
- GMT-6.0.0.tar.gz
- gshhg-gmt-2.3.7.tar.gz

Extract them into /usr/local as root user.

Install GMTSAR

- https://github.com/gmtsar/gmtsar

- https://github.com/gmtsar/gmtsar/wiki/GMTSAR-Wiki-Page

Refer to the Wiki page for installation instructions.

Test samples:

- https://topex.ucsd.edu/gmtsar/downloads/

- Download the gmtsar and extract to /usr/local/gmtsar-master
- Run
  - autoconf
  - ./configure
  - make
  - make install (if no error occurred in previous step)

Add /usr/local/gmtsar-master/bin to searching path in ~/.cshrc (for tcsh):

```
set path = ($path   /usr/local/gmtsar-master/bin)
```

Try a command (e.g., sbas) to see whether it works.

Install iGPS

Obtain the package from

- https://www.ngs.noaa.gov/gps-toolbox/Tian.htm
- https://github.com/igps-ftk/iGPS (updated more frequently)
- https://sourceforge.net/projects/igps/

Extract the package to a directory. Add the following to the user variable $PATH.

- $iGPS/sh
- $iGPS/ftk/bin/Linux_x86_64 (if you are using X64 Linux)

E.g., for tcsh (~/.cshrc):

```
setenv  iGPS ${HOME}/iGPS
set path = ($path  ${iGPS}/sh  ${iGPS}/ftk/bin/Linux_x86_64)
```

Compile the ftk source code. Enter $iGPs/ftk, run

```
./install_igpsftk
```

Or, if no need to compile the source (simply create links for existing executables).

```
./install_igpsftk_links
```

Try *hello* to check whether it works.

```
[tianyf@bogon ~]$ hello
 Usage: hello ofile.name
 hello: test whether the compiled FORTRAN77 code support large(>99) file unit.
```

Install GAMIT/GLOBK(optional)

- iGPS now has a Fortran ToolKit (ftk)

  It calls some functions in GAMIT/GLOBK software.

  – The gglib.a files compiled using gfortran can be found in $iGPS/ftk/gglib/.

  – If you have GAMIT/GLOBK installed, use ***arlib*** to create your own library file.

- Some iGPS Shell scripts utilize the doy executable in GAMIT software, for conversion between various formats of date

  Note: the day-of-year from ***doy*** utility and GMTSAR differ by one day.

  A sample doy executable can be found in $iGPS/ftk/bin/Linux_x86_64.

```
[tianyf@bogon ~]$ doy 2023 1
Date 2023/01/01  0:00 hrs, DOY   1 JD  2459945.5000 MJD  59945.0000
GPS Week  2243 Day of week  0, GPS Seconds      0 Day of Week Sun
Decimal Year 2023.000000000 GRACE Seconds 725803200.0
```

Add executable paths

If you use C-Shell (e.g., tcsh), add the following lines to your ~/.cshrc file.
Please change the version number accordingly.

```
#for GMT (if install your own version)
set path = ($path   /usr/local/GMT-6.0.0/bin)

#for GMTSAR
set path = ($path   /usr/local/gmt5sar20200529/bin)

#for iGPS
setenv   iGPS ${HOME}/iGPS
set path = ($path   ${iGPS}/sh   ${iGPS}/ftk/bin/Linux_x86_64)

#for GAMIT/GLOBK (if present)
set path = ($path   ${HOME}/gg/com   ${HOME}/gg/gamit/bin   ${HOME}/gg/kf/bin)
Please create a soft link to the GAMIT/GLOBK path in home directory first,
 ln   -s   /usr/local/gamit-v10.71      ~/gg
```

Validate your installation

In the terminal, type the following commands to test whether the software is working.

- GMT
  gmt

- GMTSAR
  sbas

- iGPS
  hello

- GAMIT/GLOBK (optional)
  doy

If no errors occur, we are ready to go.

Summary of Data

- Sentinel-1 SLC files
  $esa_data/s1/S1?_IW_SLC__1S*.zip
  Tool:
    - sh_asf_s1_get_slc_py

- Orbits
  $esa_data/aux_poeorb/20??/S1A_OPER_AUX_POEORB_OPOD_*.EOF
  $esa_data/aux_resorb/20??/ S1A_OPER_AUX_RESORB_OPOD_*.EOF (for latest data)
  Tool:
    - sh_asf_s1_get_aux_orb
    - sh_esa_s1_get_aux_orb_gnss

- DEM
  $esa_data/topo/srtm3/grid/china.grd
  ~4.0GB
  If use your own data (dem.grd), it is not necessary.

Summary of Software

- GMT
- GMTSAR
- iGPS
  - IDL (optional)
- GAMIT/GLOBK (optional)
- Tools
  - aria2, wget, curl

Set Environment Variables

- esa_data

  Where are the data?

- esa_unzip

  Temporary directory to unzip the SLC zip files.

- iGPS

  Where is iGPS installed?

Set Environment Variables

- Example

For C Shell (e.g., tcsh), in ~/.cshrc:

```
setenv  esa_data  /g4d/esa.data
setenv  esa_unzip  /sar/tmp_esa_unzip

set GMT=/usr/local/GMT-6.0.0
set path=($GMT/bin $path)

setenv  GMTSAR  /usr/local/gmt5sar20220909
set path = ($GMTSAR/bin $path)

setenv  iGPS  /home/tianyf/iGPS
set path = ($path   $iGPS/sh   $iGPS/ftk/bin/Linux_x86_64)

#gamit/globk
set path = (~/gg/com  ~/gg/gamit/bin  ~/gg/kf/bin $path)
setenv HELP_DIR ~/gg/help/
```

Now we go ahead …

CONFIGURATION FILES FOR PROCESSING

Before Processing: Configuration Files

- Processing path (e.g., /sar/proc/test_expt)
  - batch_tops.config (GMTSAR configuration file)
  - input.lst (S1 frame list)
  - dem.grd (DEM)
  - overlapping.*.kml (if no dem.grd given;optional)
  - pins.kml (two points along track direction; optional)
  - F1 (for iw1)
  - F2 (for iw2)
  - F3 (for iw3)
  - f123 (for merging iw1,iw2,iw3)

batch_tops.config

The most important parameter is the desired pixel size of output result, controlled by multi-looking factors.

- Full resolution (25m)
  - range_dec = 4
  - azimuth_dec = 1
  - For small landslide; mine subsidence; etc.
- Normal resolution (50m)
  - range_dec = 8
  - azimuth_dec = 2
  - For large landslide; regional ground subsidence.
- Full resolution (100m)
  - range_dec = 16
  - azimuth_dec = 4
  - For crustal deformation monitoring.

Change the filter_wavelength and dec_factor accordingly.

batch_tops.config by iGPS

There are several templates in iGPS

- $iGPS/tables/
  - batch_tops.config.interseismic
  - batch_tops.config.landslide
  - batch_tops.config.normal

Ground Pixel Size: full resolution

- ~25m Localized deformation: landslide analysis

```
# filters
# look at the filter/ folder to choose other filters
filter_wavelength = 100

# decimation of images
# decimation control the size of the amplitude and phase images. It is
either 1 or 2.
# Set the decimation to be 1 if you want higher resolution images.
# Set the decimation to be 2 if you want images with smaller file size.
#
dec_factor = 1

# for tops processing, to force the decimation factor
# recommended range decimation to be 8, azimuth decimation to be 2
range_dec = 4
azimuth_dec = 1
```

Ground Pixel Size: normal

- ~50m Regional deformation: balance between image size and pixel size

```
# filters
# look at the filter/ folder to choose other filters
filter_wavelength = 200

# decimation of images
# decimation control the size of the amplitude and phase images. It is
either 1 or 2.
# Set the decimation to be 1 if you want higher resolution images.
# Set the decimation to be 2 if you want images with smaller file size.
#
dec_factor = 1

# for tops processing, to force the decimation factor
# recommended range decimation to be 8, azimuth decimation to be 2
range_dec = 8
azimuth_dec = 2
```

Ground Pixel Size: coarse

- ~100m Large-scale deformation: interseismic slip, coseismic displacements

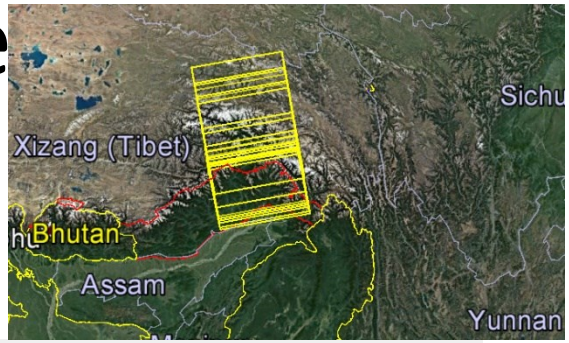
```
# filters
# look at the filter/ folder to choose other filters
filter_wavelength = 400

# decimation of images
# decimation control the size of the amplitude and phase images. It is
either 1 or 2.
# Set the decimation to be 1 if you want higher resolution images.
# Set the decimation to be 2 if you want images with smaller file size.
#
dec_factor = 2

# for tops processing, to force the decimation factor
# recommended range decimation to be 8, azimuth decimation to be 2
range_dec = 16
azimuth_dec = 4
```

iGPS time series analysis (tsa) tool: input.lst example

Sample input.lst file for combining 2 consecutive frames along the track direction.



input.lst.ok

```
 1 S1A_IW_SLC__1SSV_20141022T114046_20141022T114115_002942_003578_A850.manifest.safe  1.0000000000000000
 2 S1A_IW_SLC__1SSV_20141022T114113_20141022T114141_002942_003578_125F.manifest.safe  1.0000000000000000
 3 S1A_IW_SLC__1SSV_20141115T114045_20141115T114115_003292_003D01_EC4F.manifest.safe  1.0000000000000000
 4 S1A_IW_SLC__1SSV_20141115T114113_20141115T114141_003292_003D01_B813.manifest.safe  1.0000000000000000
 5 S1A_IW_SLC__1SSV_20141209T:                    :0141209T114114_003642_004506_E89D.manifest.safe  1.0000000000000000
 6 S1A_IW_SLC__1SSV_20141209T:                    :0141209T114140_003642_004506_58C1.manifest.safe  1.0000000000000000
 7 S1A_IW_SLC__1SSV_20150102T11404                02T114114_003992_004CE8_DB58.manifest.safe  1.0000000000000000
 8 S1A_IW_SLC__1SSV_20150102T11411                02T114139_003992_004CE8_A363.manifest.safe  1.0000000000000000
 9 S1A_IW_SLC__1SSV_20150126T114043_20150126T114113_004342_0054BA_0232.manifest.safe  1.0000000000000000
10 S1A_IW_SLC__1SSV_20150126T114111_20150126T114138_004342_0054BA_BD58.manifest.safe  1.0000000000000000
11 S1A_IW_SLC__1SSV_20150219T114042_20150219T114112_004692_005CC5_D916.manifest.safe  1.0000000000000000
12 S1A_IW_SLC__1SSV_20150219T114110_20150219T114138_004692_005CC5_7FC7.manifest.safe  1.0000000000000000
13 S1A_IW_SLC__1SSV_20150303T114043_20150303T114112_004867_006107_E0EF.manifest.safe  1.0000000000000000
14 S1A_IW_SLC__1SSV_20150303T114110_20150303T114138_004867_006107_2D6F.manifest.safe  1.0000000000000000
15 S1A_IW_SLC__1SSV_20150327T114043_20150327T114113_005217_00696A_915B.manifest.safe  1.0000000000000000
```

day 1

day 2

day 3

day 4

Blank first character

S1 frame names used for processing

Percentage of overlapping between frames

Get input file list: extract metainfo files

iGPS use **.manifest.safe* information to get spatial coverage of frames.

- To extract *.safe files:

  sh_s1_unzip_manifest -o output_path -p input_path

  e.g.,

  sh_s1_unzip_manifest -p `pwd` -o `pwd`

  sh_s1_unzip_manifest -o /g4d/esa.data/safe -p /g4d/esa.data/s1

- Search for frames covering the same geographical area, using metainfo in *.safe files.
  - IDL code: ${iGPS/sar/**s1_manifest_overlap.pro**
  - ftk tool: ${iGPS/ftk/sar/overlap/**s1_manifest_overlap.f**

s1_manifest_overlap example

$ s1_manifest_overlap

Usage: **s1_manifest_overlap** path_safes target_safe opath [perc_min]

For a given frame (S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_015870_01A273_941C.manifest.safe), run the command

```
s1_manifest_overlap
/cygdrive/c/Downloads/esa.data/metainfo/manifest.safe/D048
S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_015870_01A273_941C.manifest.safe  `pwd` .8
```

The output files are:

- overlapping.S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_015870_01A273_941C.manifest.safe.kml
- overlapping.S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_015870_01A273_941C.manifest.safe.psxy
- overlapping.S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_015870_01A273_941C.manifest.safe.txt

Kml – to view in Google Earth; *psxy – to plot with gmt;* txt – frame list for iGPS

s1_manifest_overlap

- Sample output
- Exclude some frames by commenting out (adding non-blank character, e.g. x, in the first column) the corresponding lines

*overlapping.S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_015870_01A273_941C.manifest.safe.txt - Notepad

File Edit Format View Help

```
* source path: /cygdrive/c/Downloads/esa.data/metainfo/manifest.safe/D048
* target: S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_015870_01A273_941C.manifest.safe
* minimum percentage of overlapping:              0.80000
* number of matched scenes:        171
 S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_015870_01A273_941C.manifest.safe          1.00000000
 S1A_IW_SLC__1SDV_20170408T000152_20170408T000219_016045_01A7AC_5B49.manifest.safe          1.00000000
 S1A_IW_SLC__1SDV_20170420T000152_20170420T000219_016220_01AD0F_E1A6.manifest.safe          1.00000000
x S1A_IW_SLC__1SDV_20170502T000153_20170502T000220_016395_01B25B_2D9D.manifest.safe          1.00000000
 S1A_IW_SLC__1SDV_20170514T000154_20170514T000221_016570_01B7A9_1916.manifest.safe          1.00000000
 S1A_IW_SLC__1SDV_20170526T000154_20170526T000221_016745_01BD09_E928.manifest.safe          1.00000000
 S1A_IW_SLC__1SDV_20170607T000155_20170607T000222_016920_01C27F_EC2D.manifest.safe          1.00000000
 S1A_IW_SLC__1SDV_20170619T000156_20170619T000223_017095_01C7E1_778C.manifest.safe          1.00000000
 S1A_IW_SLC__1SDV_20170701T000156_20170701T000223_017270_01CD28_58CE.manifest.safe          1.00000000
```

Ln 8, Col 1 | 100% | Unix (LF) | UTF-8

INSAR PROCESSING

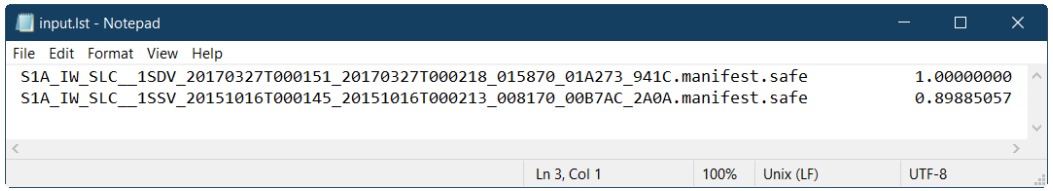
The first processing experiment

- $HOME/gsar/test1st/

  top level of directory

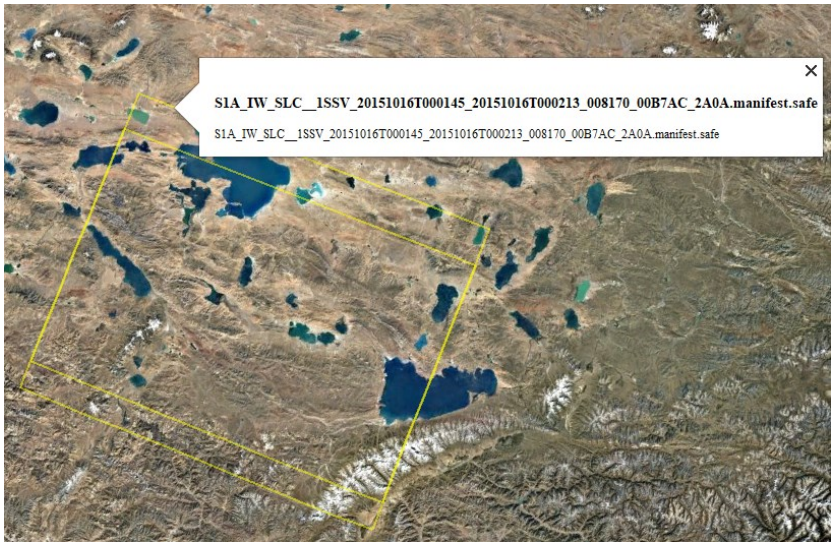
  – input.lst

    - frame list; two frames



  – overlapping.S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_015870_01A273_941C.manifest.safe.kml

    - For clipping DEM from china.grd



Unpack SLC Zip Files

GMTSAR cannot handle compressed Sentinel-1 SLC files (*.zip) directly.

First, we uncompress the data to a temporary location (e.g., $esa_unzip), using the sh_s1_unzip script:

- **sh_s1_unzip** input.lst

```
[tianyf@gpsac8 test1st]$ sh_esa_s1_unzip input.lst
sh_esa_s1_unzip_node -path /g8g/esa.data/s1 -file input.lst -iw iw1,iw2,iw3 -u n
[sh_esa_s1_unzip_node]INFO:iw to extract is iw1 iw2 iw3
iw_typ is iw1
tmp is iw1 iw2 iw3
iw_typ is iw2
tmp is iw1 iw2 iw3
iw_typ is iw3
tmp is iw1 iw2 iw3
[sh_esa_s1_unzip_node]INFO:iw to exclude is
[sh_esa_s1_unzip_node]INFO:iw remain is  iw1 iw2 iw3
dos2unix: converting file input.lst to Unix format ...
[sh_esa_s1_unzip_node]INFO: 1 / 2 S1A_IW_SLC__1SDV_20170327T000151_20170327T0002
18_015870_01A273_941C.manifest.safe
[sh_esa_s1_unzip_node]INFO: extracting S1A_IW_SLC__1SDV_20170327T000151_20170327
T000218_015870_01A273_941C.zip
unzip -n /g8g/esa.data/s1/S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_01587
0_01A273_941C.zip -x *-vh-* -d /g11e/esa_unzip/
Archive:  /g8g/esa.data/s1/S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_0158
70_01A273_941C.zip
   creating: /g11e/esa_unzip/S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_01
5870_01A273_941C.SAFE/
   creating: /g11e/esa_unzip/S1A_IW_SLC__1SDV_20170327T000151_20170327T000218_01
5870_01A273_941C.SAFE/support/
```

sh_s1_unzip

sh_s1_unzip script accepts 2 parameters

1. Data list file (e.g., input.lst)
2. Subswaths (iw1,iw2,iw3)
   - If not present, extract all subswaths;
   - Can be any combination of iw1, iw2, and iw3, e.g.,

```
sh_s1_unzip   file
sh_s1_unzip   file   iw1
sh_s1_unzip   file   iw1,iw3
```

After the processing completes, use sh_s1_unzip_clean to delete the uncompressed data from $esa_unzip directory, e.g.,

```
sh_s1_unzip_clean    input.lst.ok
```

Interferometric processing

GMTSAR can only process only one subswath (e.g., iw1) each time.

If you want a whole frame, process each subswath (iw1/iw2/iw3) individually, then merge the interferograms together.

First, create a directory (e.g. F1) for processing iw1. Under F1, run:

sh_s1_run_tsa -file ../input.lst -proc_type normal -iw iw1

```
[tianyf@gpsac8 F1]$ sh_esa_s1_run_tsa -file ../input.lst -proc_type normal -iw iw1
[sh_esa_s1_run_tsa]INFO: session test1st
[sh_esa_s1_run_tsa]WARNING: DEM file ../dem.grd is mondatory and missing!
[sh_esa_s1_run_tsa]INFO: creating dem.grd file from KML files if available
[sh_esa_s1_run_tsa]INFO: geographical ranges 87.5167 91.1022 29.583 32.4332
[sh_esa_s1_run_tsa]INFO: topo range zmin zmax 0 7059.84472656
Make dem.kml and dem.png
gs -q -dNOPAUSE -dBATCH -dNOSAFER -dSCANCONVERTERTYPE=2 -dMaxBitmap=2147483647 -dUse
FastColor=true -dGraphicsAlphaBits=2 -dTextAlphaBits=4 -sDEVICE=pngalpha  -g4303x342
0 -r1200 -sOutputFile='dem.png' './psconvert_5896d.eps'
/home/tianyf/gsar/test1st/F1
[sh_esa_s1_run_tsa]INRO: input file is /home/tianyf/gsar/test1st/F1/../input.lst
[sh_esa_s1_run_tsa]INRO: subswath is iw1
[sh_esa_s1_run_tsa]INRO: ROI file is
[sh_esa_s1_run_tsa]INFO: default configuration file (/g8g/esa.data/config/batch_tops
.config.normal) copied.
[sh_esa_s1_run_tsa]INRO: 2 scenes to processing
[sh_esa_s1_run_tsa]INRO: (1) prepare the data (link & assemble/stitch ...)
[sh_esa_s1_run_tsa]INRO: output log to log.asmb
[sh_esa_s1_run_tsa]INRO: link orbit files to ./raw directory
[sh_esa_s1_run_tsa]INRO: return to /home/tianyf/gsar/test1st/F1
[sh_esa_s1_run_tsa]INRO: create spatiotemporal baseline information
```

It may take long time to align the images, create interferograms, and unwrap the phases!

Repeat the command for F2 (iw2) and F3(iw3) swaths.

"tsa stands for time series analysis "

What does sh_s1_run_tsa do?

1) Reading frame list to process (e.g., input.lst)
2) Copy configuration template (batch_tops.config) to frame root directory
3) Create and link dem.grd if not present
4) Under subswath directory (F1/F2/F3), link unpacked Sentinel-1 measurement file (*.tiff, *.xml) to raw0 directory. Link orbits (*.EOF) to raw0
5) Link or merge measurement files (*.tiff, *.xml) to raw directory, link orbits
6) Create data.in from files in raw.
7) Create spatial-temporal baselines (baseline*) using preproc_batch_tops.csh
8) In raw, align images using preproc_batch_tops_esd.csh
9) Create baseline file (get_baseline_table.csh) with aligned images
10) Create interferogram list (intf.in) from baseline_table.dat, and update batch_tops.config for master scene, using sh_s1_prep_proc_baseline
11) Call intf_tops.csh to processing interferograms
12) Create interferogram list files (intf.tab1, scene.tab1) from intf.in for SBAS, using sh_sar_prep_sbas
13) Copy preview images of processed interferograms from intf_all to intf_all_png, using sh_sar_cp_intf_png
14) Create interferogram list files (intf.tab, scene.tab) for SBAS according to files in intf_all_png, using sh_sar_intf_tab_from_png
15) Run SBAS to derive displacements and velocities, using sh_sar_call_sbas

Merge Subswaths (iw1,iw2,iw3)

1. Create interferograms for each subswath separately (without unwrapping);
2. Use GMTSAR's merge_batch.csh to mosaic phase files and then unwrap it.

At the same level as F1,F2,F3, run iGPS script

sh_s1_prep_f123

Will create a new directory (f123) and searching for interferograms to merge (intf.in.f123.1) . Enter f123 directory, and run

merge_batch.csh intf.in.f123.1 batch_tops.config

Sample intf.in.f123.1:

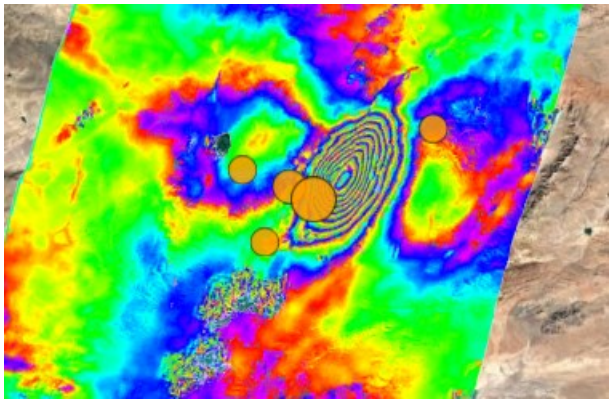
../F1/intf_all/2014298_2014346/:S1_20141026_ALL_F1.PRM:S1_20141213_ALL_F1.PRM,../F2/intf_all/2014298_2014346/:S1_20141026_ALL_F2.PRM:S1_20141213_ALL_F2.PRM,../F3/intf_all/2014298_2014346/:S1_20141026_ALL_F3.PRM:S1_20141213_ALL_F3.PRM

Note: merge_batch.csh will not move interferograms into intf_all directory. Please move them manually.

TEST RUN: 2020-07-22 RIGANPEI CO EARTHQUAKE

Example: Riganpei Co earthquake

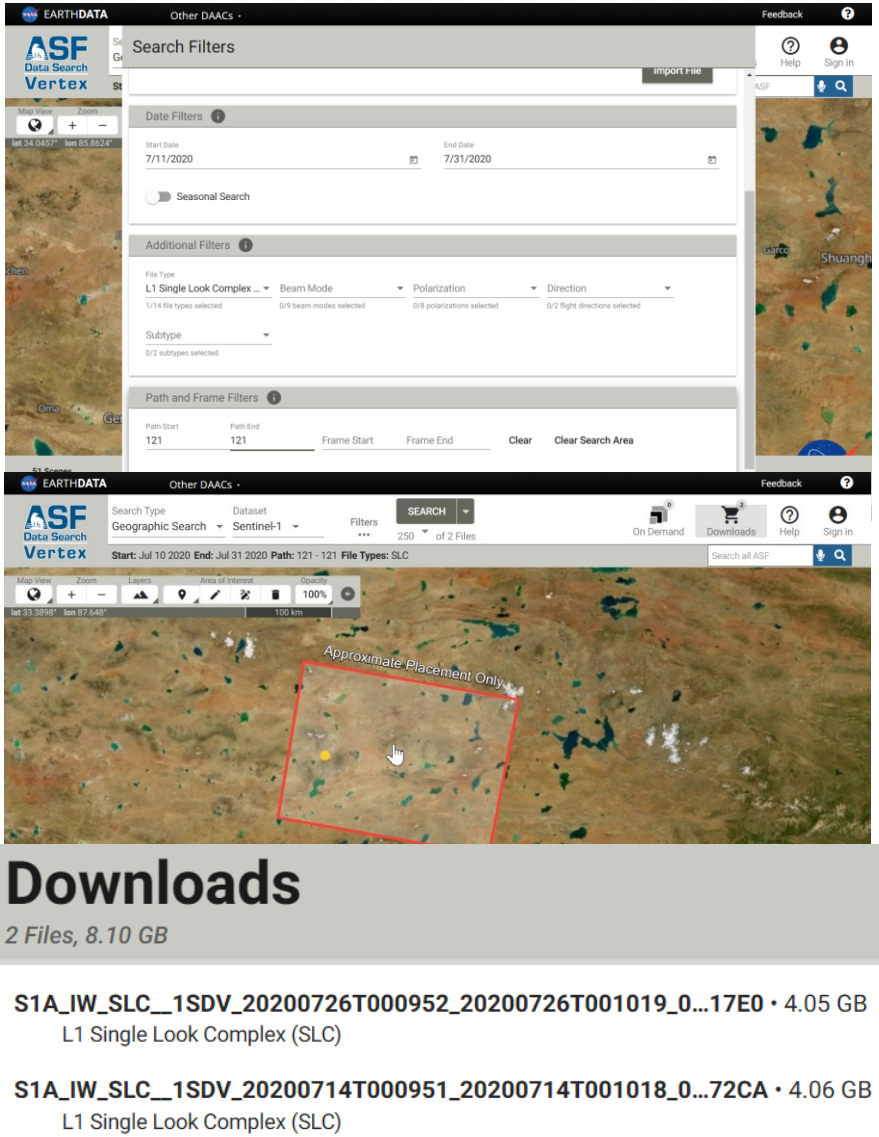
- 2020-07-22 a normal earthquake on Riganpei Co fault in central Tibet



- Event page: https://earthquake.usgs.gov/earthquakes/eventpage/us6000b26j/executive

Example: Riganpei Co earthquake

- Data
  - Descending 121
  - Downloading script: iGPS\example\coseismic.insar.sentinel-1.20220722.RiganpeiCo\run_get_data



Example: Riganpei Co earthquake

- Orbits
  - POE

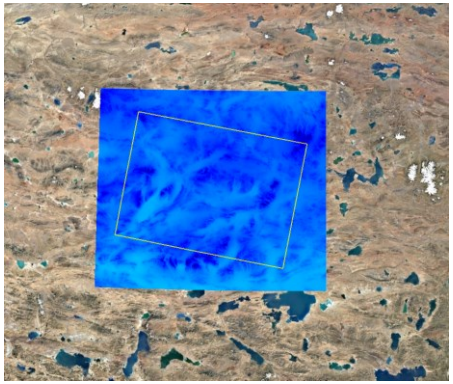
- From ESA (using public account gnssguest):

  sh_esa_s1_get_aux_orb_gnss -d 2020-07-26

  sh_esa_s1_get_aux_orb_gnss -d 2020-07-14

Example: Riganpei Co earthquake

- DEM
  - Get $esa_data/topo/strm3/grid/china.grd (provided by iGPS)
    - iGPS will cut the file according to the KML range and put the dem.grd file in the root directory of processing



  - Or, obtain it from https://topex.ucsd.edu/gmtsar/demgen/

    Put dem.grd file in the root directory of processing

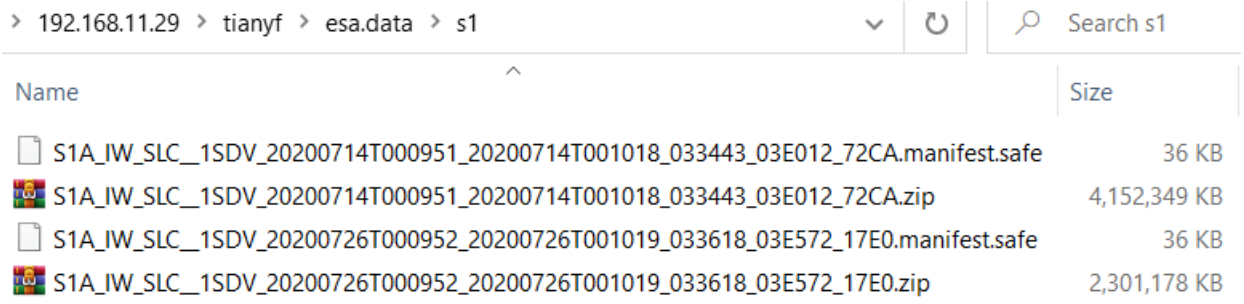
Example: Riganpei Co earthquake

Prepare Input: frames to be processed

- Extract meta data (*.safe)

```
[tianyf@bogon eq_riganpeico]$ sh_s1_unzip_manifest /home/tianyf/esa.data/s1/
/home/tianyf/esa.data/s1
[sh_S1_unzip_manifest]INFO: Usage: sh_s1_unzip_manifest [out_path  [input_path] ]
[sh_S1_unzip_manifest]INFO:   Default:
[sh_S1_unzip_manifest]INFO:     out_path: /home/tianyf/esa.data/safe/S1
[sh_S1_unzip_manifest]INFO:     input_path: /home/tianyf/esa.data/s1
[sh_S1_unzip_manifest]INFO:   Currently:
[sh_S1_unzip_manifest]INFO:     out_path: /home/tianyf/esa.data/s1
[sh_S1_unzip_manifest]INFO:     input_path: /home/tianyf/esa.data/s1
[sh_S1_unzip_manifest]INFO: extracting
/home/tianyf/esa.data/s1/S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA
.manifest.safe
[sh_S1_unzip_manifest]INFO: extracting
/home/tianyf/esa.data/s1/S1A_IW_SLC__1SDV_20200726T000952_20200726T001019_033618_03E572_17E0
.manifest.safe
[sh_S1_unzip_manifest]INFO: # 2 manifest.safe files added.
```

Now we have



Example: Riganpei Co earthquake

Prepare Input: frames to be processed

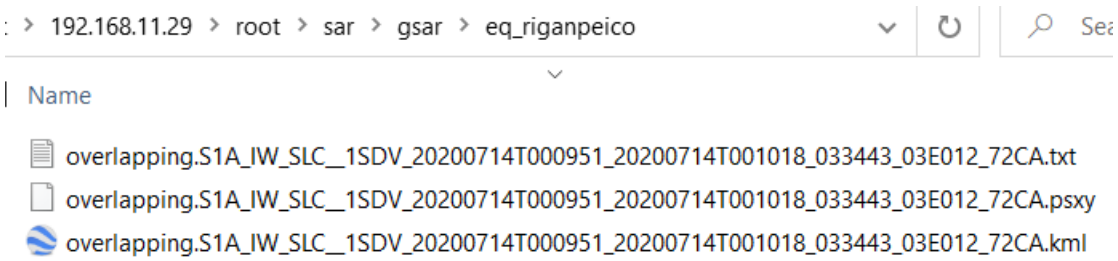
- Search for overlapping frames

  In the root directory of processing, run

```
[tianyf@bogon eq_riganpeico]$ s1_manifest_overlap /home/tianyf/esa.data/s1/
S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA `pwd`

[]path:/home/tianyf/esa.data/s1/
[]target:S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA
[]opath:/sar/gsar/eq_riganpeico
[]perc_min:     0.80
…
 perc for            2  is    1.0000000000000000
 []out:/sar/gsar/eq_riganpeico/overlapping.S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.txt
 []out
KML:/sar/gsar/eq_riganpeico/overlapping.S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.kml
 []out:/sar/gsar/eq_riganpeico/overlapping.S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.psxy
```

Now we have



Example: Riganpei Co earthquake

Unpack SLC zip files to temporary directory ($esa_unzip).

```
[tianyf@bogon eq_riganpeico]$ sh_s1_unzip
overlapping.S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E0
12_72CA.txt

…
 [sh_s1_unzip_node]INFO: 1 / 2
S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.manifest.safe
[sh_s1_unzip_node]INFO: extracting
S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.zip
unzip -n
/home/tianyf/esa.data/s1/S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.zi
p -x *-vh-* -d /sar/esa_unzip
Archive:
/home/tianyf/esa.data/s1/S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.zi
p
   creating:
/sar/esa_unzip/S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.SAFE/
…
```

Example: Riganpei Co earthquake

Process the 3rd subswath (F3)

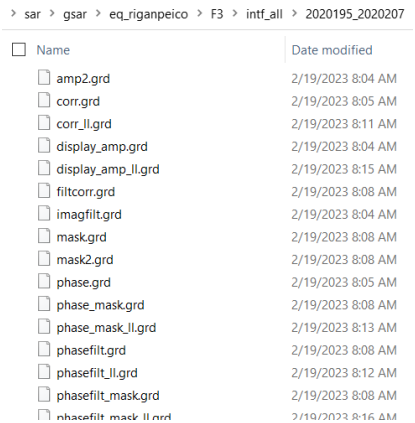
In the root directory of processing, create a F3 directory.

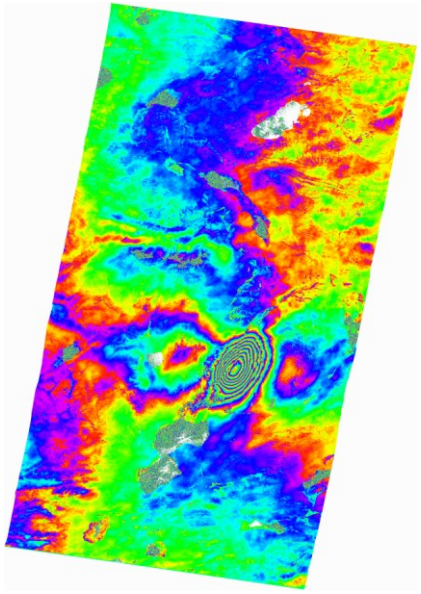
In F3, run

```
sh_s1_run_tsa -file
../overlapping.S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.txt -iw iw3 -proc_type interseismic
```

If no errors occur, we will have a bunch of files in the interferogram directory (in intf_all).

Make sure you have enough disk space and memory (>2GB?).





Check the image files for results preview.

Example: Riganpei Co earthquake

Repeat the processing for iw1 (F1) and iw2 (F2) subswaths.

```
In F2:
sh_s1_run_tsa -file
../overlapping.S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.txt -iw iw2 -proc_type interseismic

In F1:
sh_s1_run_tsa -file
../overlapping.S1A_IW_SLC__1SDV_20200714T000951_20200714T001018_033443_03E012_72CA.txt -iw iw1 -proc_type interseismic
```

Mosaic iw1+iw2+iw3

After processed iw1,iw2 and iw3, run

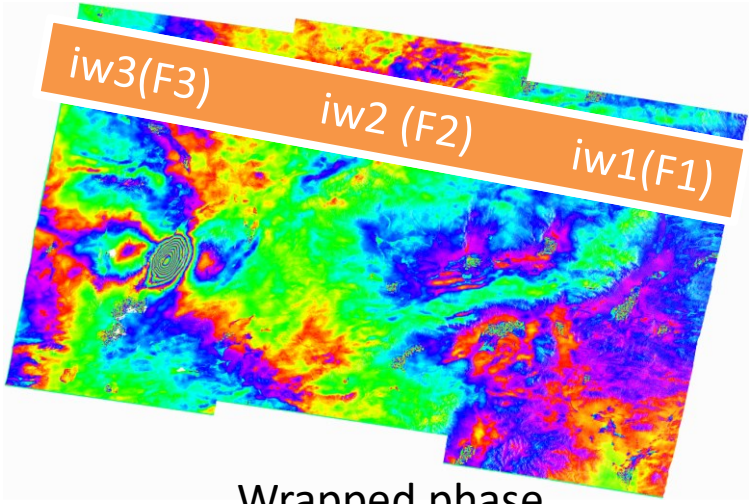
sh_s1_prep_f123

to prepare files for merging.

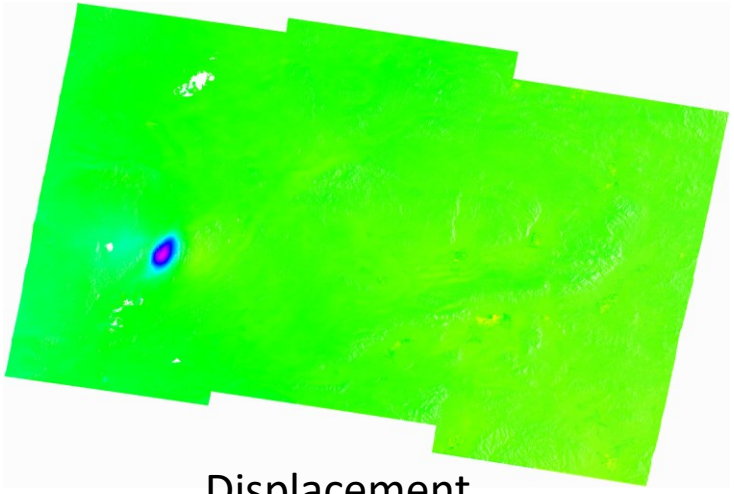
Enter f123 directory, run

merge_batch.csh intf.in.f123.1 batch_tops.config

to do the merging (and unwrapping) job.



Wrapped phase



Displacement

LEVEL-1 PROCESSING

Interrupt merge_batch.csh, and continue …

If some interferograms have already been created, i.e., the intf.in.f123.1 file exists, we need to get the remaining ones to process.

Searching for unfinished interferograms:

sh_s1_prep_f123_in

Will create log2 file and extract the unfinished interferograms list to intf.in.f123.2

Use merge_batch2.csh (revised from merge_batch.csh) to complete the task:

merge_batch2.csh intf.in.f123.1 intf.in.f123.2 batch_tops.config

merge_batch2.csh

Please note: merge_batch.csh requires that “The master image of first line should be the super_master.”

If you interrupted the processing and continue later, make sure that the master image of the first line remains the same. Otherwise, the size (number of rows/columns) of interferogram may differ.

iGPS revised the GMTSAR merge_batch.csh script to extract master information from the first interferogram list file (intf.in.f123.1), e.g.

merge_batch2.csh intf.in.f123.1 intf.in.f123.2 batch_tops.config

Parallel Version of Merging Scripts

- merge_batch_parallel.csh intf.in.f123.1 batch_tops.config N
- merge_batch2_parallel.csh intf.in.f123.1 intf.in.f123.2 batch_tops.config N

Where N is the number of parallel jobs.

Note: make sure the back geocoding file (trans.dat) is generated in f123 directory, which means running merge_batch.csh for at least one interferogram before running paralleling jobs.

When the dimensions of corr and unwrap files are not consistent, one can use gmt grdcut command to clip out the common area (or the area of interest given by polygon KML file) using the iGPS tsa script sh_sar_intf_all_cut_roi

Clip and Mosaic for Single Subswath(iw1/iw2/iw3)

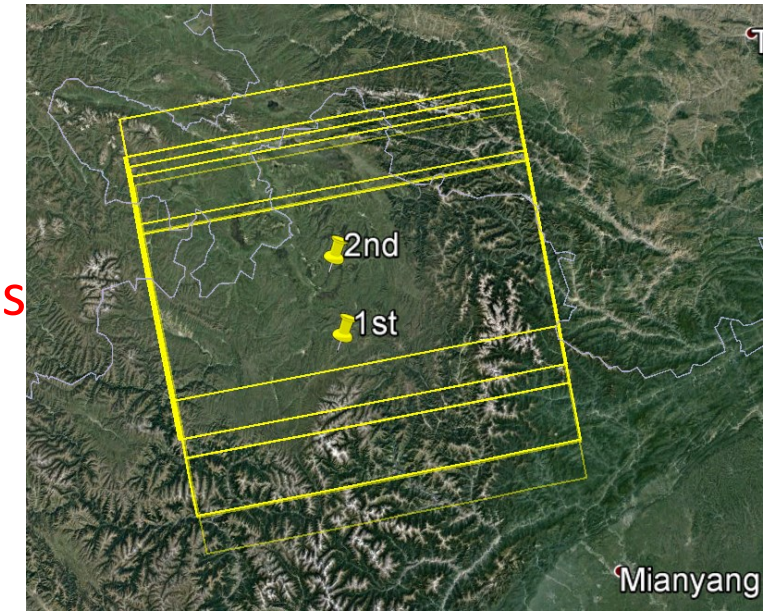
- By burst
  - For single frame
  - Merge two or more consecutive frames and then clip
- By row/column
  - Perform clipping on coregistered SLC images
  - Perform clipping on interferograms
  - Resample interferograms

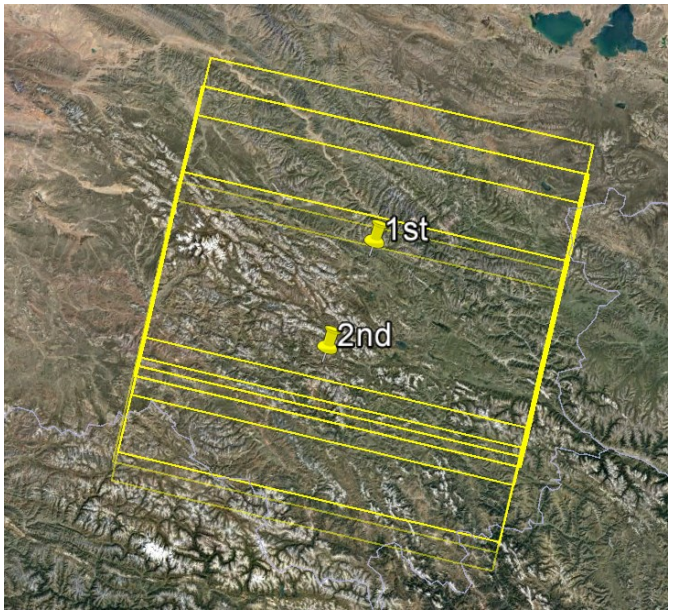
Clip by Burst: from Single Frame

Prepare a KML file containing two points, with the first point being acquired earlier.

- Ascending data: 1st point in the south; 2nd point in the north
- Descending data: 1st point in the north; 2nd point in the south

The two points should spans at least 2-3 bursts





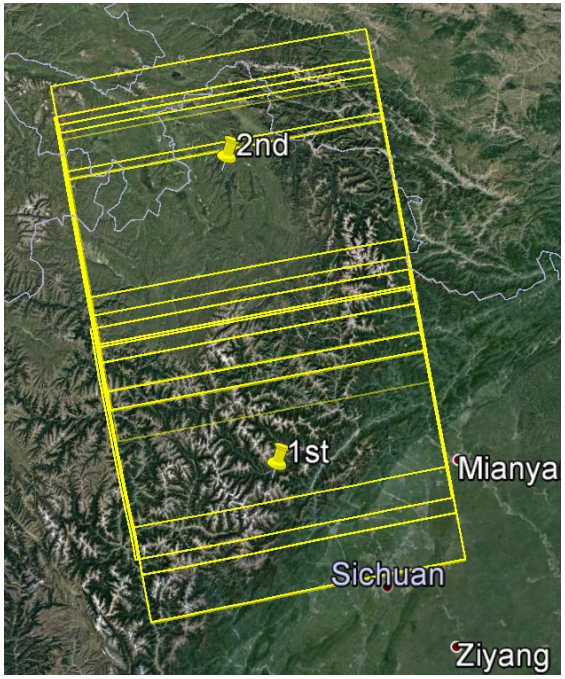
When calling sh_s1_run_tsa script, adding -roi option:

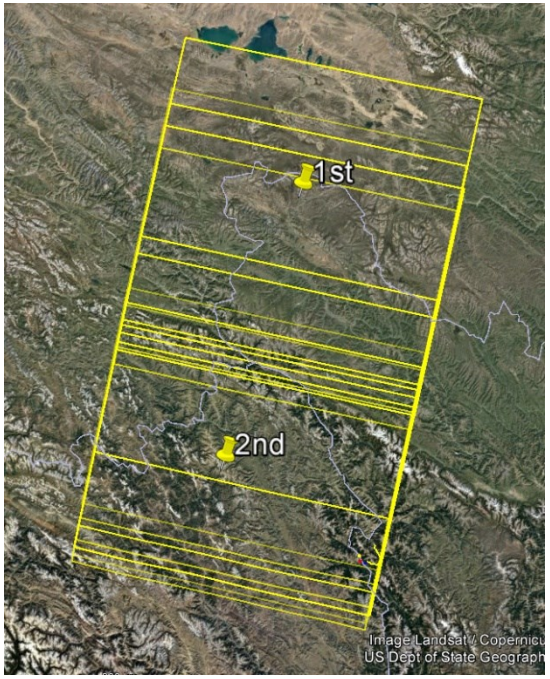
```
sh_s1_run_tsa -file input.lst -roi pins.kml
```

Clip by Burst: from a Long Swath (Multiple Frames)

The same as the single frame case.

NOTE:
With older GMTSAR, the two points usually can span at most 17-20 bursts, if first assemble all tiff files together (classic tiff file cannot exceed 4GB size).
If errors occur, try removing this option.





When calling sh_s1_run_tsa script, adding -roi option:

```
sh_s1_run_tsa -file input.lst -roi pins.kml
```

Clip by Row/Column: on Aligned SLC Files

sh_slc_cut script in iGPS

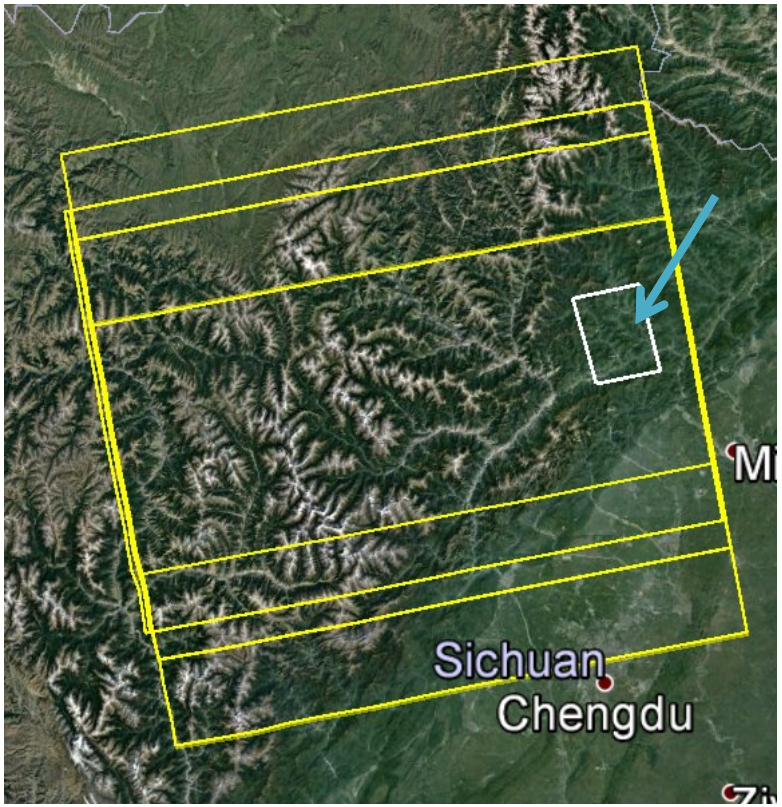
- Input:
  - ROI KML file

- Example:

In F1 (or F2/F3), run

sh_slc_cut -file roi.kml

iGPS's sh_s1_init_F_cut script can initiate the environment and cut the SLC file. E.g., in the root directory of processing (parent of F1/F2/F3/), run



sh_s1_init_F_cut -file my_roi.kml -iw iw2

Will create a F2.my_roi directory, copy necessary files to it, cut SLC in F2/raw and save new SLC files to F2/raw.my_roi/, and create a link to it in F2.my_roi

Clip by Row/Column: on Interferograms

- Purpose:

  Cut corr_cut.grd and unwrap_mask.grd files in intf_all directory.

- Tool:
  - iGPS's sh_sar_intf_all_cut_roi script

- Example:

  sh_sar_intf_all_cut_roi -file roi.kml -opath intf_all_roi

  It will convert geographical range in roi.kml into radar coordinate system, and use GMT's grdcut command to clip out the data of ROI.

Resample the Interferograms: Downgrade the Resolution

- Purpose:

  Resample corr_cut.grd and unwrap_mask.grd files in intf_all directory to a lower resolution.

- Tool:
  - iGPS's sh_sar_intf_all_resample script

- Example:

  sh_sar_intf_all_resample -r 2

  Here, 2 is the downgrade factor (means from 25m to 50m, or from 50m to 100m, etc.). New interferograms will be saved in intf_all_x2

Snaphu: Coherence Threshold in Unwrapping

In batch_tops.config, the threshold can be set to a much small one, e.g.,

threshold_snaphu = 0.01

After obtain the deformation results, create a mask according to the coherence images of a few interferograms, with a reasonable threshold (e.g., 0.05). In our experiences, such a value can mask out nearly all decorrelated Earth surface (i.e., water body, desert, snow/ice, and forest).

iGPS's sh_sar_sbas_corr_mask creates a mask and performs masking on the vel_ll.grd file. The mask is also used to clip displacement files.

Example:

sh_sar_sbas_corr_mask -corr_min .05

Snaphu： mst vs. mcf

- Default:
  snaphu …. -mst
- To change to MCF:
  snaphu …. --mcf
- They work with no big differences when the coherence is good.
- When the decorrelation is heavy,
  - it takes long time for mst. Use mcf instead.
  - Mst likely produces more unwrapping errors (?).
- Using mcf consumes much more physical memory.

Interrupt intf_tops.csh and Continue Processing

The step of creating interferograms (intf_tops.csh) is time-consuming. Sometimes one may want to rearrange the order of processing, or pause a while for other work. After interrupt the processing,

1. Under the subswath directory (F1/F2/F3), use ***sh_sar_cp_intf_png*** to copy preview image (*.png) from intf_all to intf_all_png for interferograms processed.

2. Use ***sh_s1_intf_in_unfinished*** to get list of interferograms not processed
    1. Input: intf.in, intf_all_png/, baseline_table.dat, scene.tab1
    2. Output: intf.in.rem

3. Run ***intf_tops.csh*** or intf_tops_parallel.csh to continue the processing, e.g.,

    intf_tops.csh intf.in.rem batch_tops.config

    intf_tops_parallel.csh intf.in.rem batch_tops.config 8

    Make sure the proc_stage is set to 2 in the batch_tops.config! Otherwise (if proc_stage = 1), the topo/trans.dat file will be created each time running intf_tops.csh.

Get New Data? Update the Processing

Question: How to do when new S1 SLC data are added?

The answer: sh_s1_run_tsa_update

No need to process the old data again. It just aligns the new data frames to the reference one.

The outputs are:

- New aligned SLC files
  - raw/S1_20*
- data.in (updated)
- baseline_table.dat (updated)
- intf.in (updated)

Example:

sh_s1_run_tsa_update -file new_data_file -iw iw1

Note: new data list file should contain the reference one!

SBAS

Steps:

1) First, find which interferograms had been processed (saved in intf_all).

   iGPS use the PNG image files to do this job. Using sh_sar_cp_intf_png, the varied preview files (phase, unwrapped phase, displacement-los) are copied from intf_all to intf_all_png directory. Run it under subswath directory (F1/F2/F3).

2) Create all possible interferograms list (from intf.in.) for input to SBAS.

   intf.tab1 & scenes.tab1, using **sh_sar_prep_sbas**

3) Prepare intf.tab & scene.tab files for SBAS, according to PNG images in intf_all_png directory.

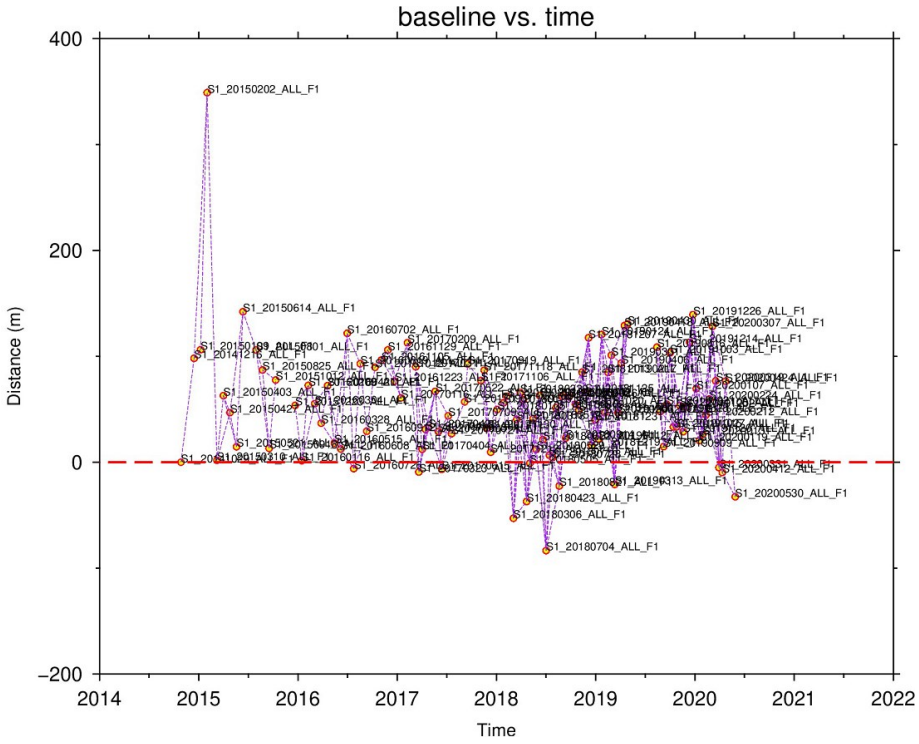
   sar_sbas_tab_from_png

4) Use **sh_sar_call_sbas** to do SBAS analysis, creating displacements and velocities.

Plots of Baselines

- sh_sar_plot_intf_tab
  Plot interferograms for SBAS processing
  Input: intf.tab and scene.tab

- sh_sar_plot_intf_in
  Plot interferograms for intf_tops.csh processing
  Input: intf.in



Outputs: f-baseline-time* files

sh_sar_call_sbas

SBAS Output Path Naming Convention

sbas.A.B.CCCC.DDDD.EEEEEEEE.FFFFFFFF.GGG.HHHH.II.ZZZ

A	-	resample level
		1 - full resolution (4:1; 25m)
		2 - 50m (8:2)
		3 - 100m (16:4)
		4 - 200m (32:8)
B	-	atm code
		0 - no aps correction
		1 - with -atm 1
		2 - with -atm 2
		3 - with -atm 3
		4 - with -atm 4
		5 - with -atm 5
		8 - GACOS only
		9 - with GACOS
CCCC	-	minimum time span (number of days)
DDDD	-	maximum time span
EEEEEEEE	-	starting date
FFFFFFFF	-	starting date
GGG	-	number of scenes
HHHH	-	number of interferograms
II	-	version number
ZZZ	-	comment

e.g.,
sbas.4.0.0001.9999.20180110.20230120.008.0008.01.___

sh_sar_call_sbas

sh_sar_call_sbas options:

- -r
  Code for interferogram pixel size
- -i
  Interferograms path (default intf_all)
- -a
  Atmospheric correction code
- -t1
  Minumum days of temporal baseline (default 0)
- -t2
  Maximum days of temporal baseline (default all)
- -c
  comments
- -ow
  overwrite output? y/n
- -p
  y: run sbas_parallel instead of sbas

e.g.,
sh_sar_call_sbas -r 4 -i intf_all_x2 –p y -t1 121 -t2 500

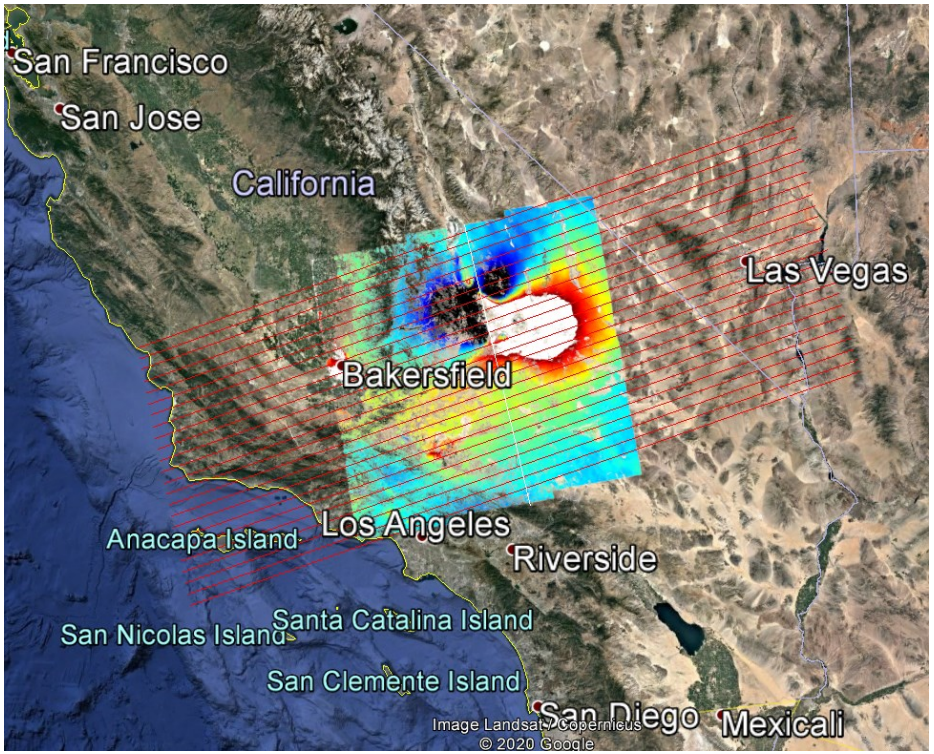
Extract Displacement Time series

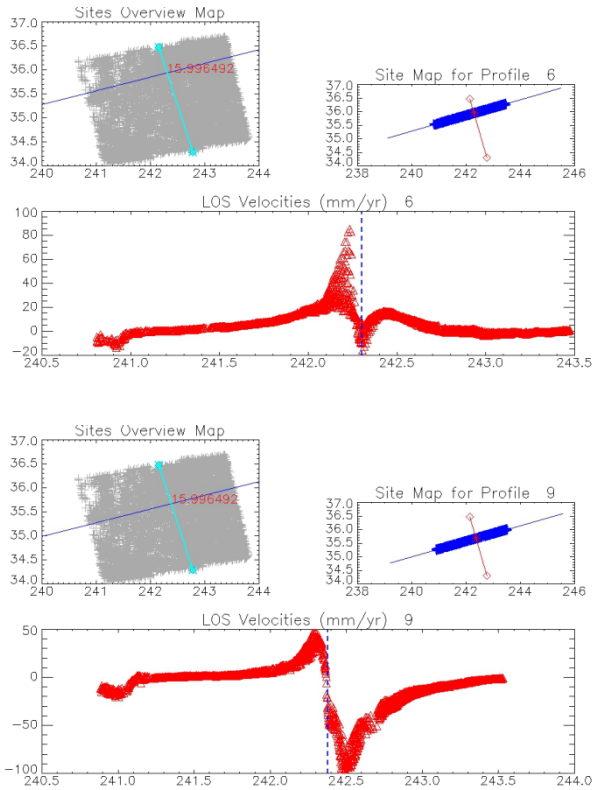
Extract displacement time series from SBAS result for individual locations (points).

- sh_sar_sbas_extract_time_series_lls

Create velocity or displacement profiles

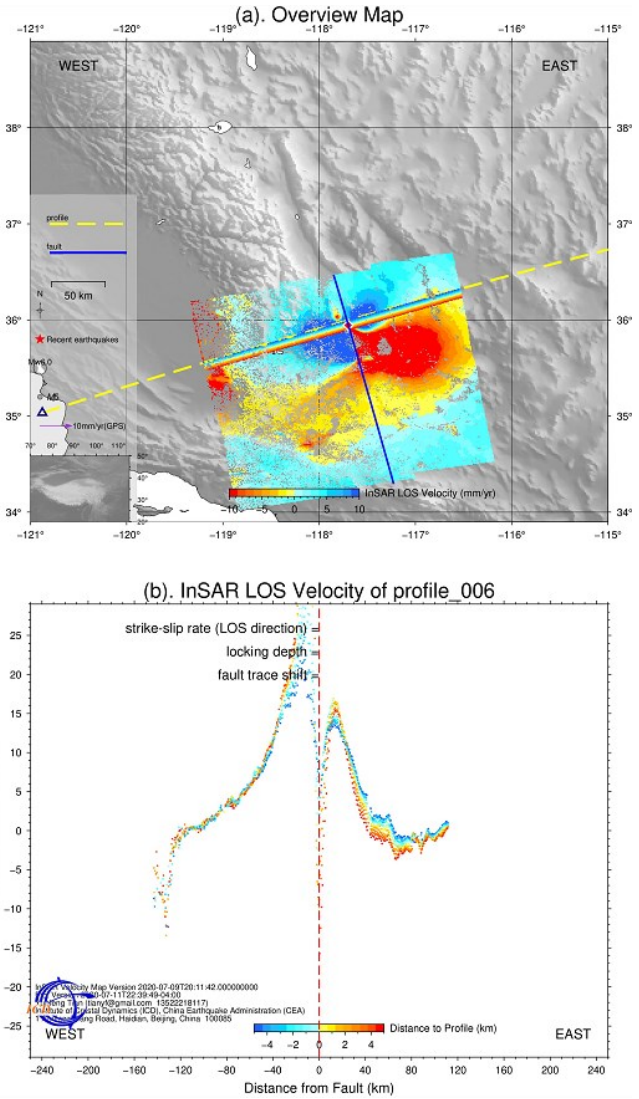
Use iGPS IDL program
SAR_LOS_PROFILES_AUTO_LLV
Create profiles perpendicular to fault line





Generate Profile Plot

- sh_sar_plot_vel_profile



Common-Point Stacking (statistics method)

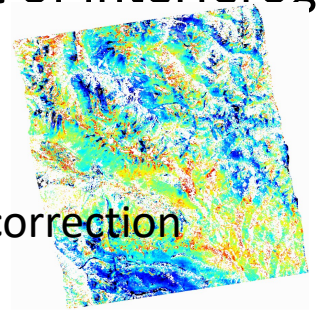
GACOS (from meteorological observations)

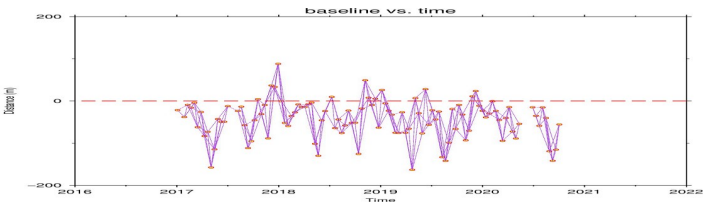
ATMOSPHERIC DELAY CORRECTION

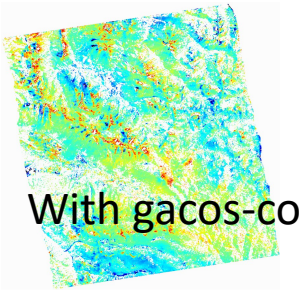
Atmospheric Delay Correction: Is it necessary?

- When the topography variation is large, atmospheric delay correction is important for short temporal baselines or a small amount of interferograms.

Without gacos-correction

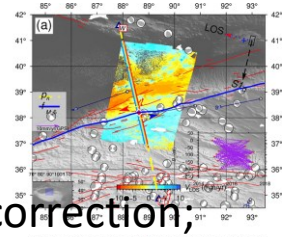




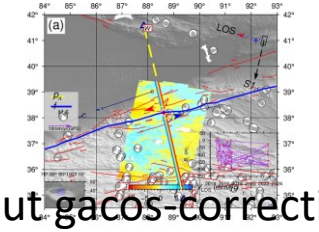


With gacos-correction

- Atmospheric delay correction, sometimes, can introduce improvement for long temporal baselines and sufficient amount of interferograms.



Without gacos-correction; short observation period



Without gacos-correction
Long time observation

GACOS Correction

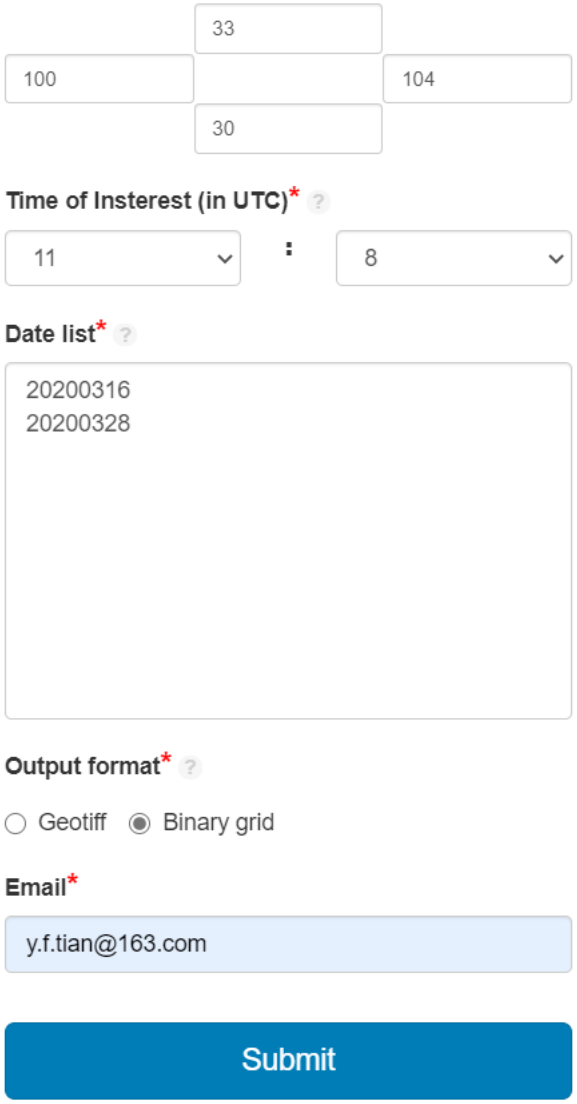
Steps:

1. Download GACOS grid data
2. Uncompress GACOS files
3. Convert binary file into NetCDF format
4. Project data from geographical coordinates to radar coordinates
5. Create GACOS corrections for interferograms
6. Apply GACOS corrections to interferograms

Step 1. Download GACOS grid data

- http://www.gacos.net/
- Output format: Binary grid

- Save the *.tgz files to **./tgz** directory

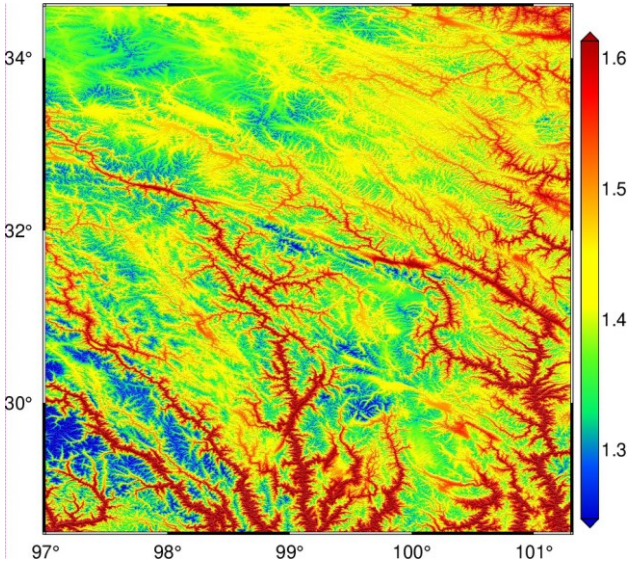


Step 2. Uncompress GACOS files

- sh_sar_gacos_tgz_unzip

Will create **ztd** directory and extract files into it.

名称	大小	类型	修改时间	属性
..		上级文件夹		
20141012.ztd	144 MB	ZTD File	12/27/2020 9:41:22 AM	-------
20141012.ztd.rsc	380 字节	RSC File	12/27/2020 9:41:27 AM	-------
20141012.ztd_preview.jpg	462 KB	JPEG image	12/27/2020 9:42:05 AM	-------
20141105.ztd	144 MB	ZTD File	12/27/2020 9:43:46 AM	-------
20141105.ztd.rsc	380 字节	RSC File	12/27/2020 9:43:51 AM	-------
20141105.ztd_preview.jpg	462 KB	JPEG image	12/27/2020 9:44:29 AM	-------
20141129.ztd	144 MB	ZTD File	12/27/2020 9:46:08 AM	-------
20141129.ztd.rsc	380 字节	RSC File	12/27/2020 9:46:13 AM	-------
20141129.ztd_preview.jpg	461 KB	JPEG image	12/27/2020 9:46:51 AM	-------



20141012.ztd_preview.jpg

Step 3. Convert binary file into NetCDF format

- sh_sar_gacos_ztd2ll

Convert files in **ztd** directory to NetCDF (*.grd) formats and save the output in **ztd.ll** directory.

Step 4. Project data from geographical coordinates to radar coordinates

- sh_sar_gacos_ll2ra

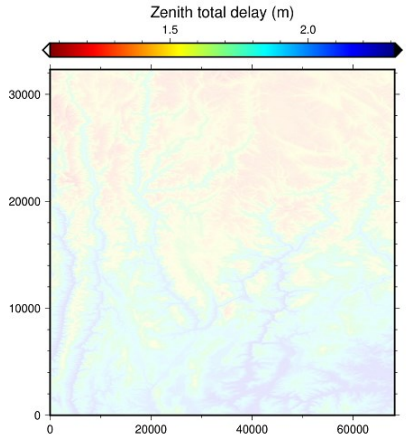
Convert data from geographical coordinates into radar coordinates, saving results in **ztd.ra** directory.

Prerequisitive:

- trans.dat (link from topo/trans.dat, e.g.,)

```
ln -s  /some_where/F1/topo/trans.dat
```

- intf_all (link from GMTSAR processing directory)

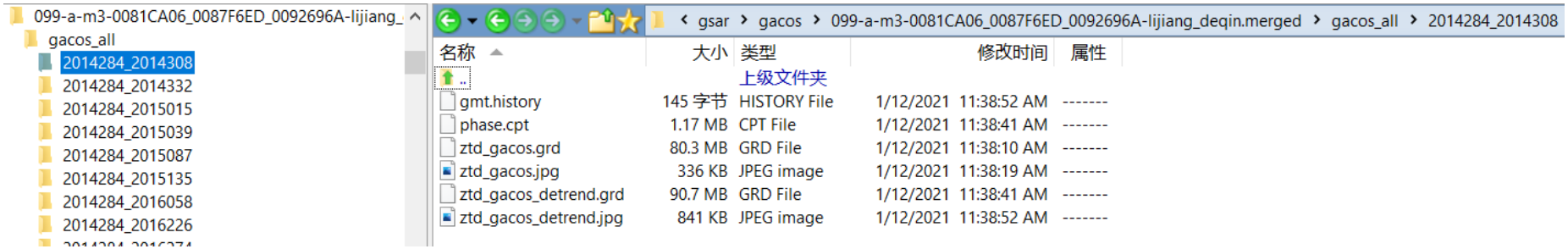


Step 5. Create GACOS corrections for interferograms

- sh_sar_gacos_intf_all

Results saved in **gacos_all**

iGPS also detrends the GACOS data (using grdtrend command of GMT) because the trend is also removed in interferograms.

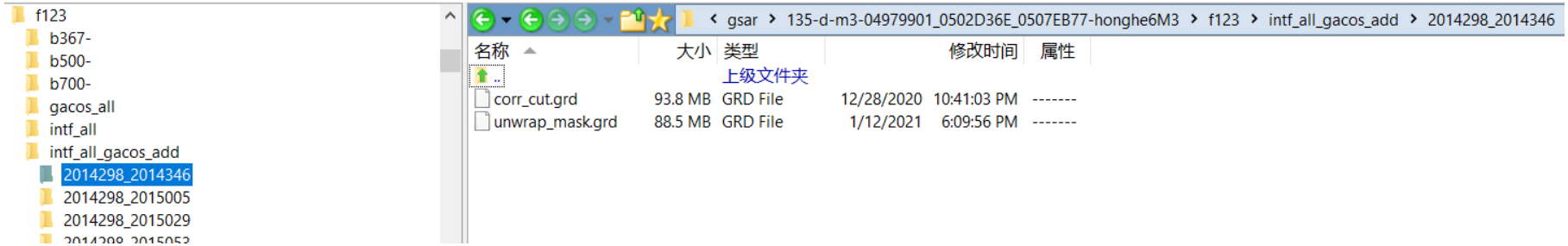


Step 6. Apply GACOS corrections to interferograms

- sh_sar_gacos_apply_intf_add

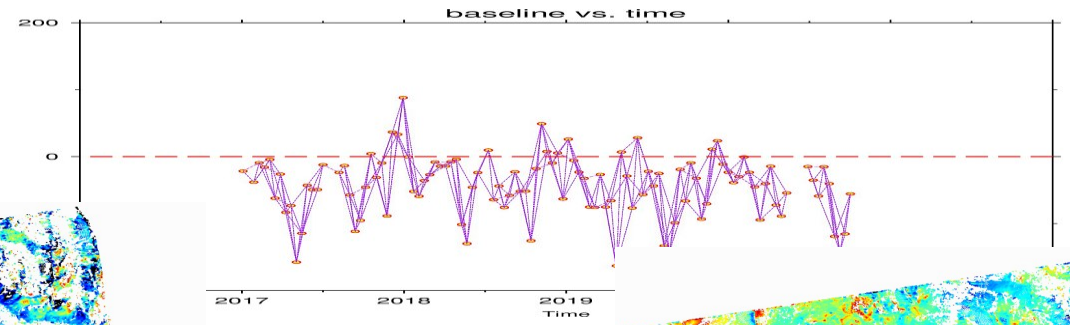
Results are saved in **intf_all_gacos_add**

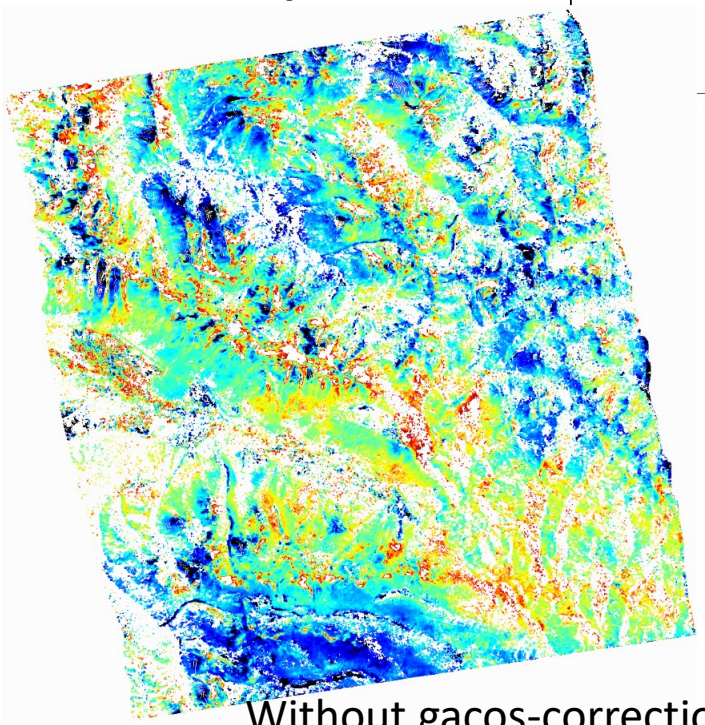
It seems that the “addition” of GACOS correction to GMTSAR’s interferogram is the correct operation.



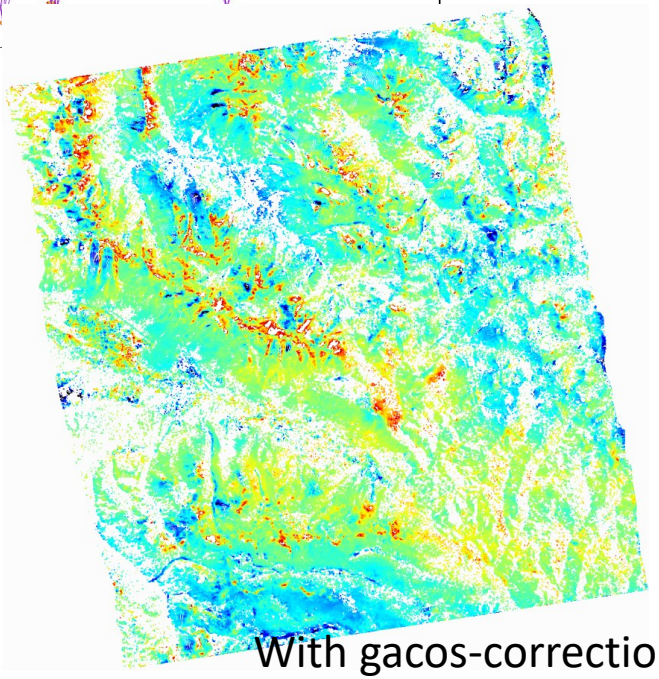
Generate velocity map and displacement time series using corrected interferograms

- sh_sar_call_sbas -ipath intf_all_gacos_add ….
- Example:





Without gacos-correction



With gacos-correction

Thank You

- Please report bugs to

  tianyf@gmail.com

Any questions/comments/suggestions/… will be appreciated!