

# *Theory and practice of phase unwrapping*

*Meng (Matt) Wei, David Sandwell*

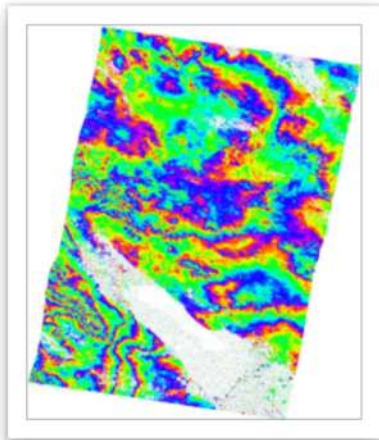
*GMTSAR short course, 2018*

*Based on notes from the last few years by:*

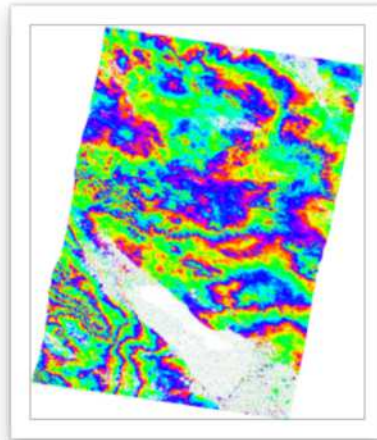
*Rob Mellors, Eric Lindsey, Xiaohua (Eric) Xu, Kurt Feigl*

*and notes from Rüdiger Gens, presented at ASF*

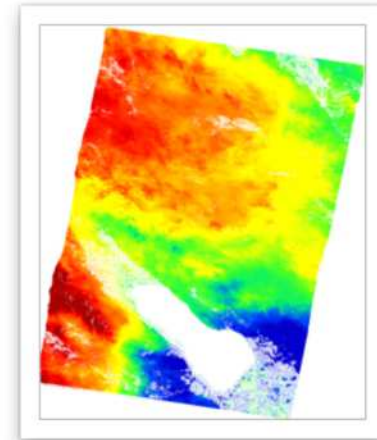
*Why are there so many files? Which file should I look at?*



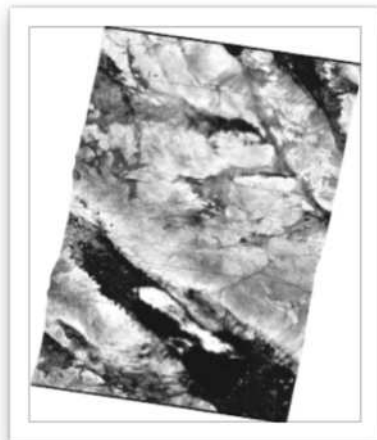
phase\_mask\_ll.png



phasefilt\_mask\_ll.png



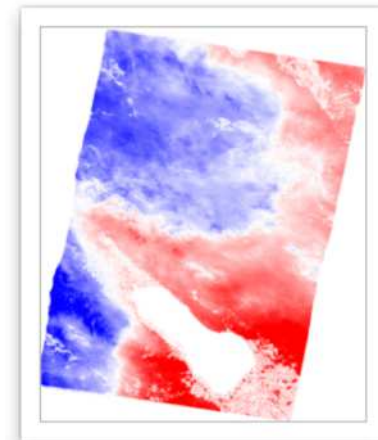
unwrap\_mask\_ll.png



corr\_ll.png

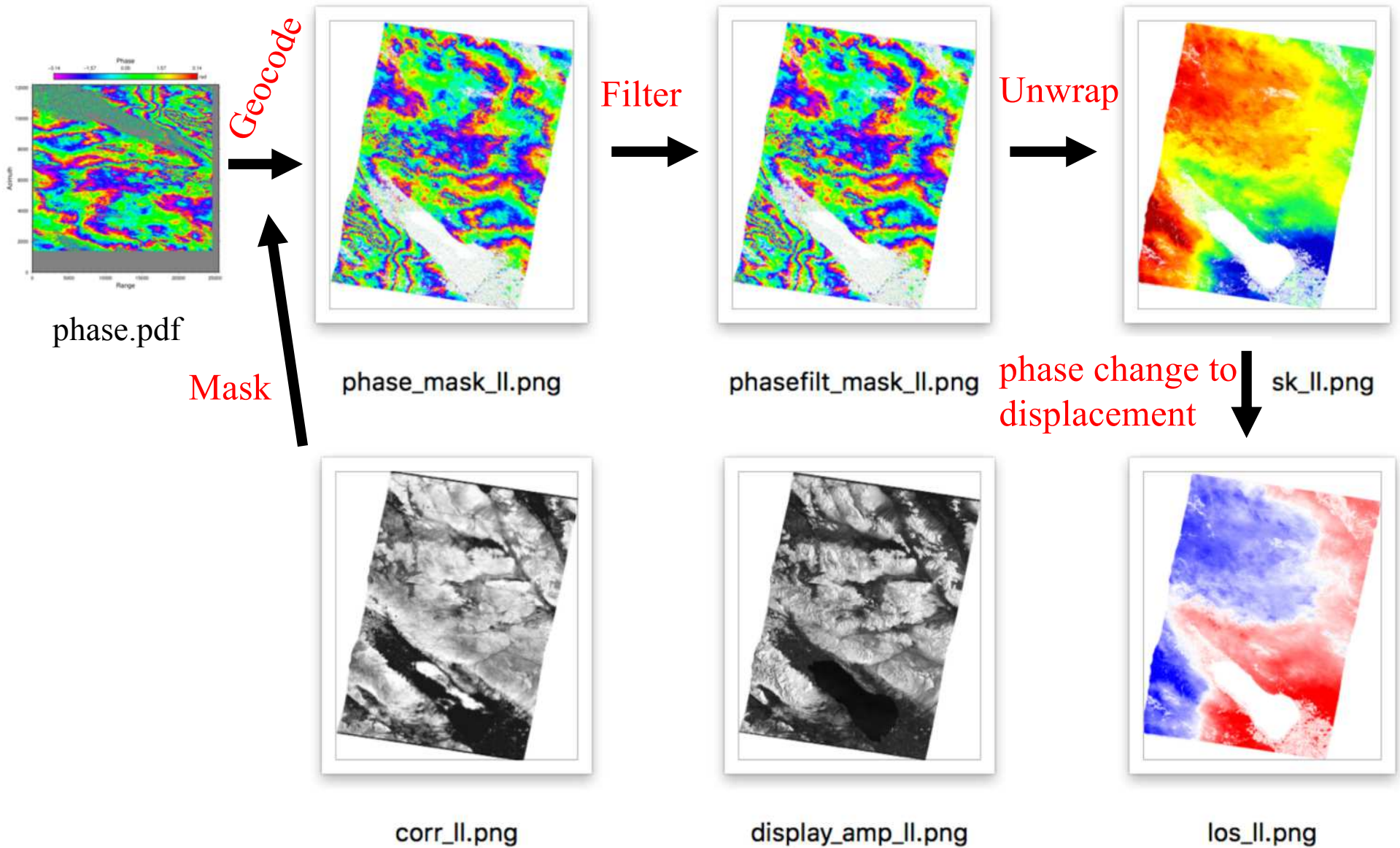


display\_amp\_ll.png



los\_ll.png

# Summary



## *overview of unwrapping*

Given an interferogram(s)

- usually need to convert phase to useful units
- we know radar wavelength and geometry

Usually requires unwrapping

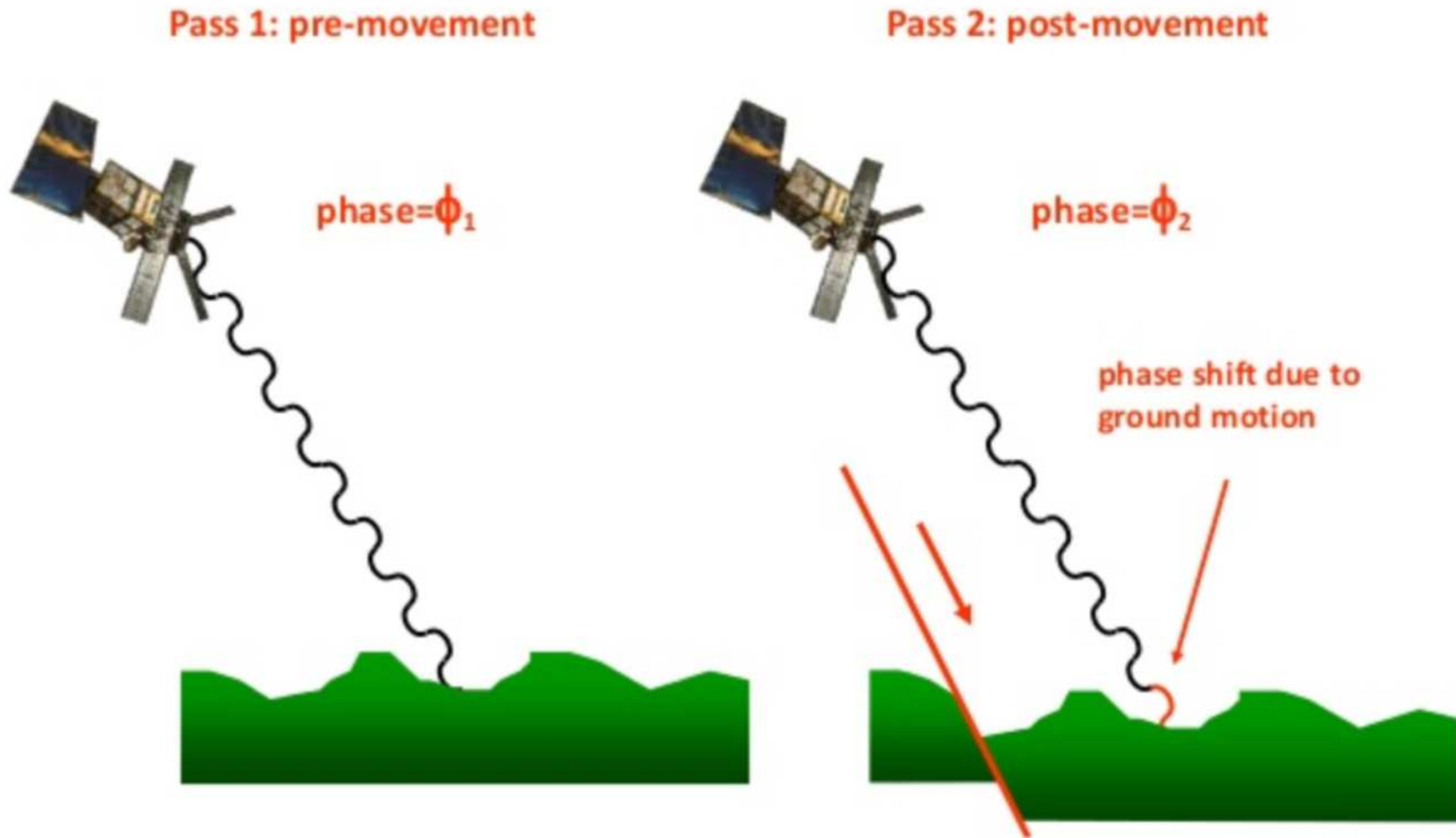
- unwrapping not always easy or fast

Two popular algorithms

- Goldstein
- SNAPHU (Chen and Zebker, 2000), default in GMTSAR
- others exist! (global, gradient, etc)

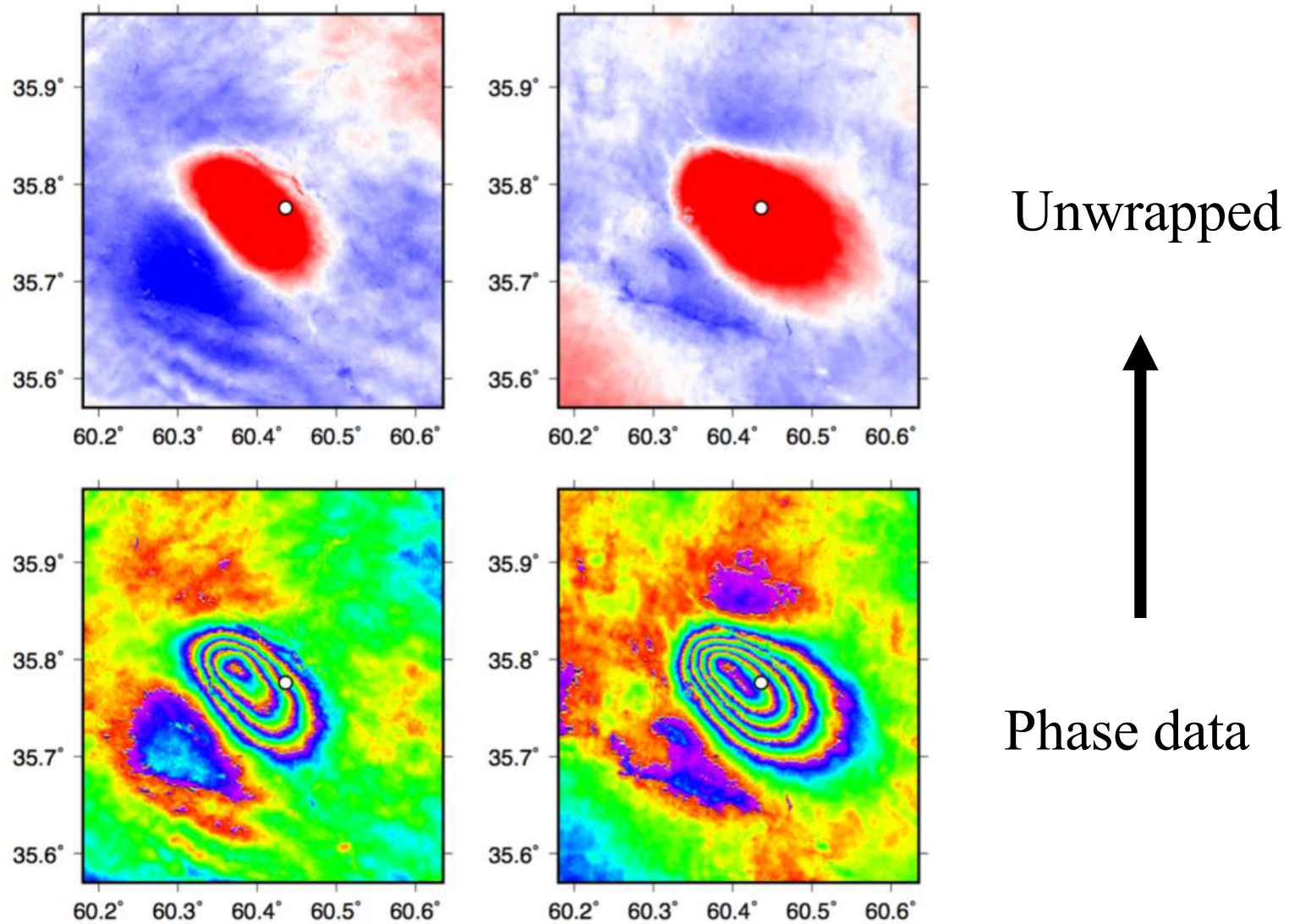
# Why phase unwrapping?

InSAR measures phase shift



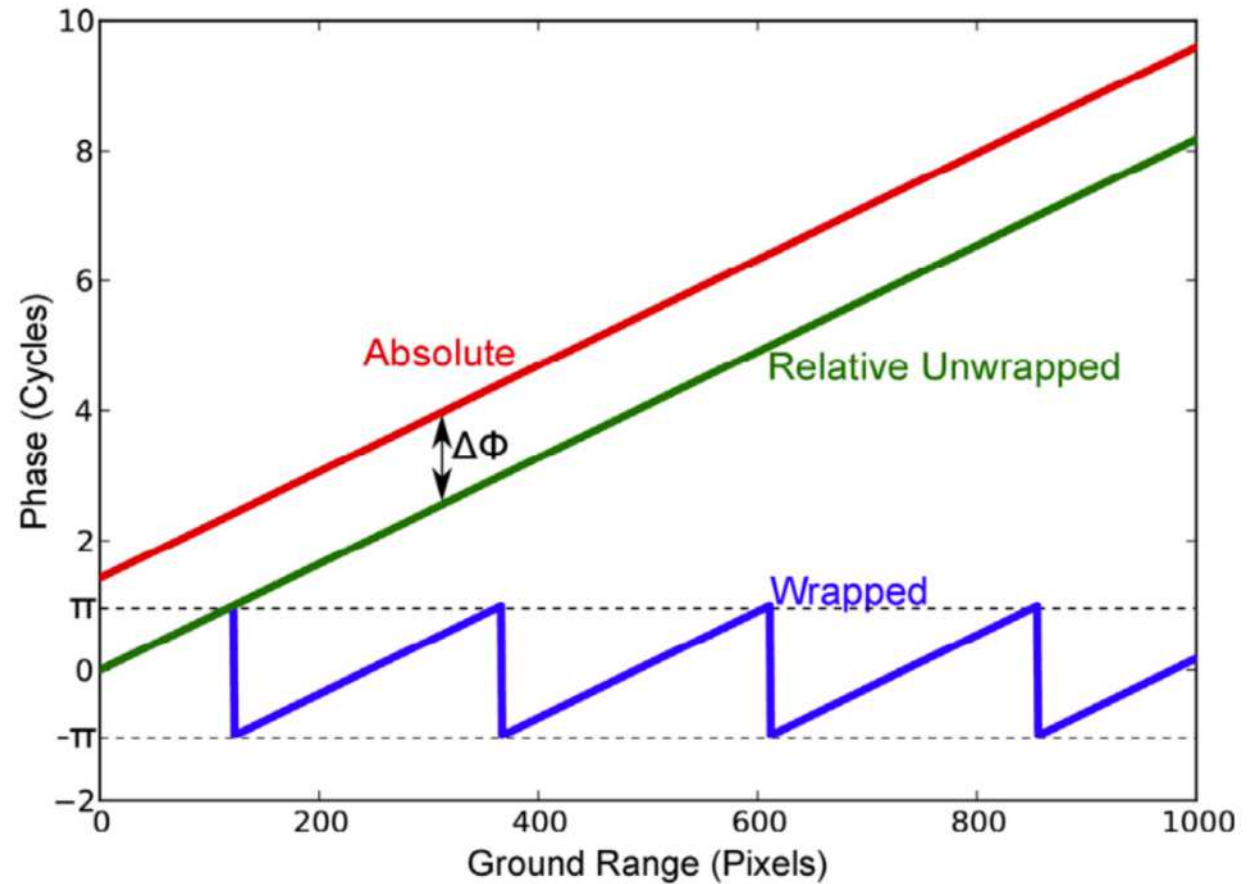
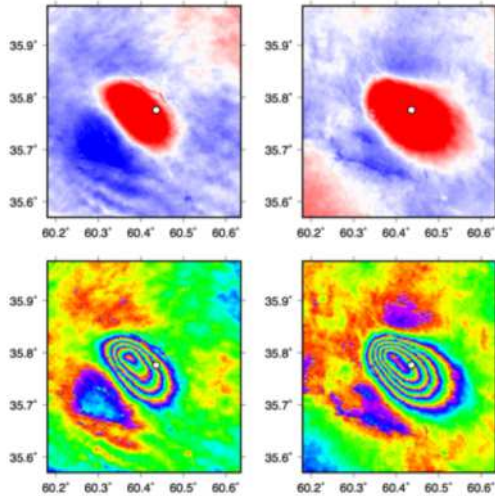


# *Why phase unwrapping?*



Sentinel, M6.1 Iran, 04/05/17, ascending & descending

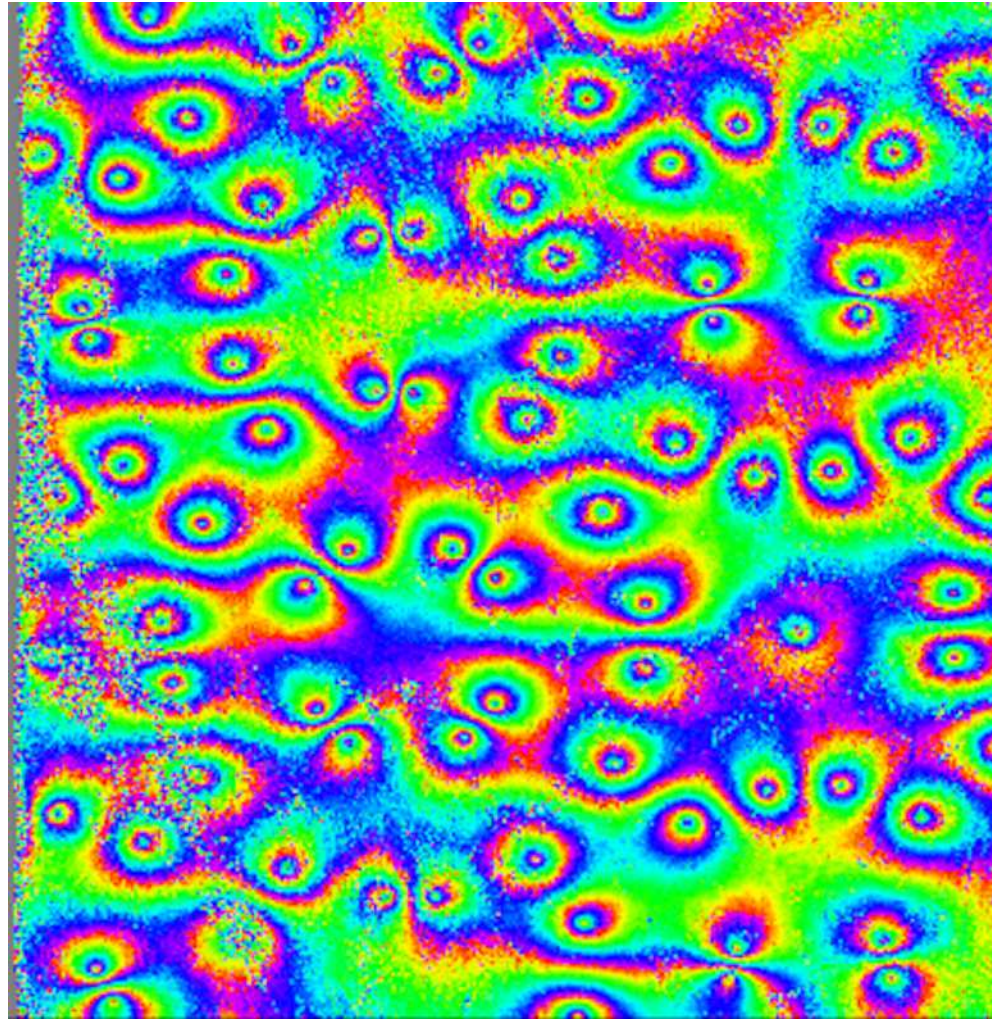
# Why phase unwrapping?



snaphu  
 $\Delta\Phi = N2\pi$

Osmanoglu et al., 2016

*Unwrapping is not always easy or fast*



An example of poor unwrapping



## *Ideal case*

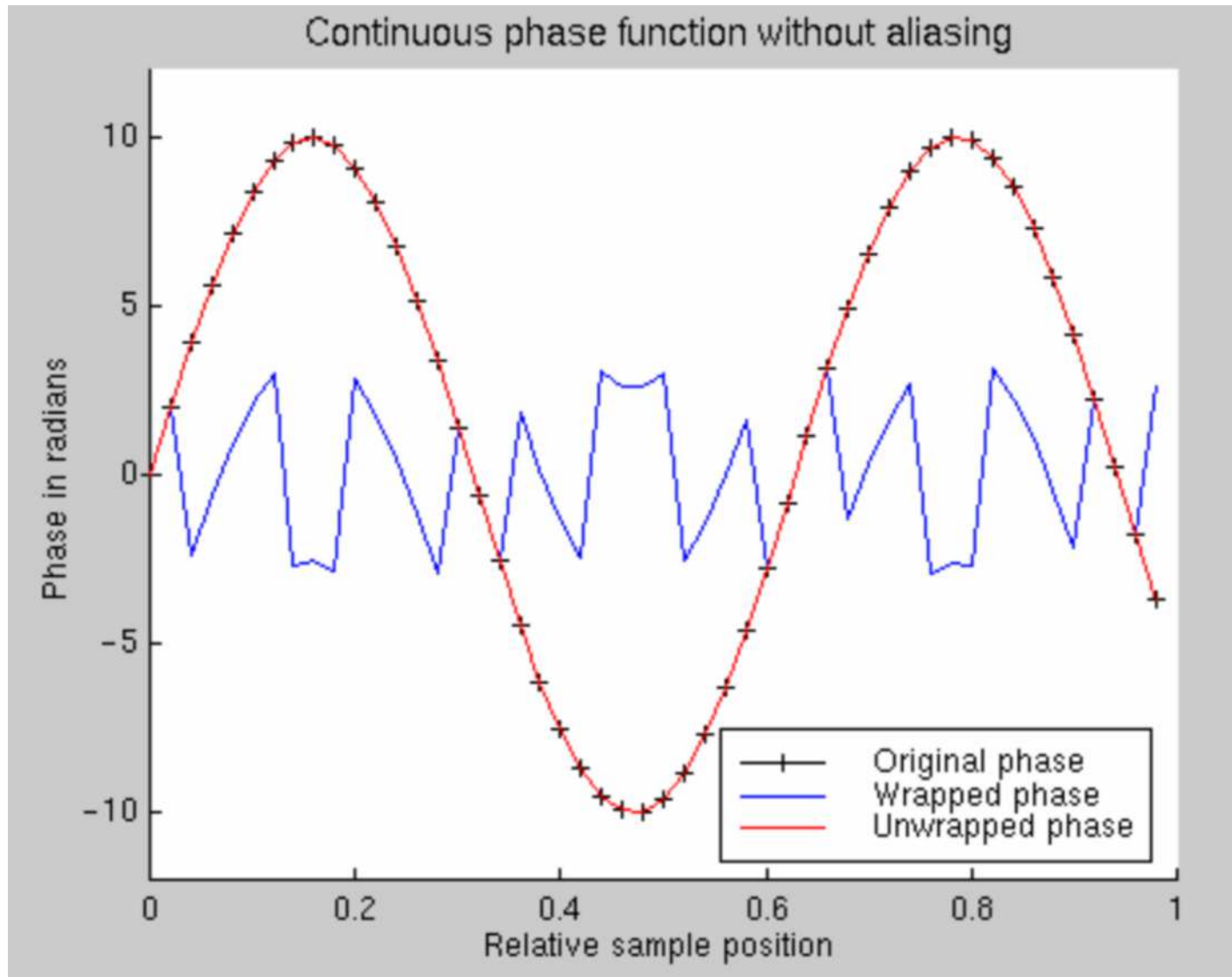
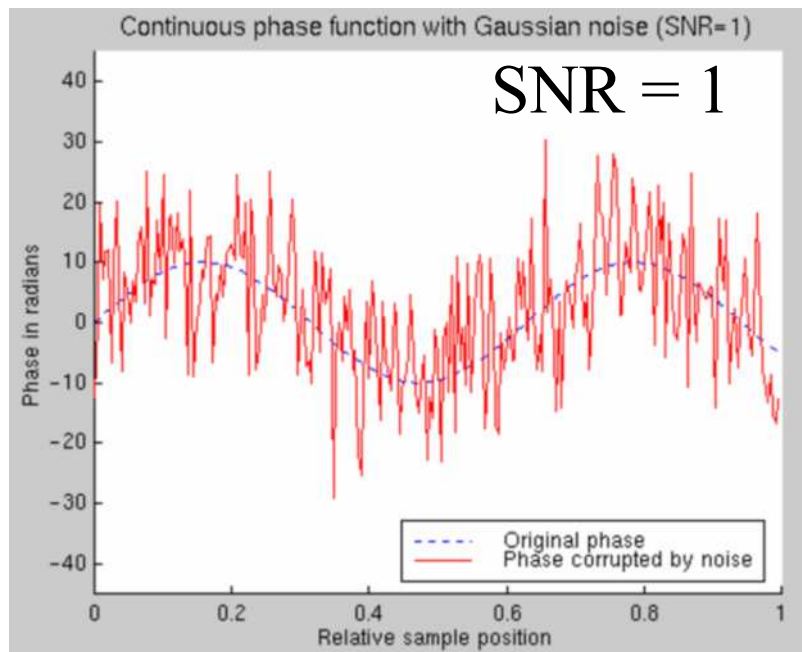
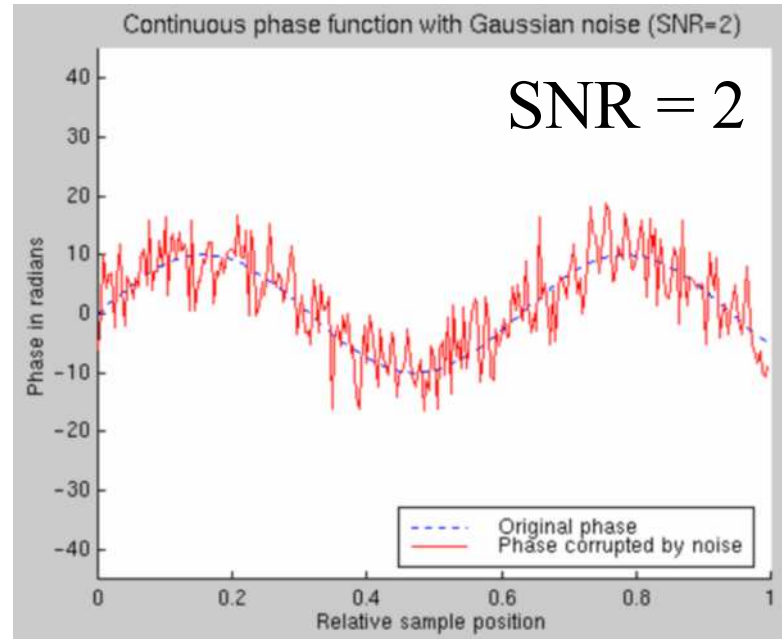
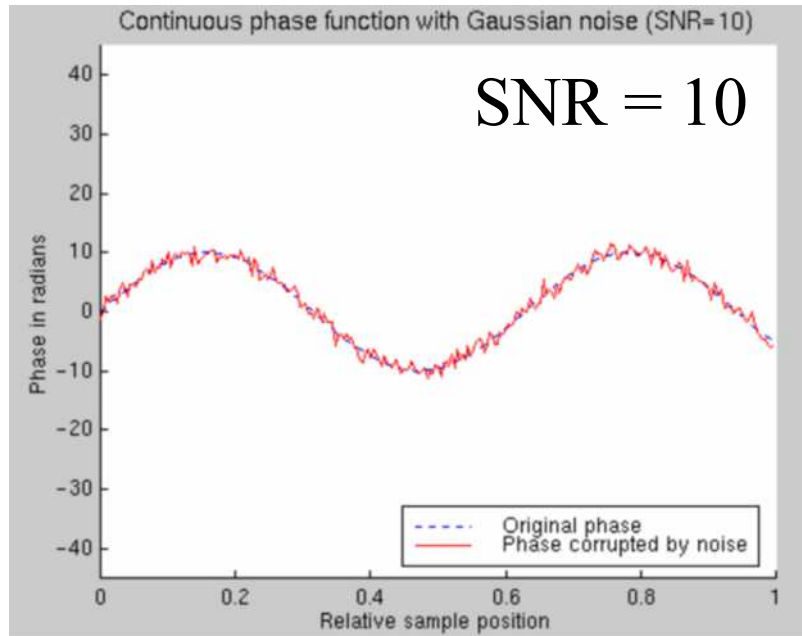


Image in courtesy of Rüdiger Gens

# Problem 1: noise

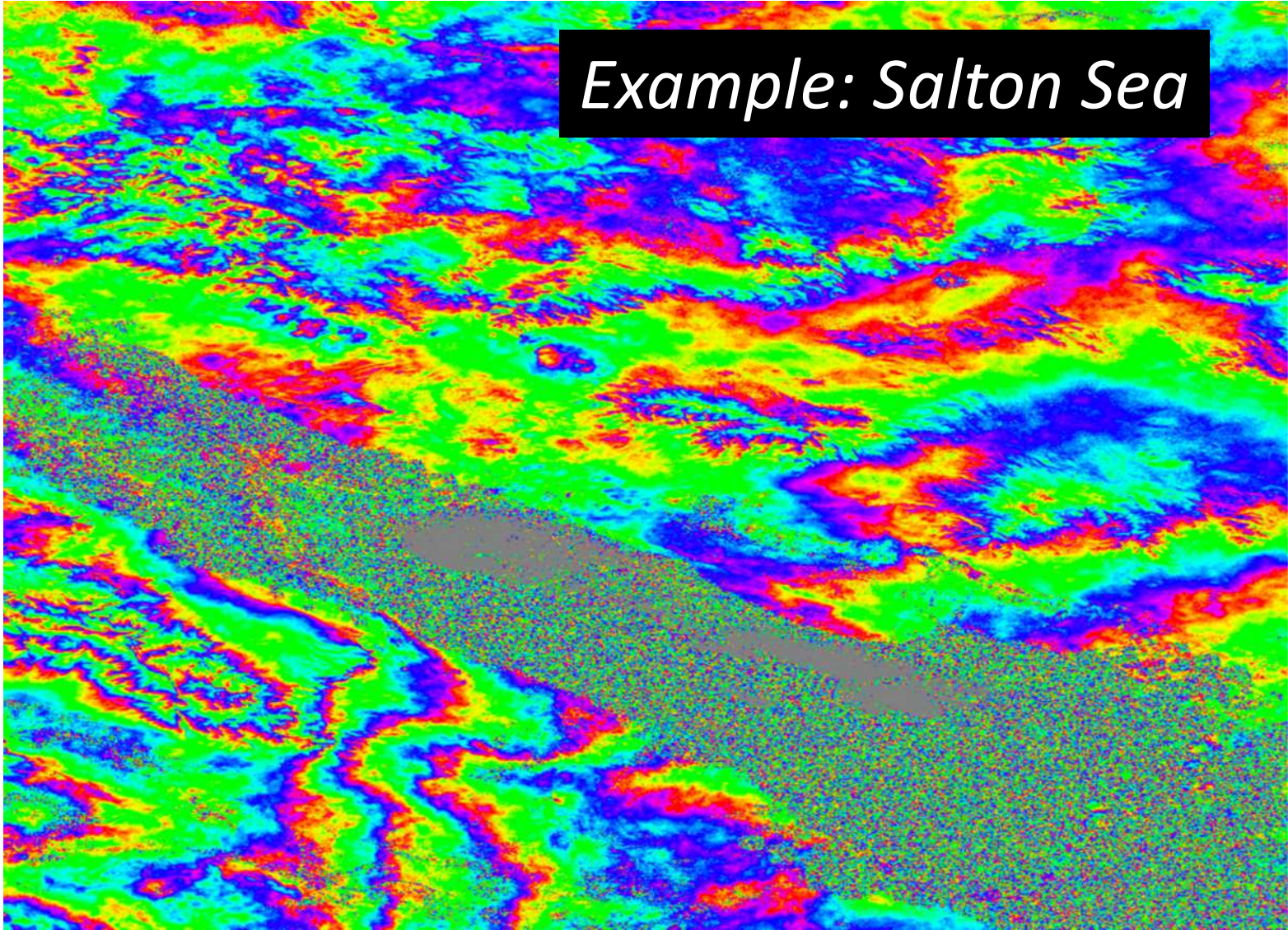


Changes on the surface (e.g., vegetation, snow, erosion) may cause the two images to de-correlate, introducing noise



## *Problem 1: noise*

*Example: Salton Sea*



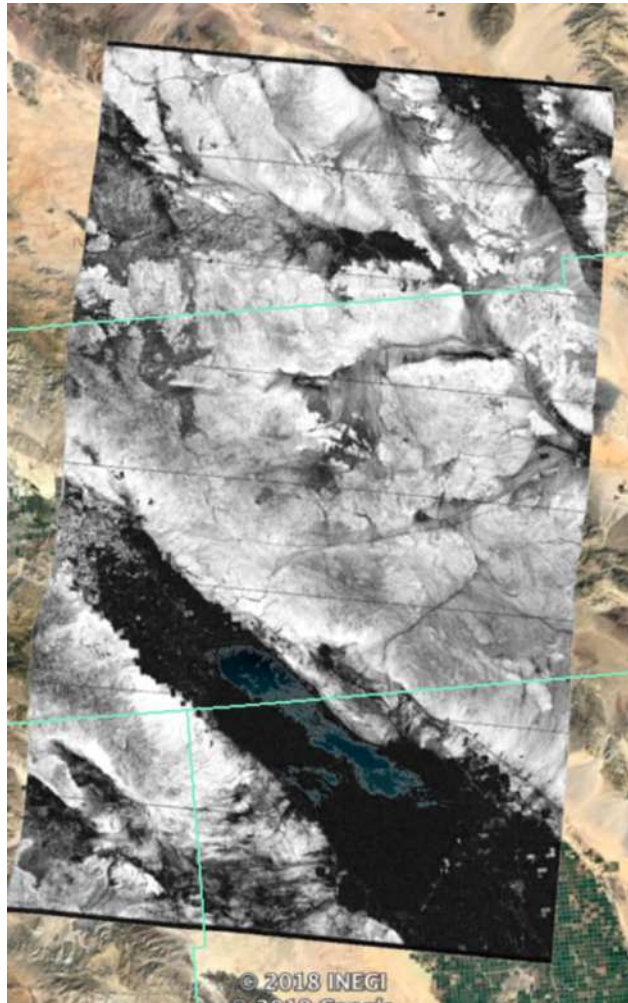
## *How to reduce noise?*

- 1) Filter to reduce noise.
- 2) Mask out areas of water and low coherence.

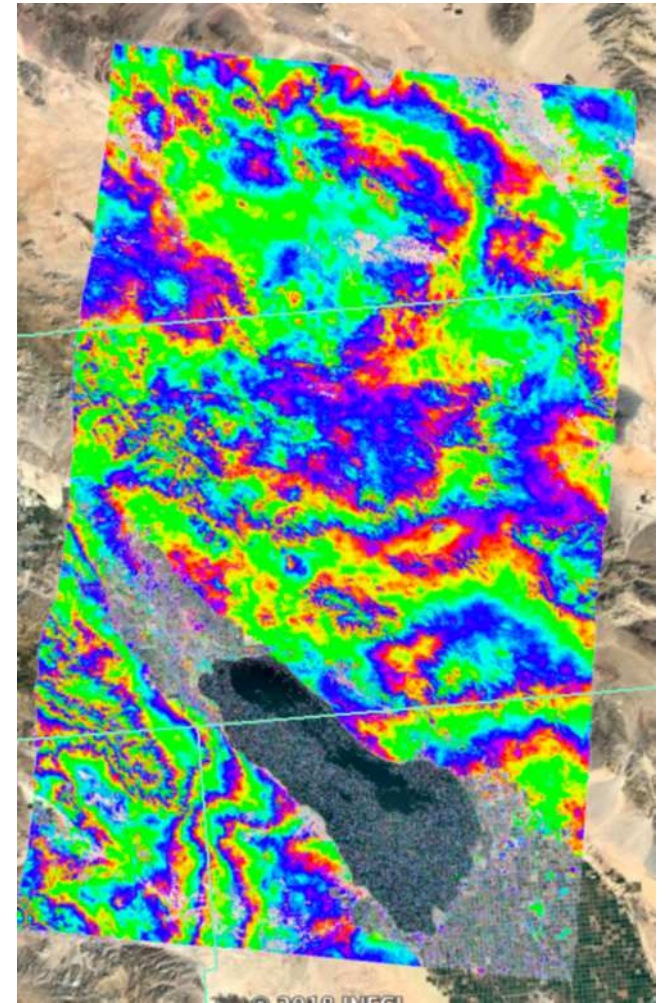


# *Reduce noise: 1. Mask*

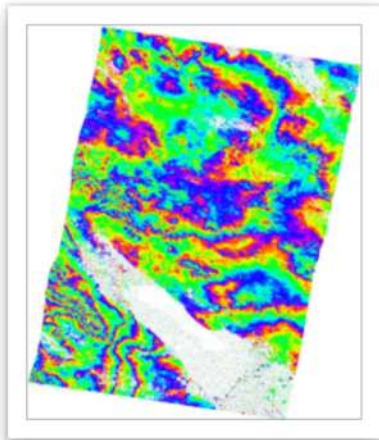
Correlation



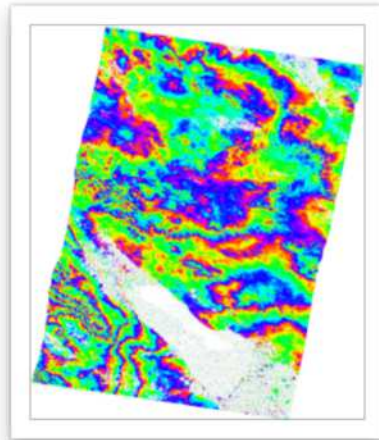
Phase masked



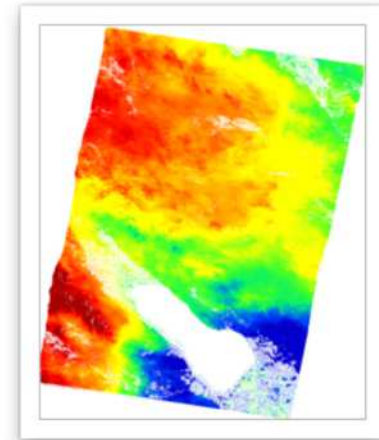
# Reduce noise: 1. Mask



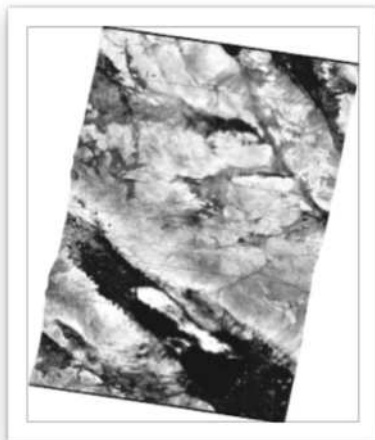
phase\_mask\_ll.png



phasefilt\_mask\_ll.png



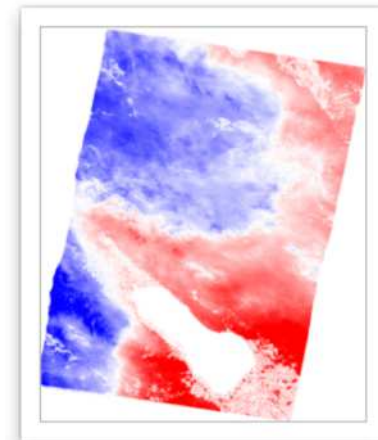
unwrap\_mask\_ll.png



corr\_ll.png



display\_amp\_ll.png



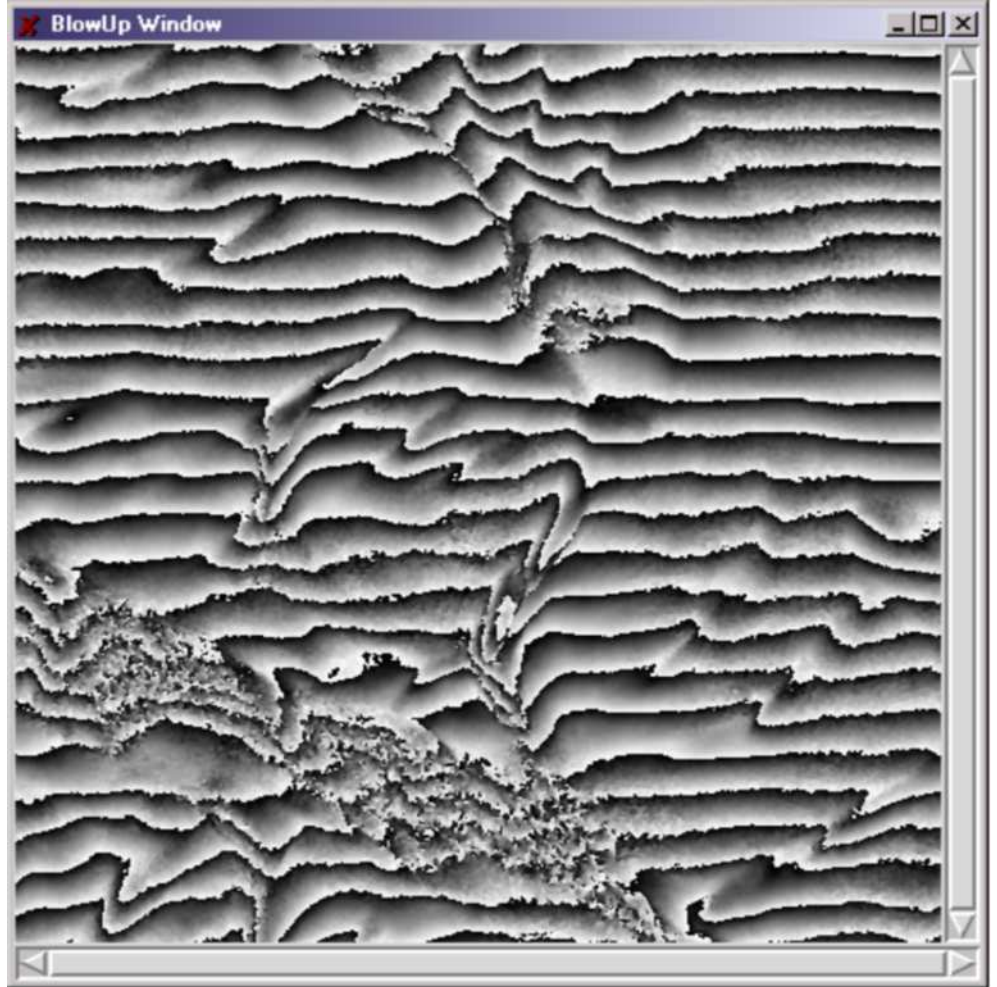
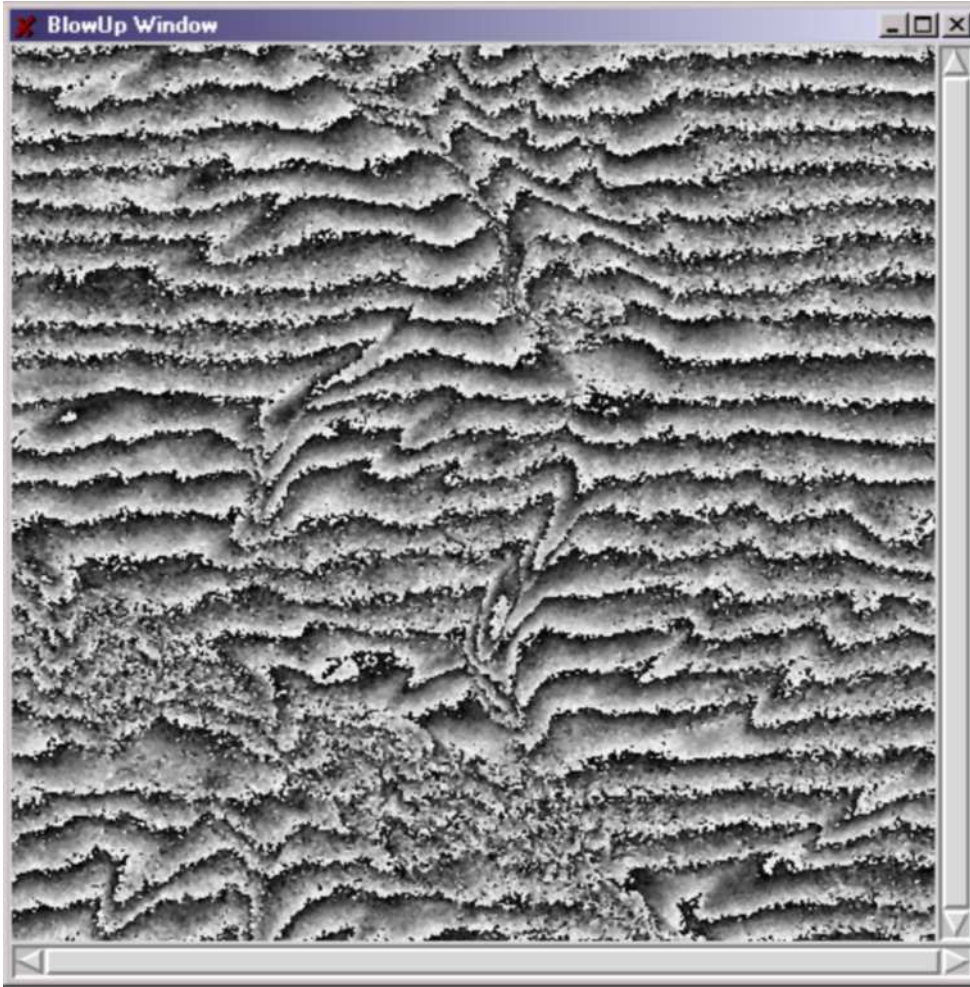
los\_ll.png



## config.s1a.txt

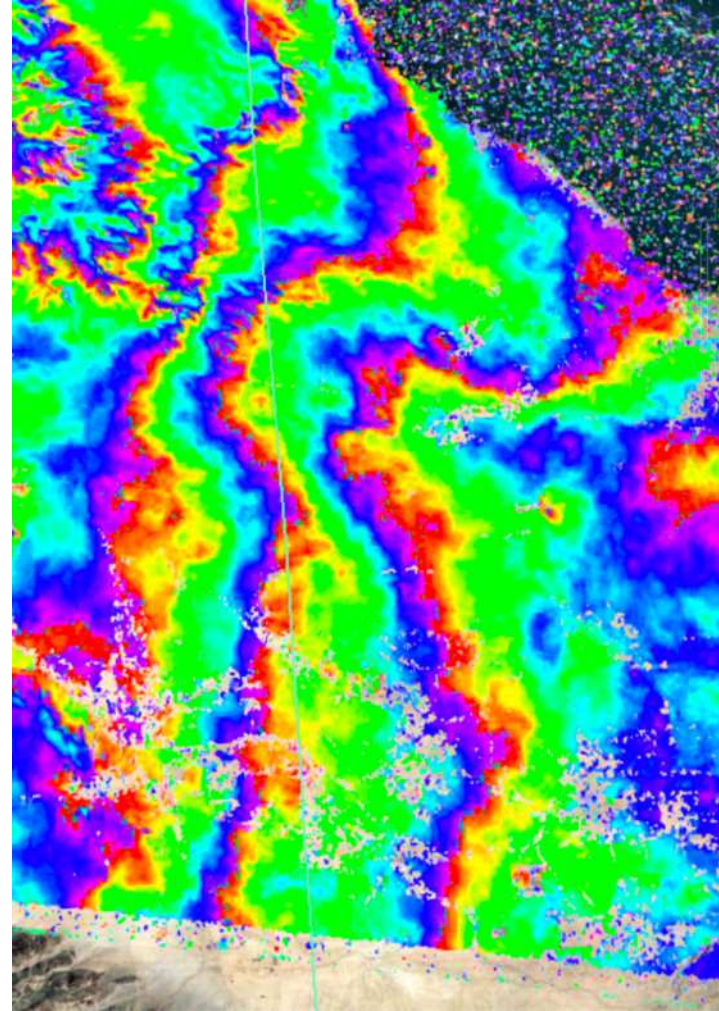
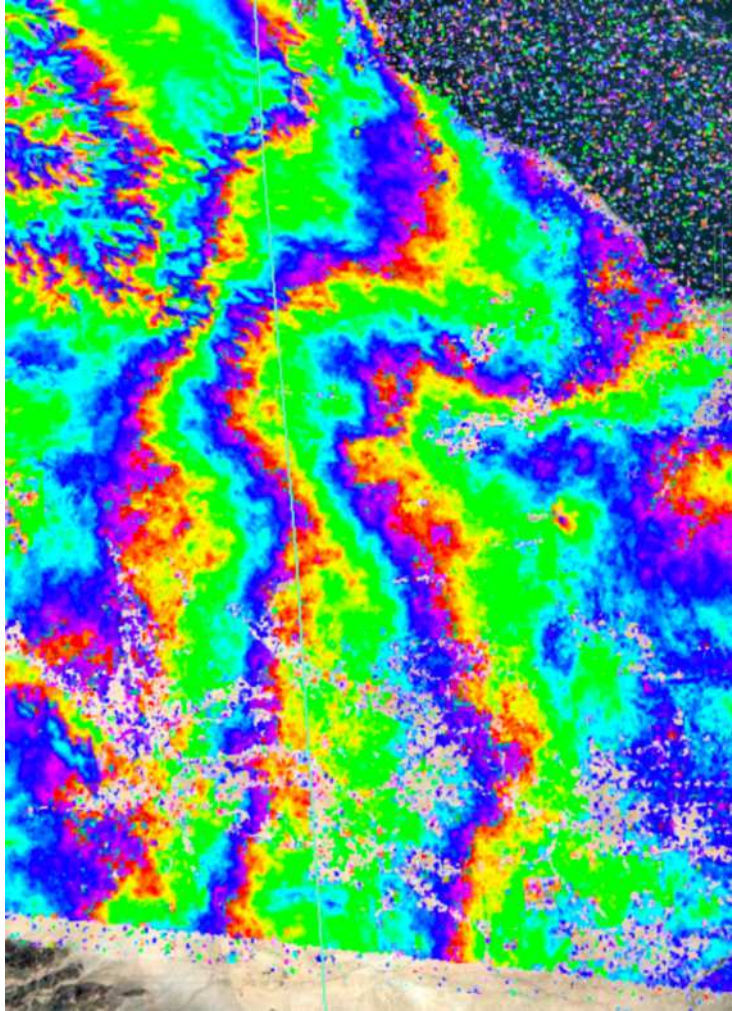
```
#####  
# parameters for unwrap phase #  
# - snaphu.csh #  
#####  
# correlation threshold for snaphu.csh (0~1)  
# set it to be 0 to skip unwrapping.  
threshold_snaphu = 0.1  
  
# region to unwrap in radar coordinates (leave it blank if unwrap the whole region)  
# example 300/5900/0/25000  
region_cut =  
  
# mask the wet region (Lakes/Oceans) before unwrapping (1 -- yes; else -- no)  
switch_land = 1  
  
#  
# Allow phase discontinuity in unrapped phase. This is needed for interferograms having  
sharp phase jumps.  
# defo_max = 0 - used for smooth unwrapped phase such as interseismic deformation  
# defo_max = 65 - will allow a phase jump of 65 cycles or 1.82 m of deformation at C-band  
#  
defomax = 0.0001  
  
#####  
# parameters for geocode #  
# - geocode.csh #  
#####  
# correlation threshold for geocode.csh (0~1)  
threshold_geocode = .1
```

## *Reduce noise: 2. Filter*





## *Reduce noise: 2. Filter*



Which one is filtered?

## *Some technical details on filtering*

Objective: improve signal-to-noise of fringes **prior** to unwrapping

### **static**

- usually low-pass
- convolve with set of filter coefficients (boxcar, Gaussian, etc)
- **GMTSAR use Gaussian filter**

### **adaptive**

- *Goldstein and Werner* [1998] spectral filter
- effective but “can significantly change the structure of the interferogram” [*Baran et al*, 2003]

## *Some technical details on filtering*

### phasefilt

- reads in real and imaginary files (imag.grd and real.grd)
- alpha = exponent for filter (default is 0.5; between 0.0 and 1.5)
- psize = patch size (usually 16 or 32)
- Can define alpha with correlation also

Run by filter.csh

Filter.csh run by p2p\*.csh scripts

creates phasefilt.grd

*(phasefilt makes filtphase.grd which is*

*flipped with grdmath to create phasefilt.grd)*

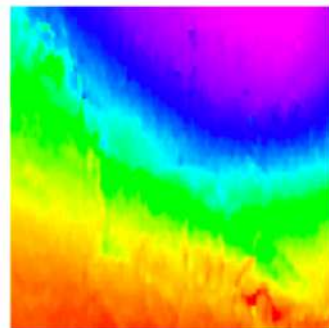
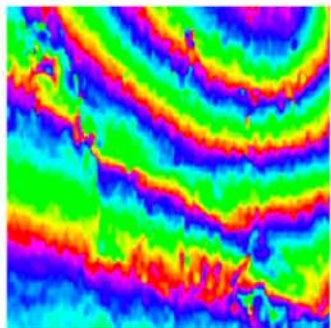
```
phasefilt -imag imagfilt.grd -real realfilt.grd -amp1 amp1.grd -amp2 amp2.grd -psize 16
```

# *Some technical details on filtering*

## Effects of adaptive filter

M 6.1      2017-04-05 06:09:12  
UTC 35.776°N 60.436°E  
13.0 km depth  
Sentinel

No filter

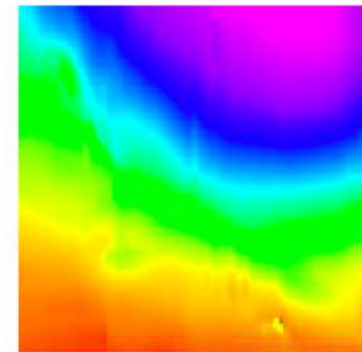
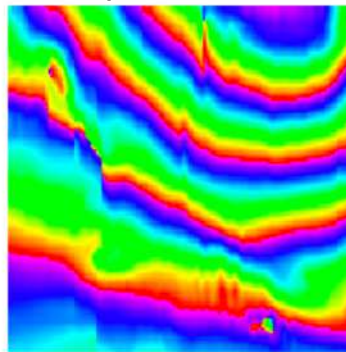


wrapped

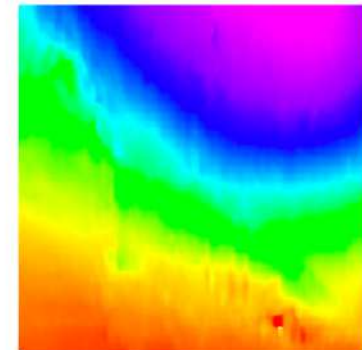
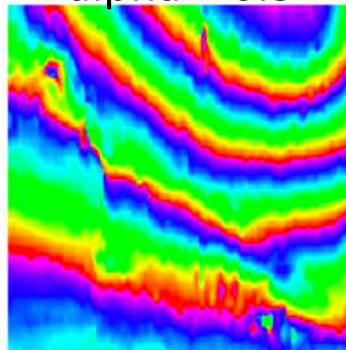
unwrapped

phasefilter, psize=32

alpha = 1.5



alpha = 0.5



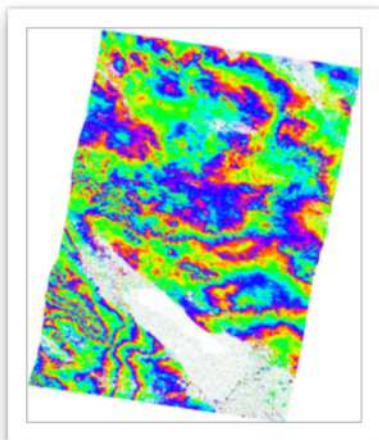
wrapped

unwrapped



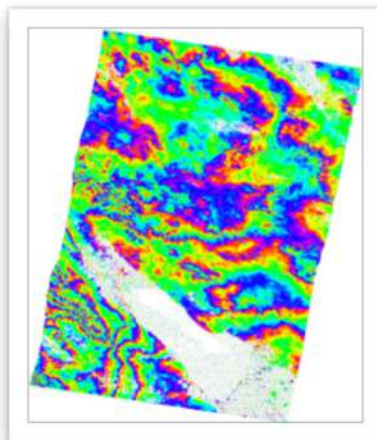
# *We do filter in GMTSAR*

Gaussian filter

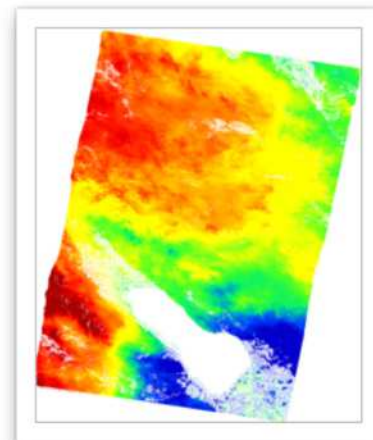


phase\_mask\_ll.png

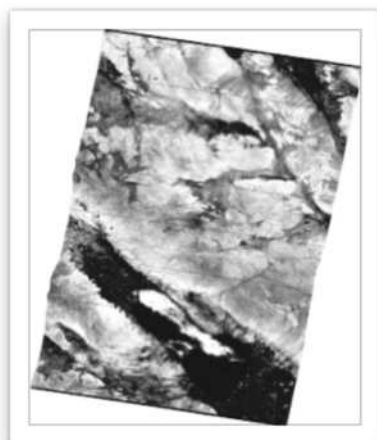
Gaussian filter  
+ Goldstein filter



phasefilt\_mask\_ll.png



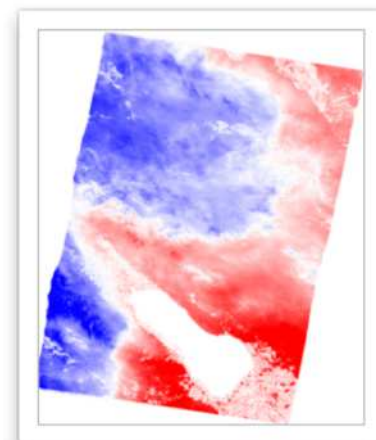
unwrap\_mask\_ll.png



corr\_ll.png



display\_amp\_ll.png

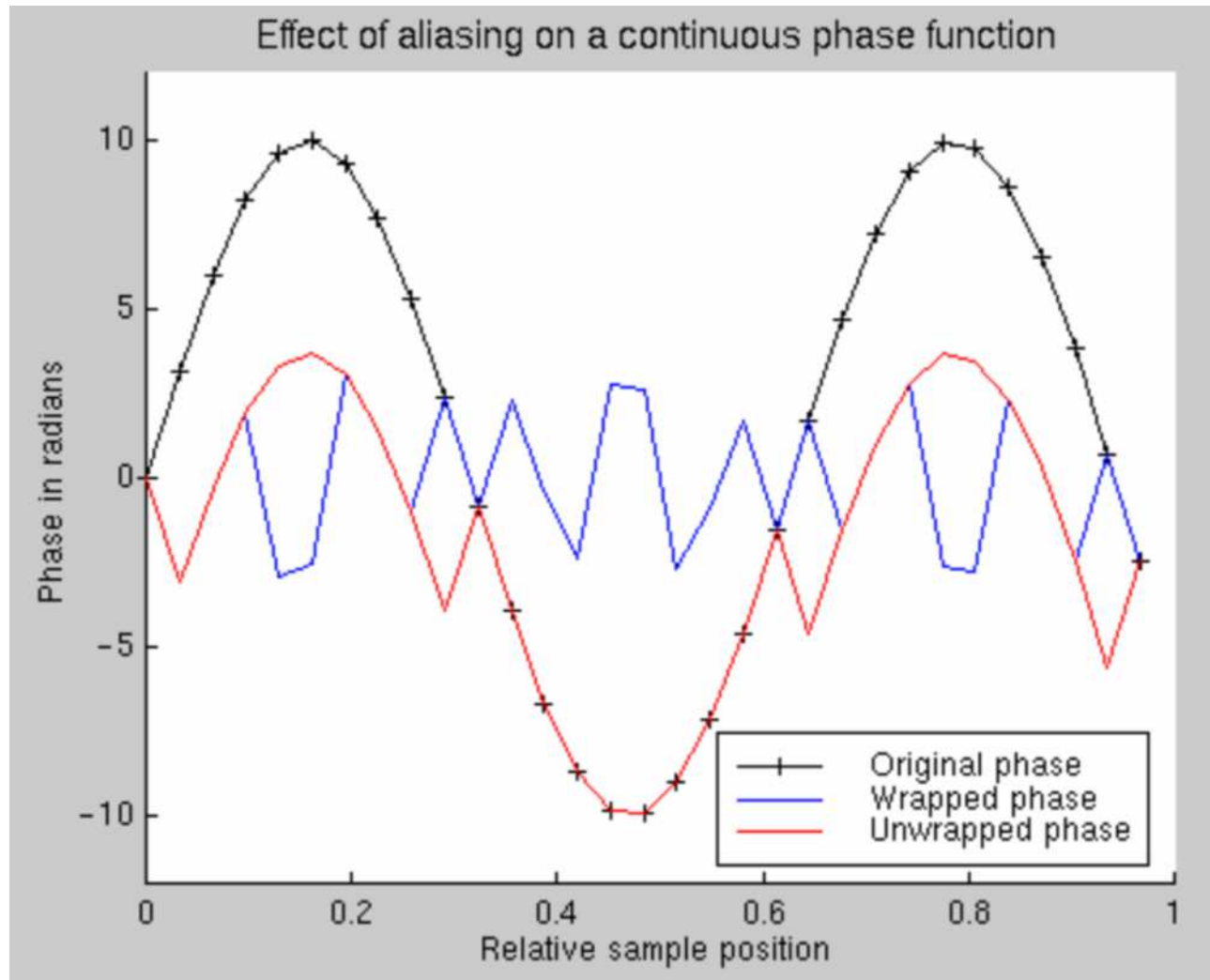


los\_ll.png

## config.s1a.txt

```
#####  
# parameters for make and filter interferograms #  
# - intf.csh #  
# - filter.csh #  
#####  
# switch the master and slave when doing intf.  
# put "1" if assume master as repeat and slave as reference  
# put "0" if assume master as reference and slave as repeat [Default]  
# phase = repeat phase - reference phase  
switch_master = 0  
  
# set the filter wavelength in meters (default is 200m)  
# this is the wavelength where the filter has a gain of 0.5  
# the images will be sampled at 1/4 wavelength or smaller  
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 = 2
```

## Problem 2: aliasing



True phase changes by more than 1 cycle ( $2\pi$  radians) between samples. Caused by large baselines, steep topography or large deformation (steep phase gradient)



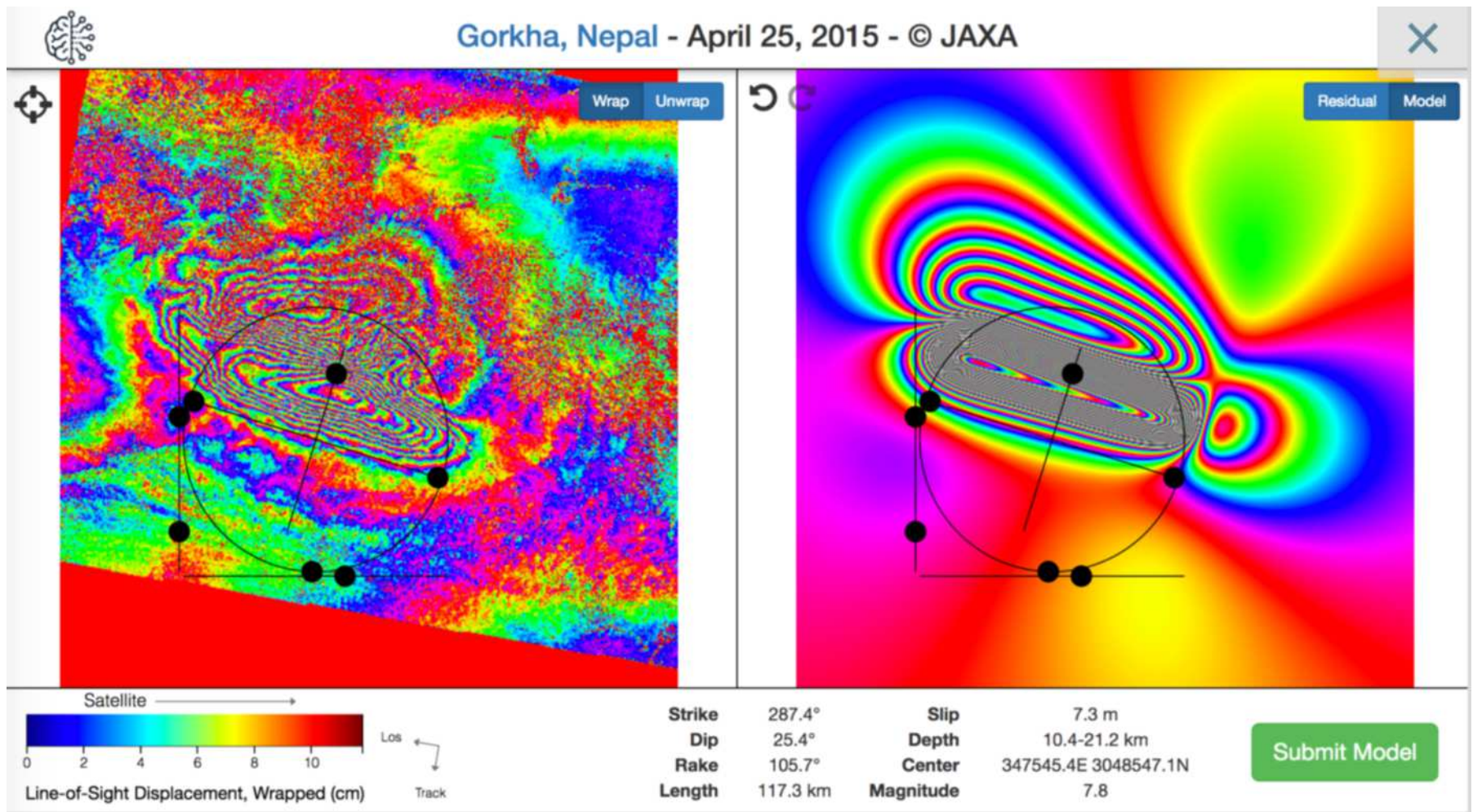
## *Reduce aliasing?*

Removing deformation prior to unwrapping

Process

- Look at it – does it look okay?
- May be impractical for large datasets and automatic processing.
- Subtract out estimated model of deformation before unwrapping.
- Can be done iteratively
- After unwrapping, add in to regain original signal.
- Can bias results with assumptions in model

# Reduce aliasing?



Nice site: <https://earthquakes.aranzgeo.com/>

## *Unwrapping algorithm: GMTSAR uses SNAPHU*

- 1) Uses a statistical estimate of 'cost'
  - 2) Other algorithms may solve with different norms (e.g.  $L^1$  or  $L^2$ , see *Ghiglia and Pratt, 1998*).
- C & Z (2000) claim low norms are best.
  - Three statistical models: topography, deformation, or smooth)
  - $L^0$  unwrapping can be slow (NP hard).
  - There are other algorithm out there.

<https://web.stanford.edu/group/radar/softwareandlinks/sw/snaphu/>

Chen and Zebker, 2000, 2001, and 2002

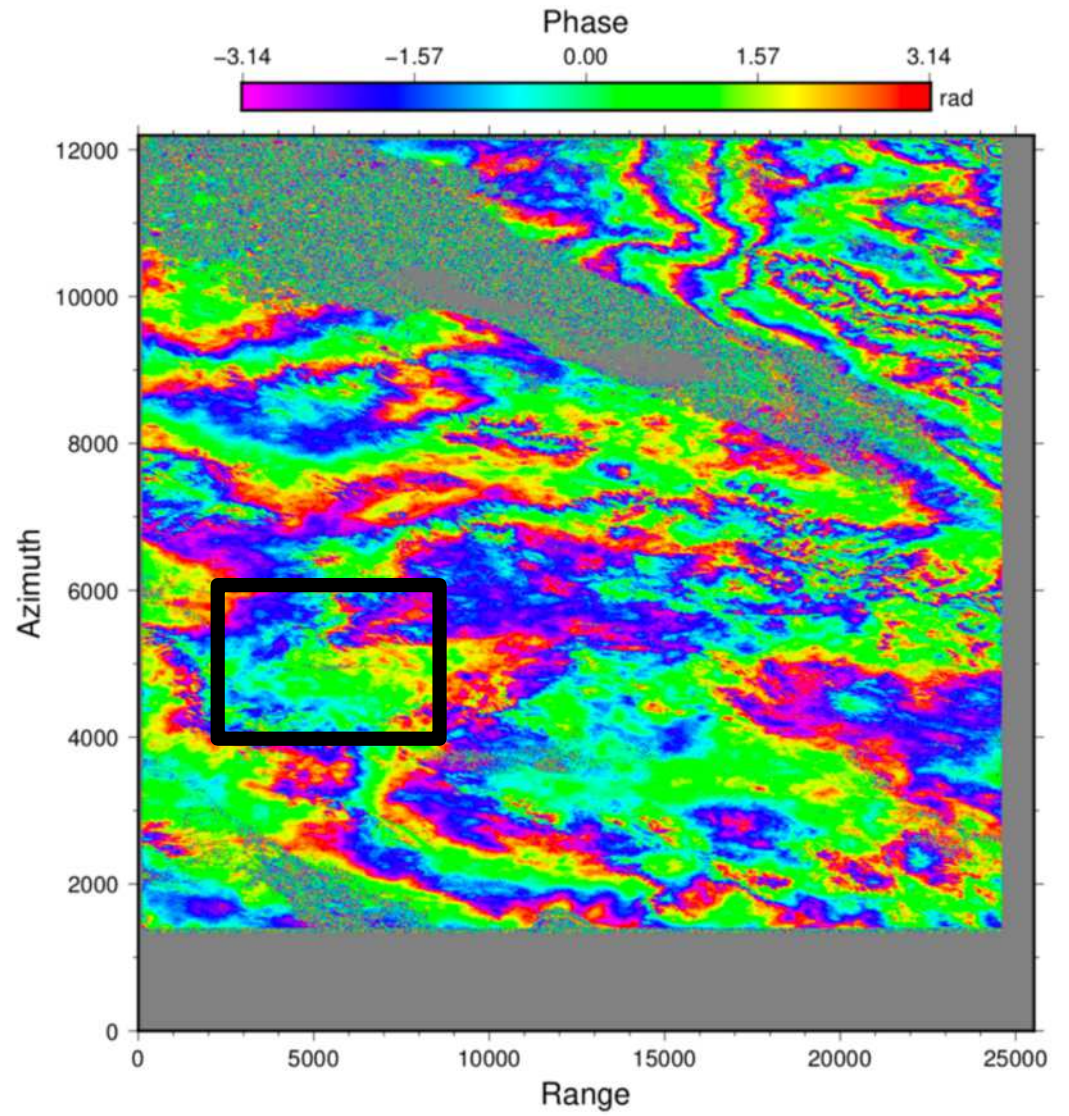
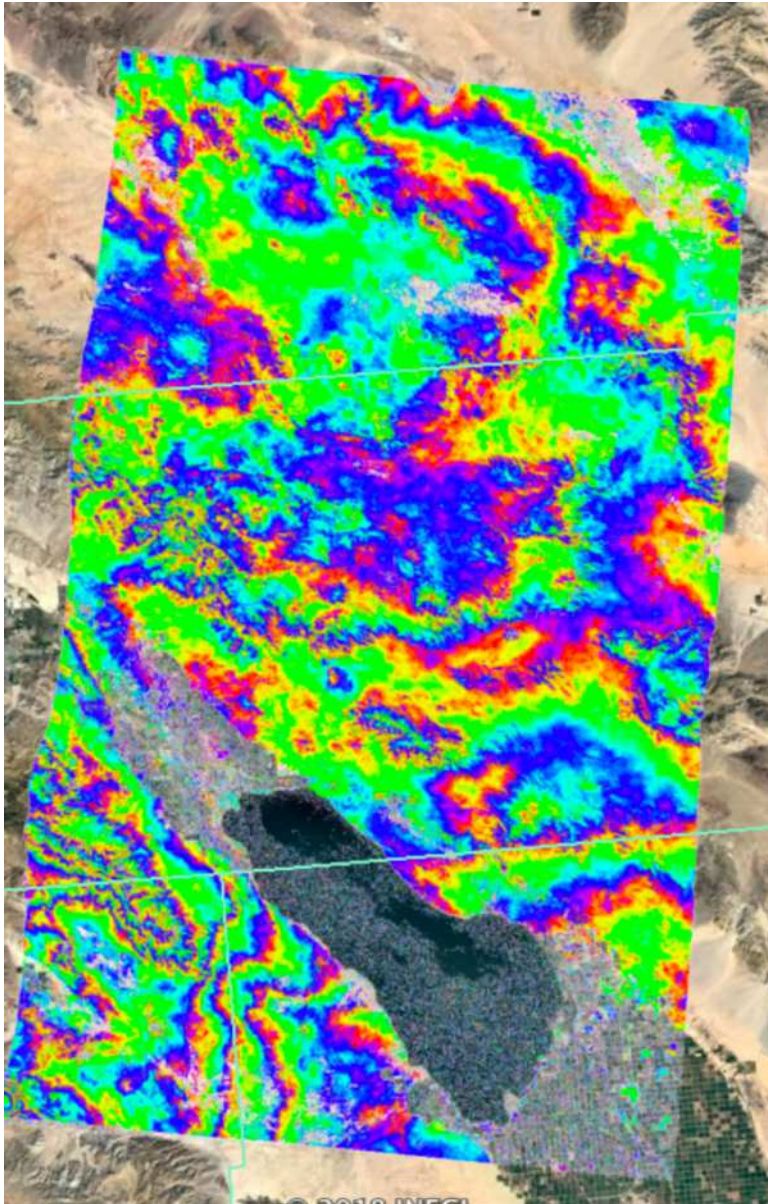


## config.s1a.txt

```
#####  
# parameters for unwrap phase #  
# - snaphu.csh #  
#####  
# correlation threshold for snaphu.csh (0~1)  
# set it to be 0 to skip unwrapping.  
threshold_snaphu = 0.1  
  
# region to unwrap in radar coordinates (leave it blank if unwrap the whole region)  
# example 300/5900/0/25000  
region_cut =  
  
# mask the wet region (Lakes/Oceans) before unwrapping (1 -- yes; else -- no)  
switch_land = 1  
  
#  
# Allow phase discontinuity in unwrapped phase. This is needed for interferograms having  
sharp phase jumps.  
# defo_max = 0 - used for smooth unwrapped phase such as interseismic deformation  
# defo_max = 65 - will allow a phase jump of 65 cycles or 1.82 m of deformation at C-band  
#  
defomax = 0.0001  
  
#####  
# parameters for geocode #  
# - geocode.csh #  
#####  
# correlation threshold for geocode.csh (0~1)  
threshold_geocode = .1
```

Area in radar coordinates, check phase.pdf

phase.pdf





## Using SNAPHU in GMTSAR

GMTSAR: `snaphu.csh`

- Makes correlation mask
- Convert `grd` to binary for `snaphu`
- Parameters: *threshold\_snaphu* and *defomax* in configuration file – see comments
- Deformation mode is default; `defomax = 0` means smooth phase (will detrend) while `defomax > 0` sets maximum phase jump
- Can also use landmask or deformation mask
- Extracts parameters from *snaphu.conf.brief* in *\$sharedir/snaphu/config*
- *snaphu.csh* run by *p2p\*csh scripts*
- Creates `unwrap.grd`

Usage: `snaphu.csh correlation threshold maximum_discontinuity [<r0>/<r1>/<a0>/<a1>]"`

Example: `snaphu.csh .12 40 1000/3000/24000/27000"`



## Challenging case for default SNAPHU

In general GMTSAR masks out low correlation, which usually masks out areas with random phase.

Sometimes a scene possesses large decorrelated areas.

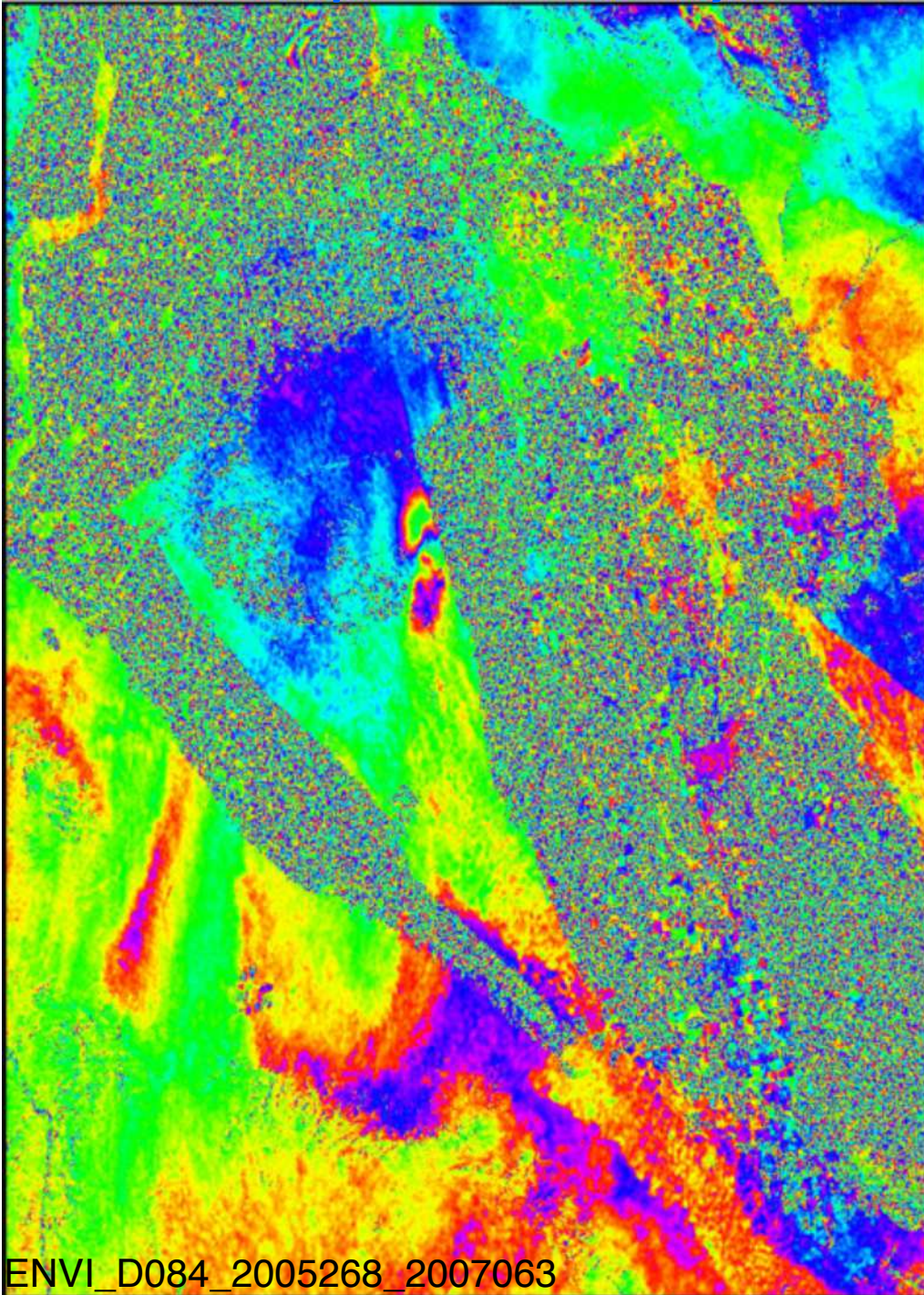
In these cases, SNAPHU can take ~forever.

- Increase threshold (not always a good idea).
  - Interpolate [in GMTSAR, *snaphu\_interpolate.csh*]
  - Or buy a better computer.
- Nearest neighbor interpolation preserves the topology of any loops containing residues
  - Unwrapped, masked result should be the same, whether or not we interpolate first

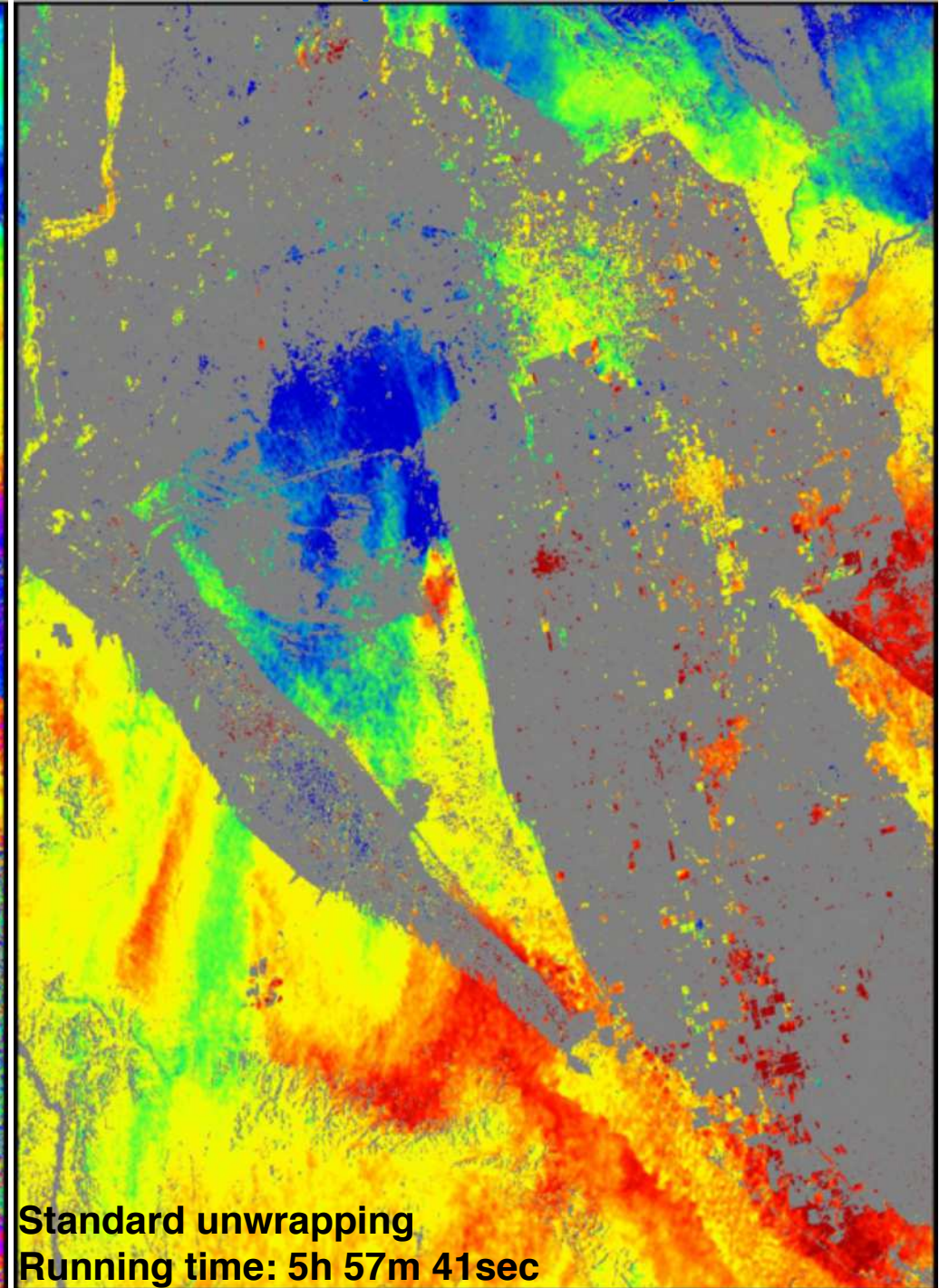
Agram and Zebker, Sparse two-dimensional phase unwrapping using regular grid methods, IEEE Geosci. Rem. Sens., 2009



*Imperial Valley, CA – standard (~6 hours)*



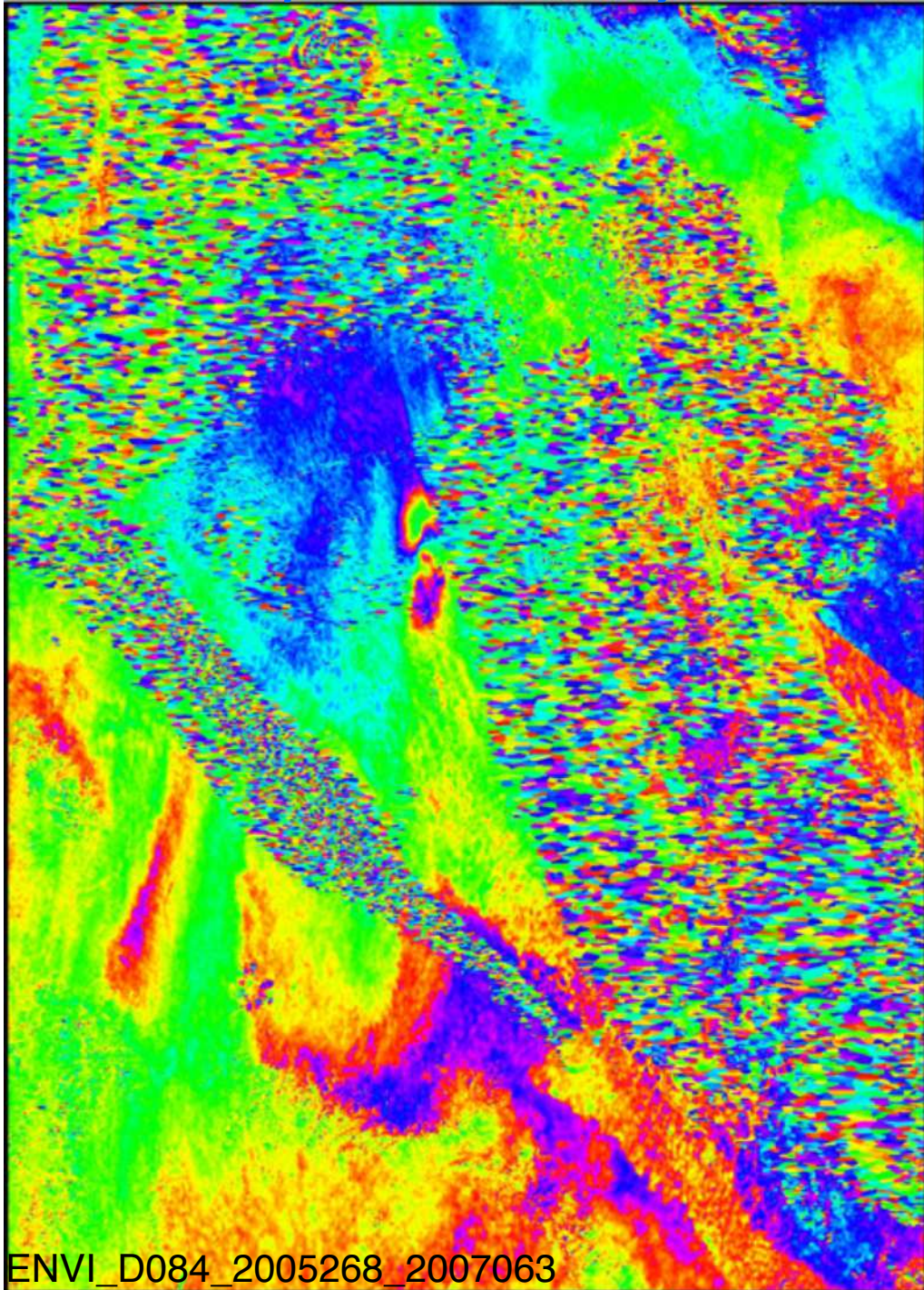
ENVI\_D084\_2005268\_2007063



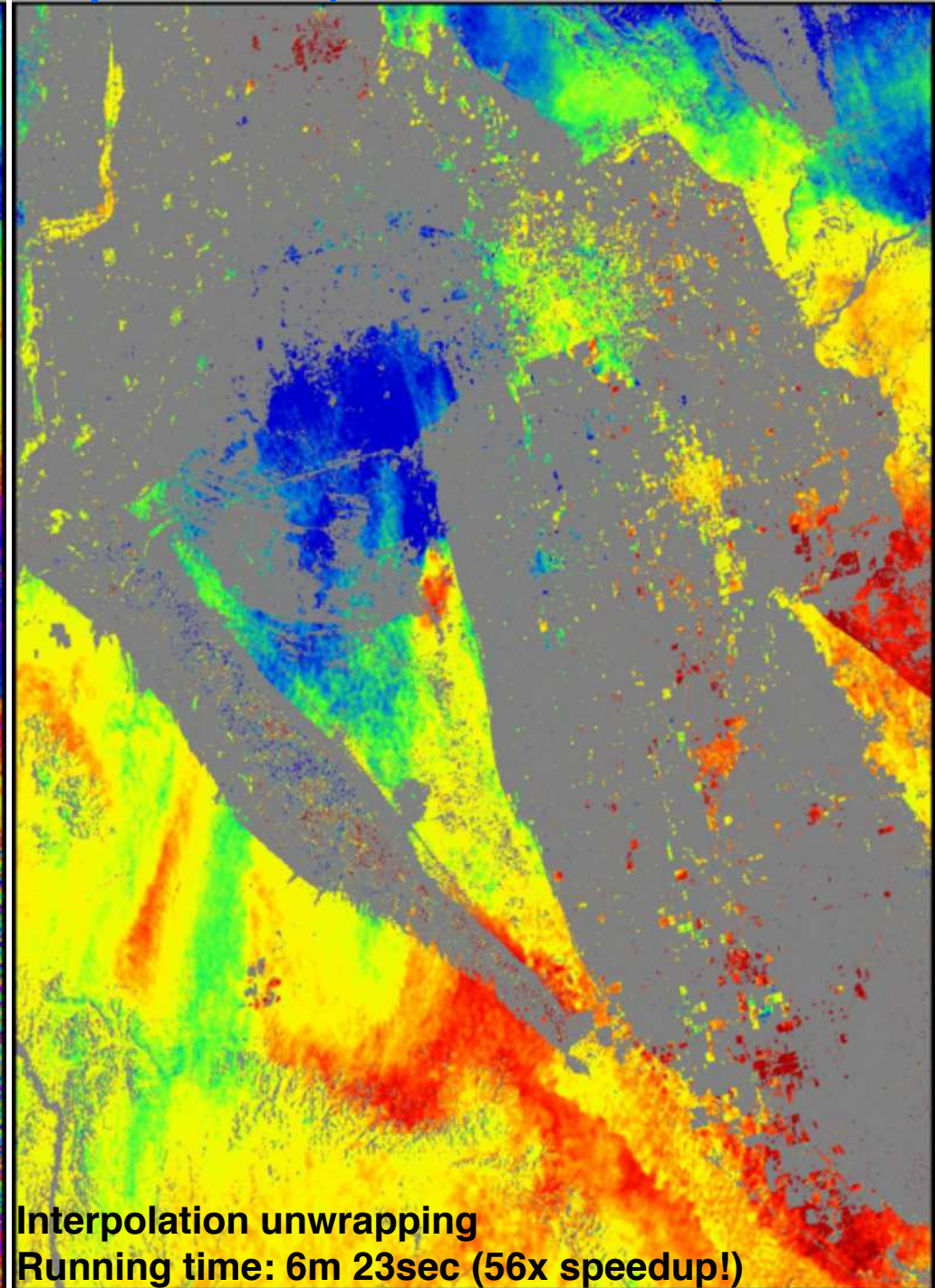
**Standard unwrapping**  
**Running time: 5h 57m 41sec**



*Imperial Valley, CA, interpolate (~6 minutes)*



ENVI\_D084\_2005268\_2007063



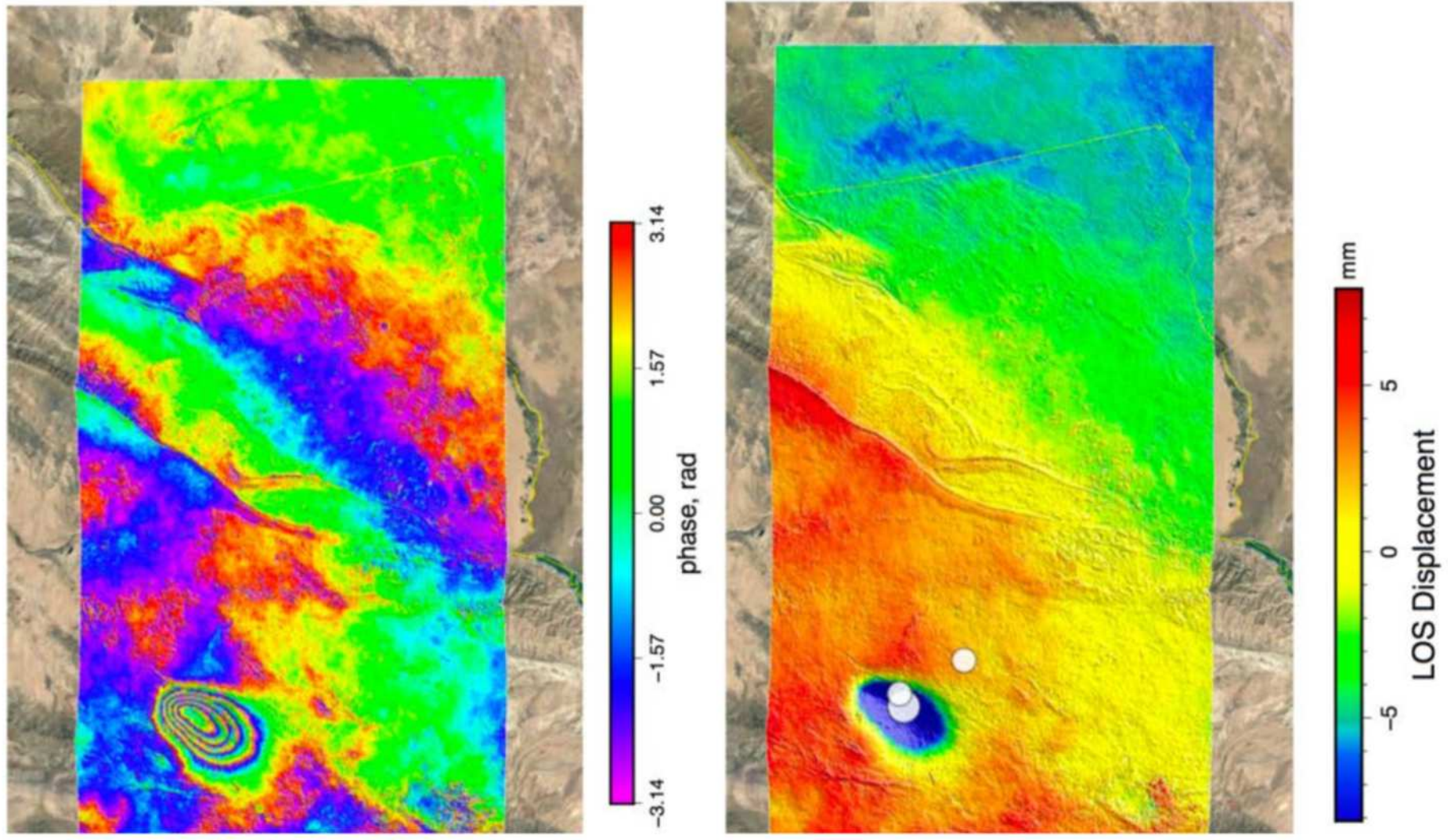
**Interpolation unwrapping**  
**Running time: 6m 23sec (56x speedup!)**



*After unwrapping:  
convert phase to displacement*

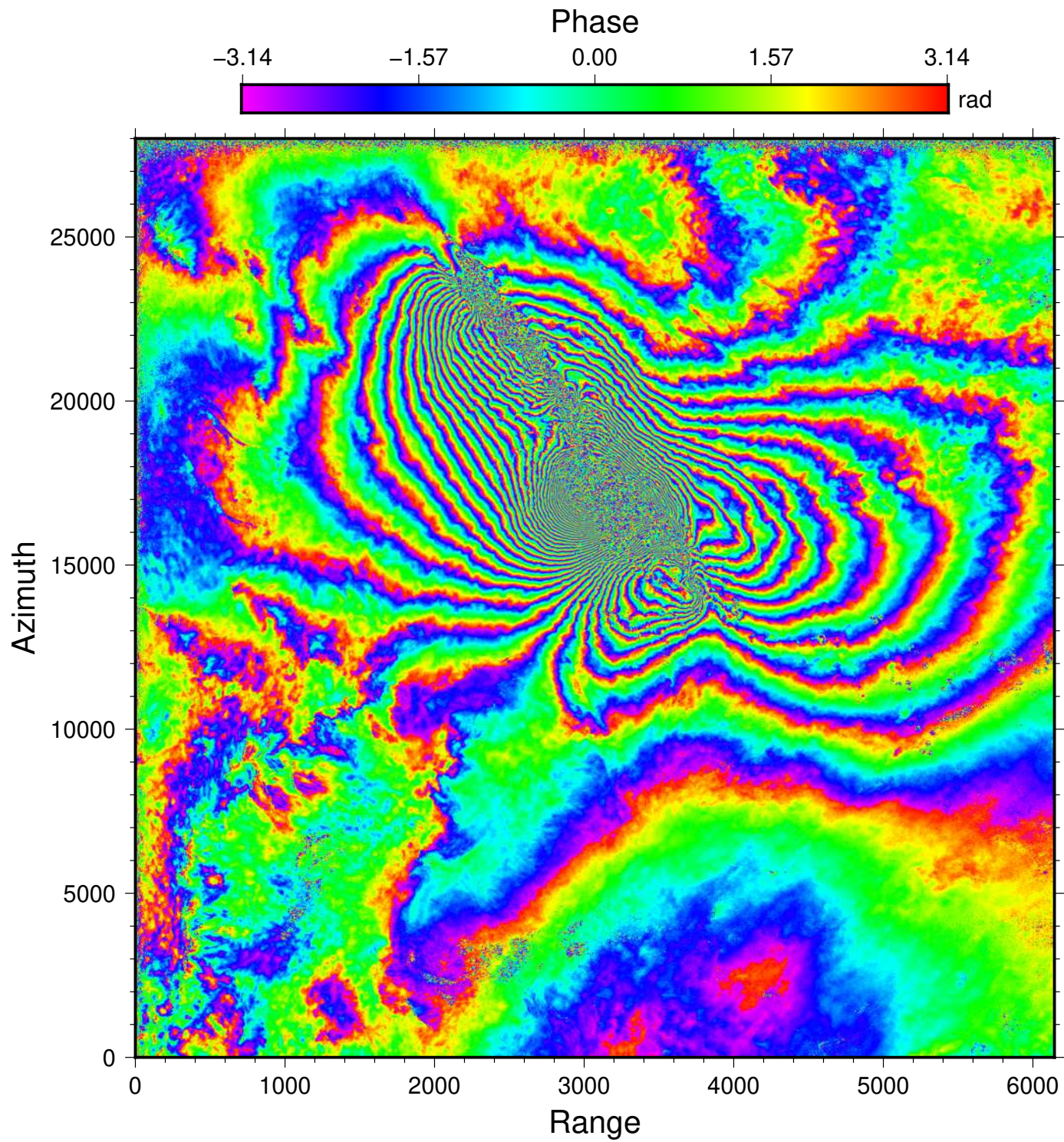
- LOS displacement =  $\Phi(t) * \lambda / 4 \pi$
- $\Phi(t)$ : (unwrapped) phase change
- $\lambda$ : wavelength of the radar system, ~5 cm for Sentinel
- Why  $4\pi$  instead of  $2\pi$ ?

*There is something wrong in this figure below.  
Can you find it? (M6.1 earthquake in Iran)*



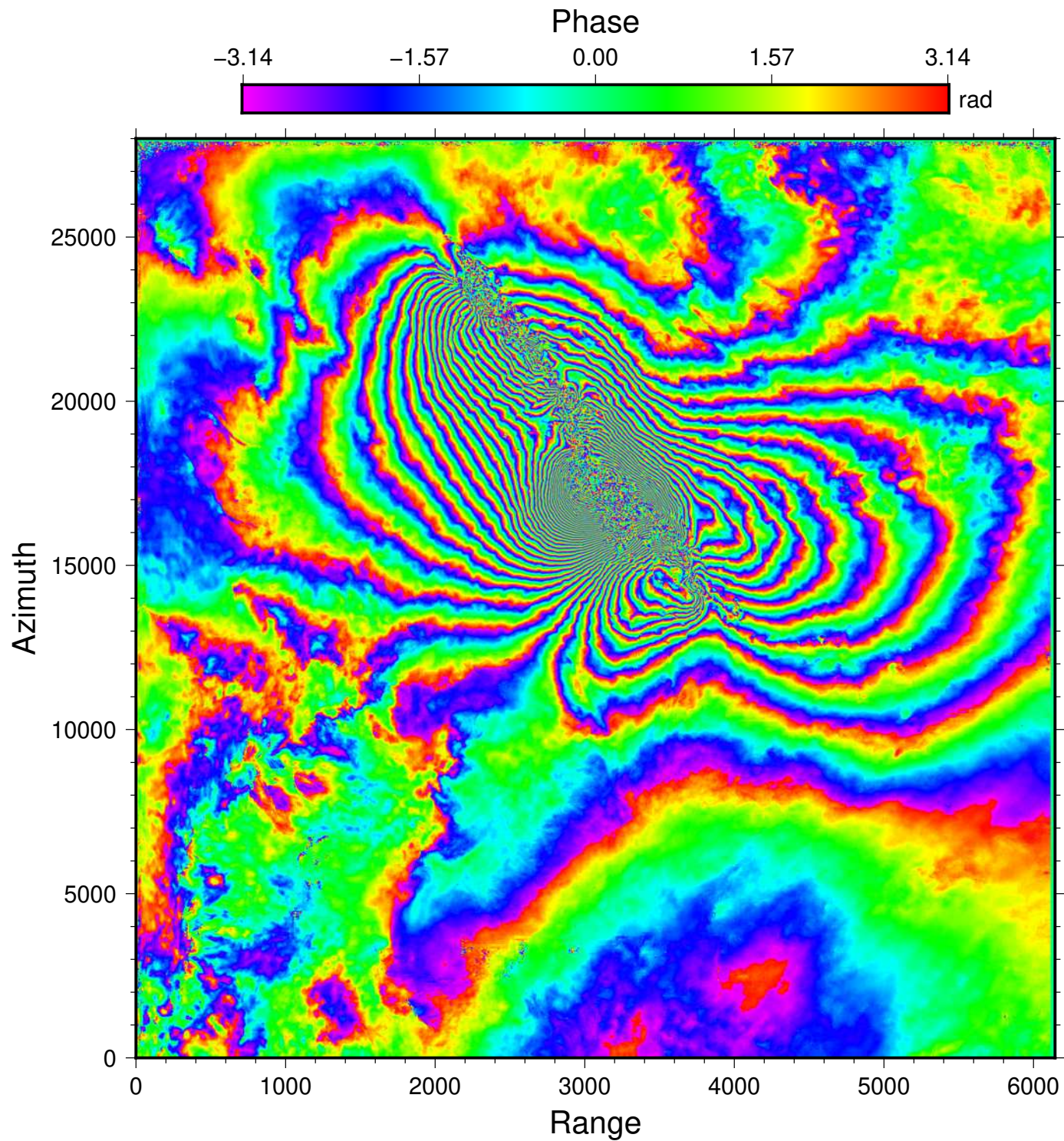
*Practical tips: always count fringes*





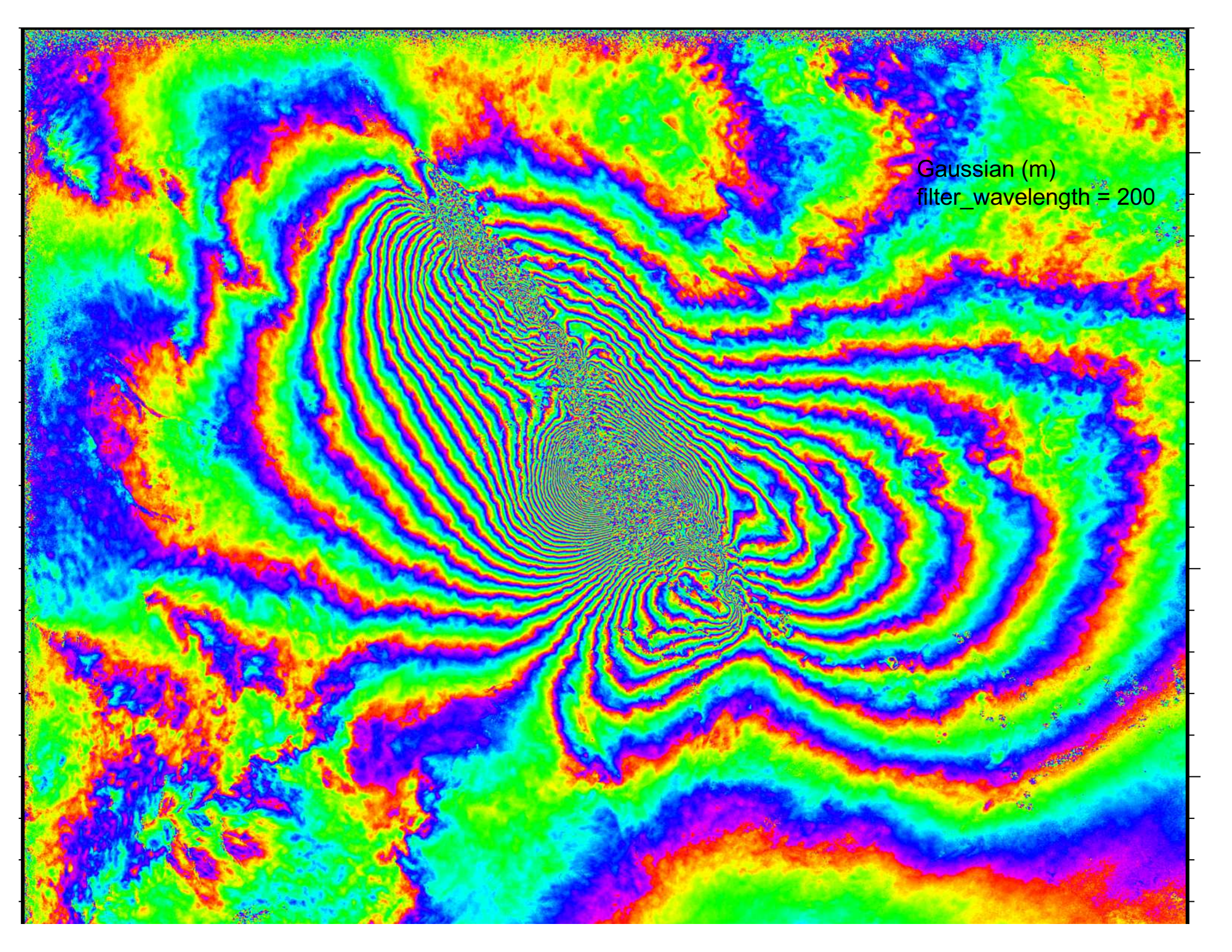
Gaussian (m)  
filter\_wavelength = 200





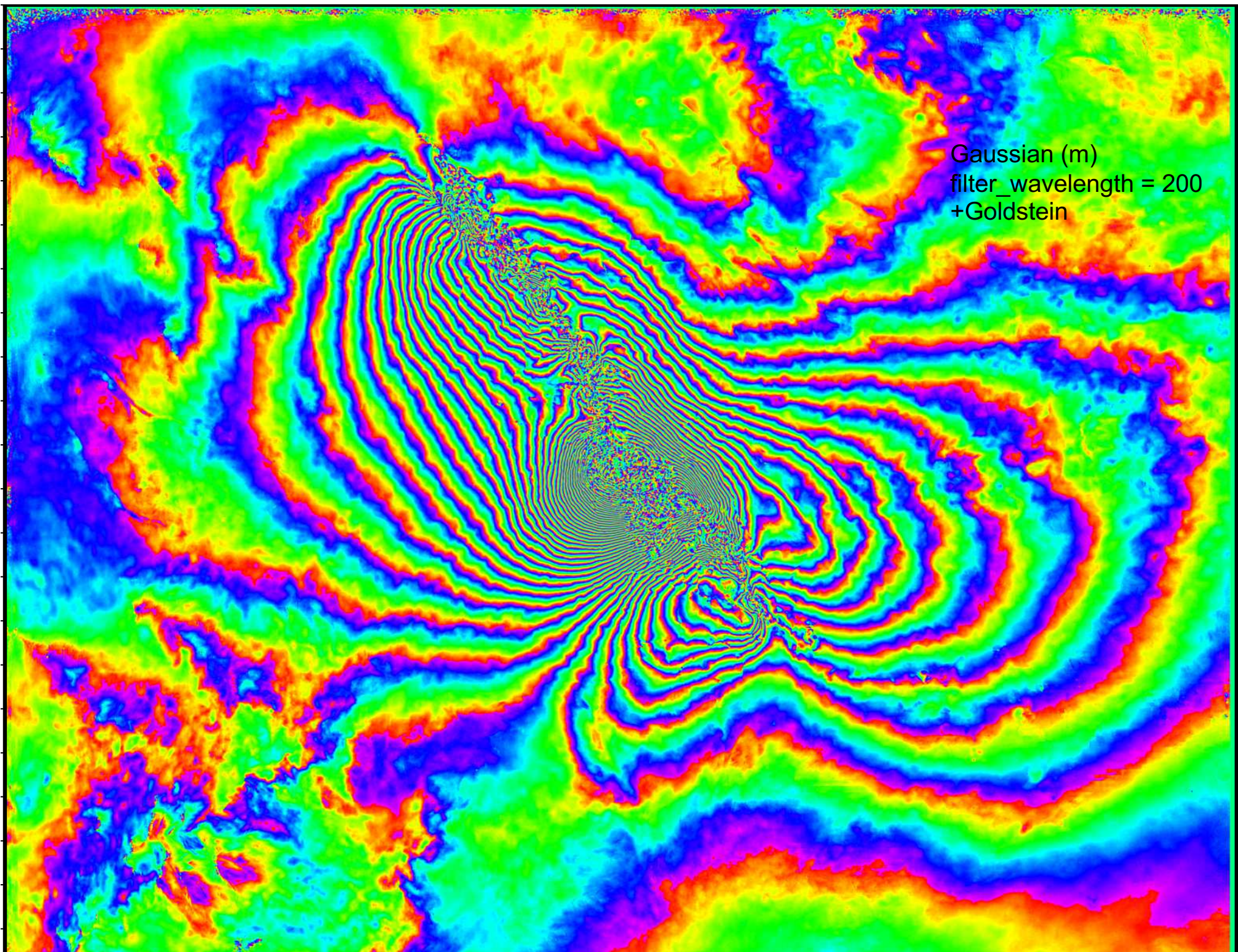
Gaussian (m)  
filter\_wavelength = 200  
+Goldstein





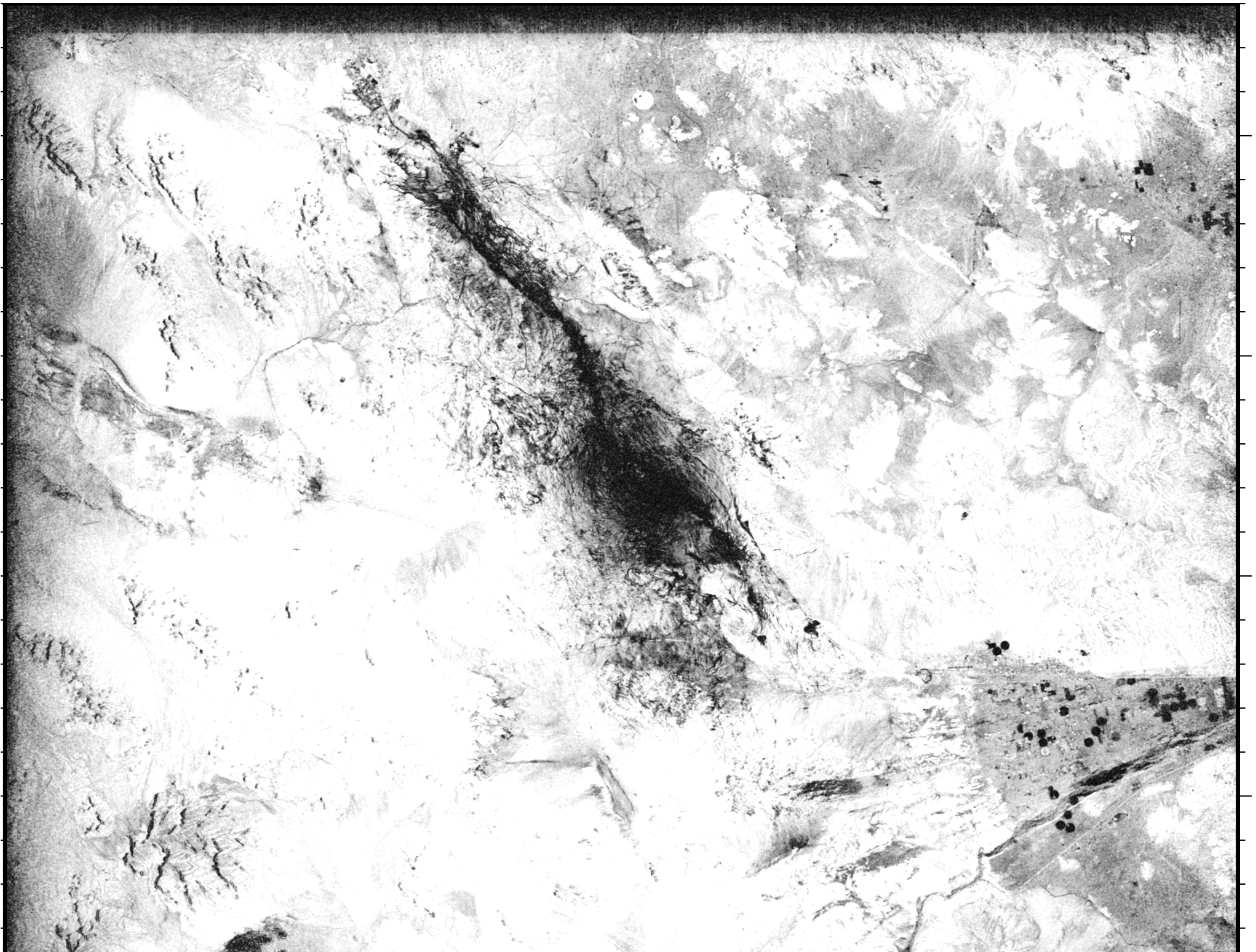
Gaussian (m)  
filter\_wavelength = 200





Gaussian (m)  
filter\_wavelength = 200  
+Goldstein





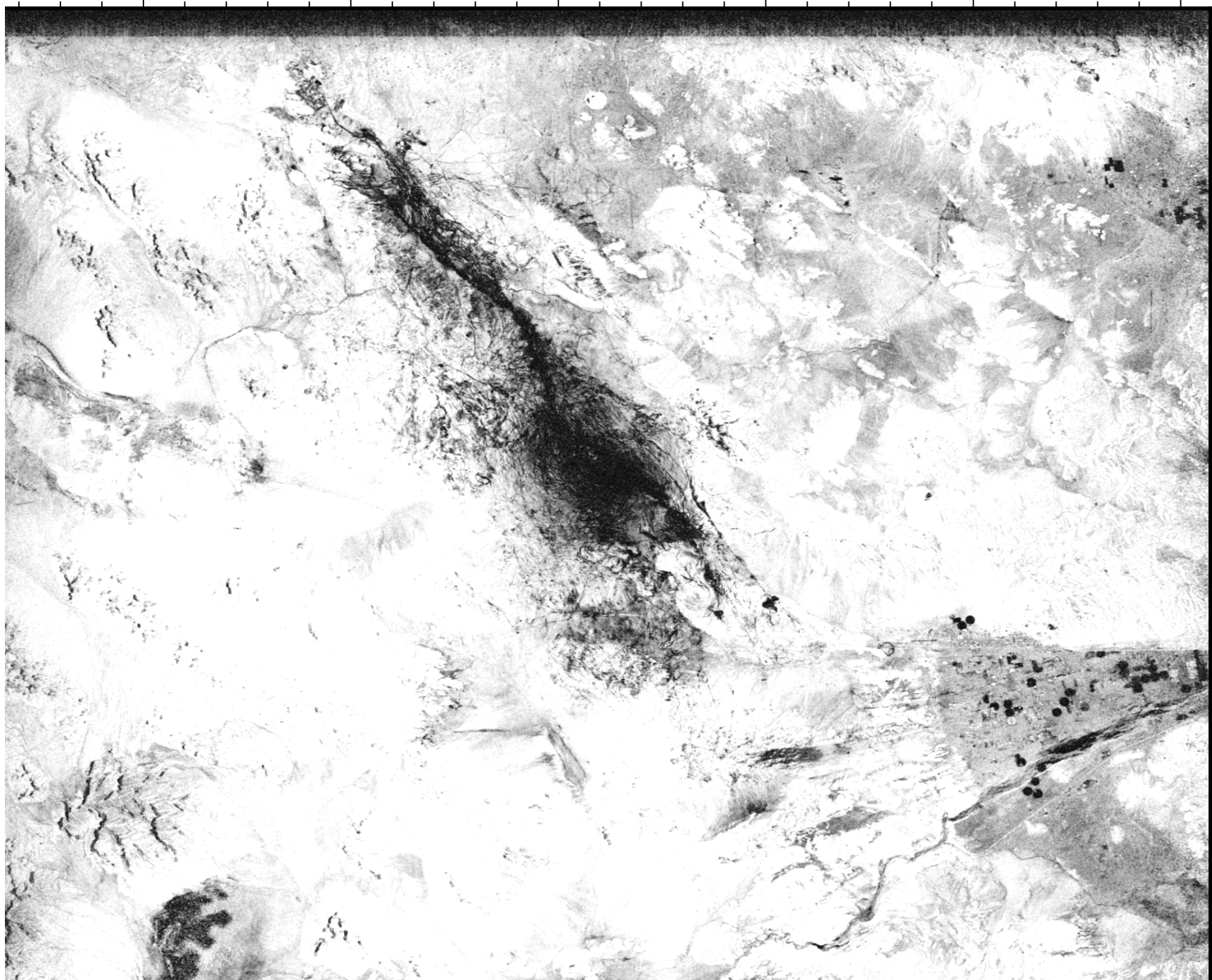
0.0

0.2

0.4

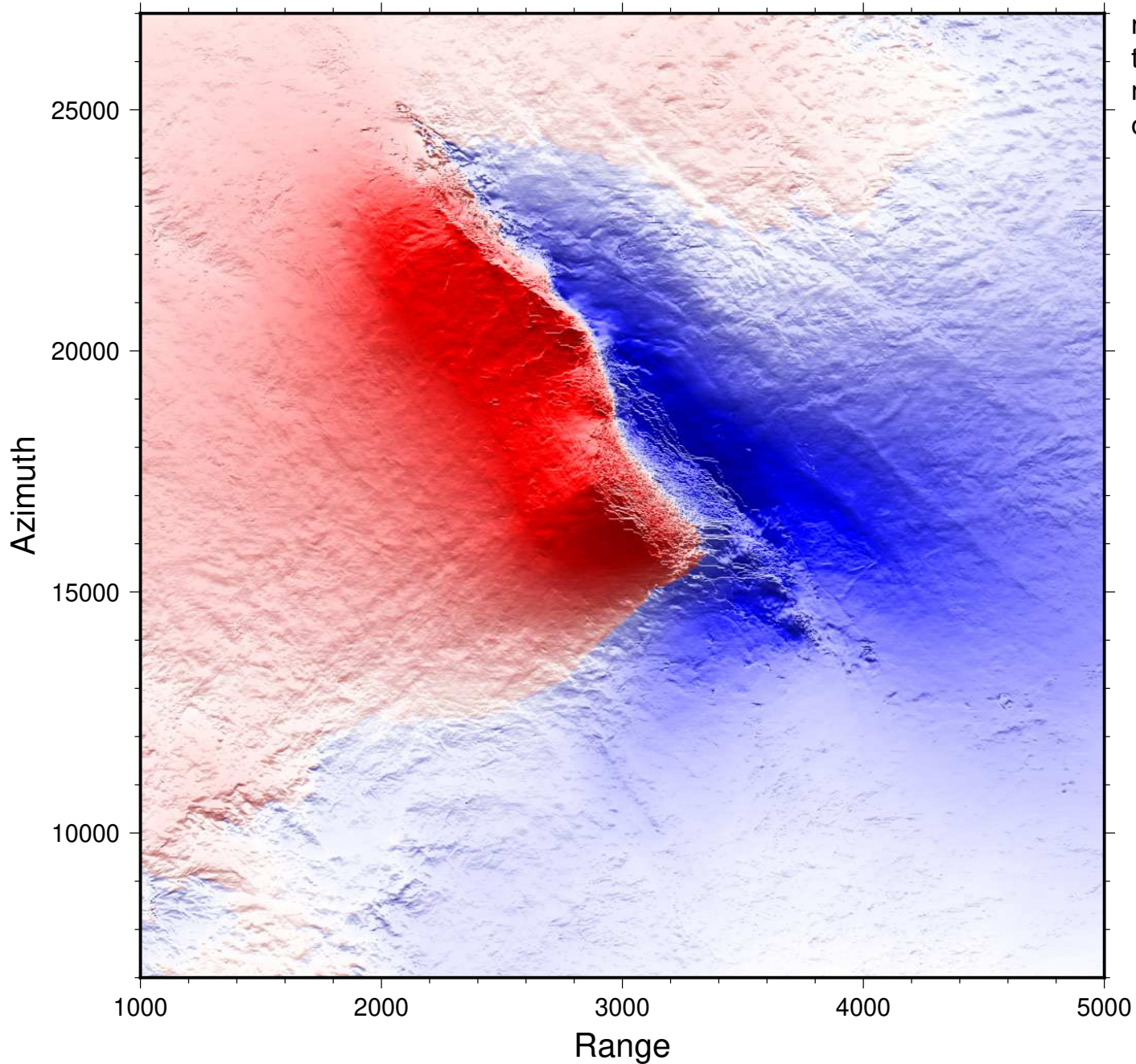
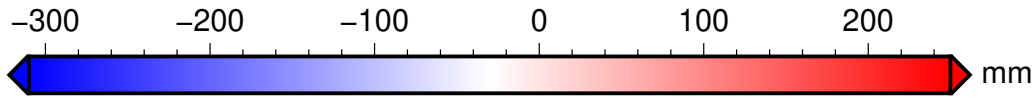
0.6

0.8





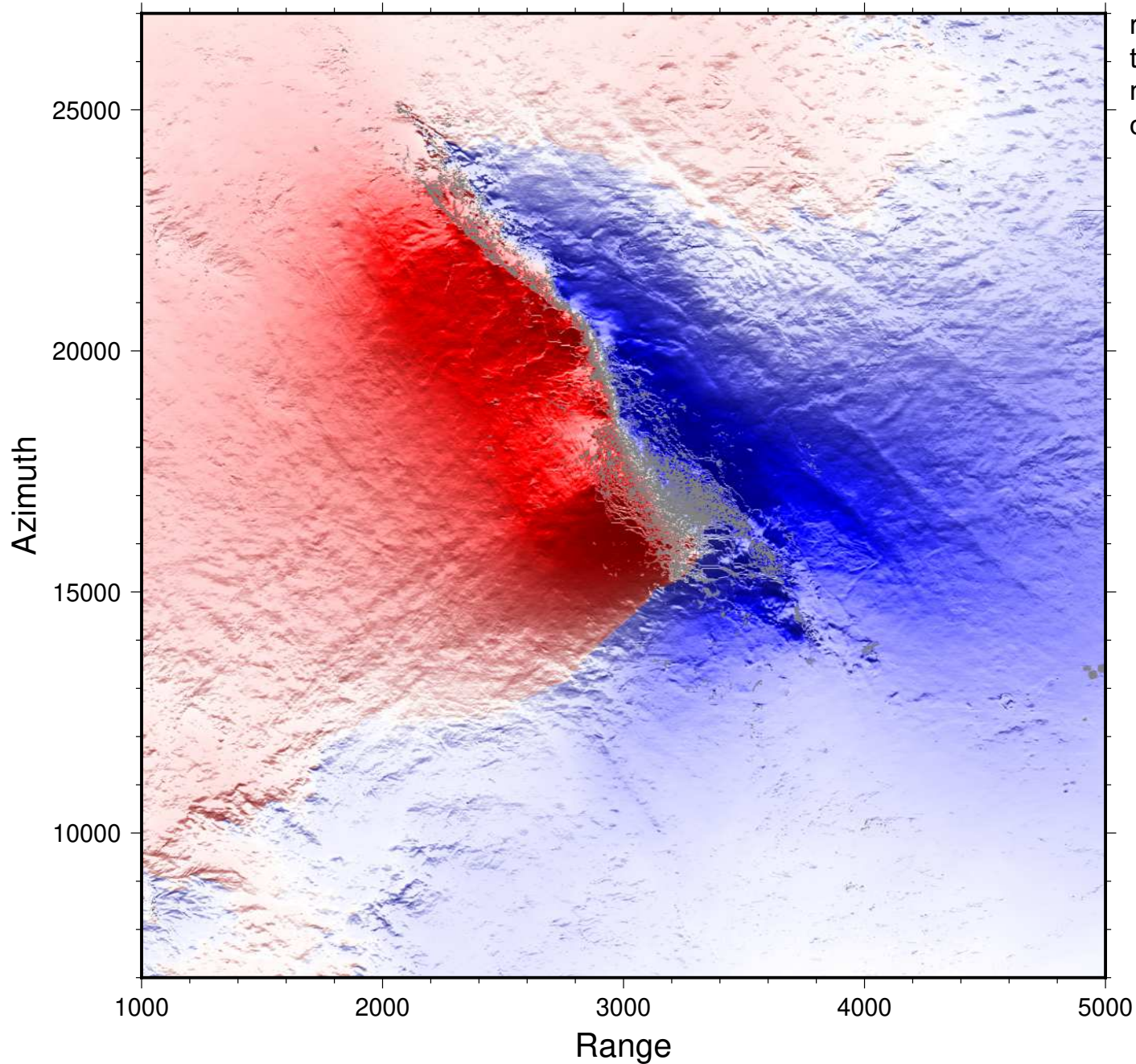
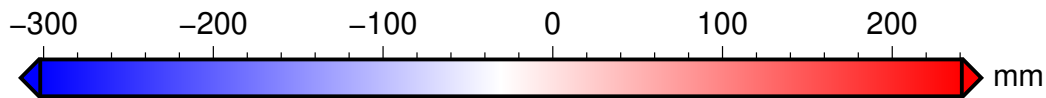
LOS displacement [range decrease →]



region\_cut = 1000/5000/7000/27000  
threshold\_snaphu = 0.01  
near\_interp = 0  
defomax = 0

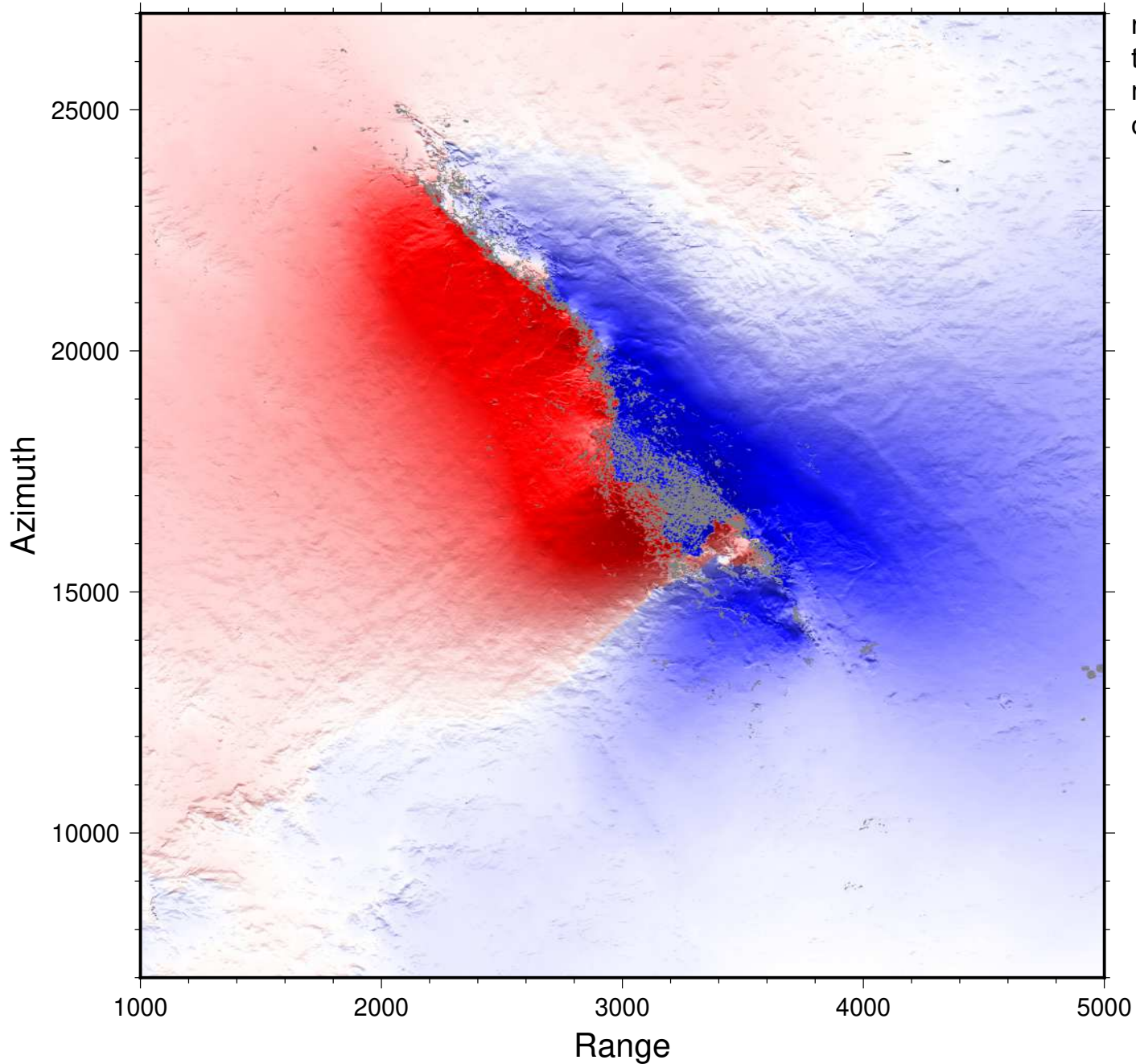
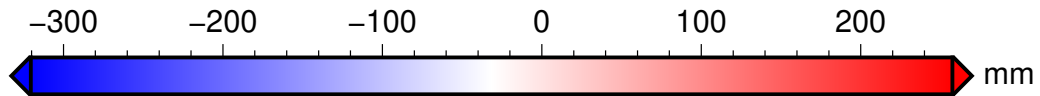


LOS displacement [range decrease →]



region\_cut = 1000/5000/7000/27000  
threshold\_snapu = 0.12  
near\_interp = 1  
defomax = 0

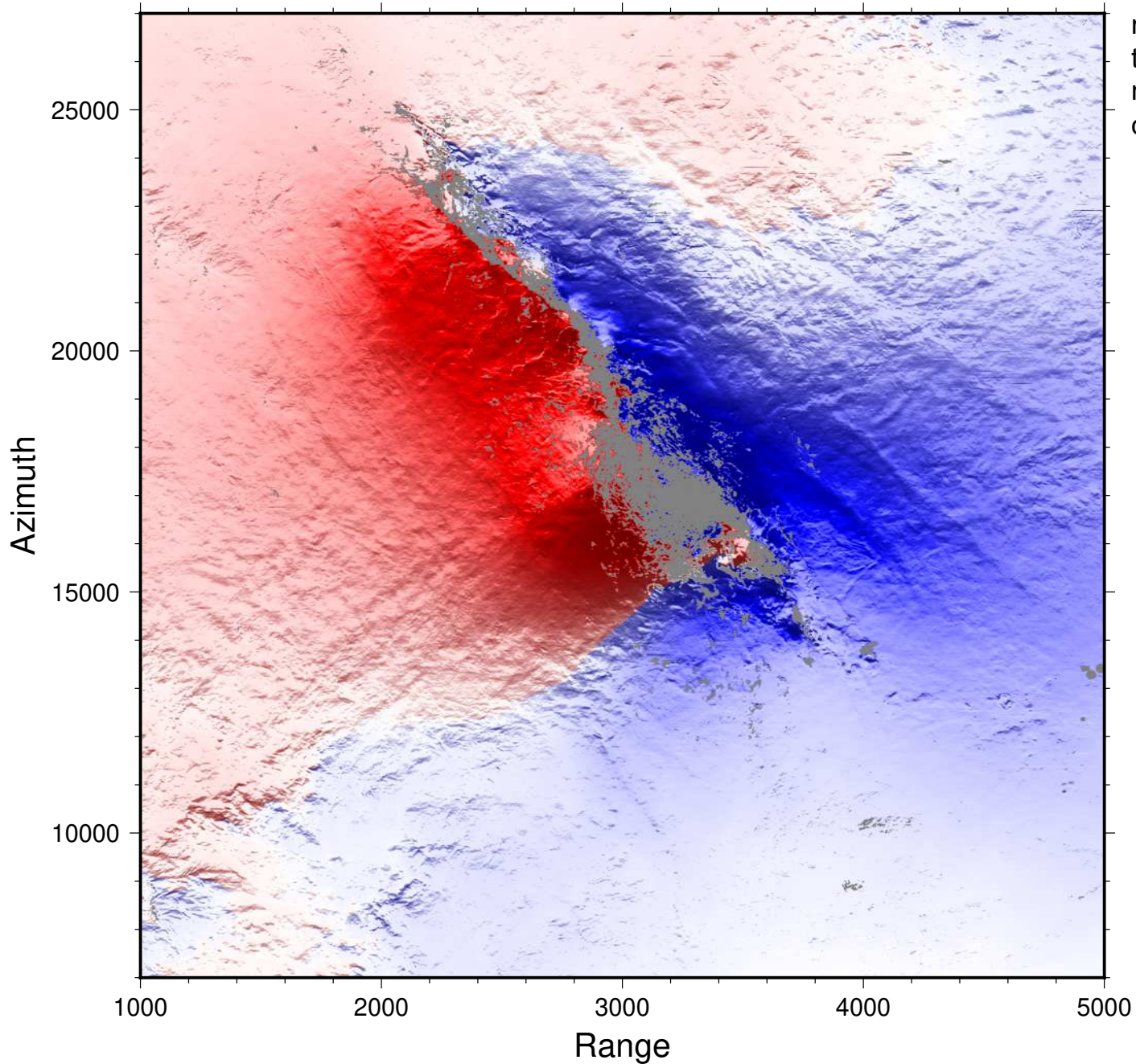
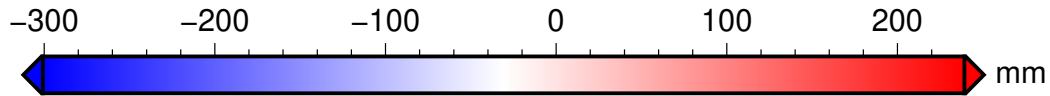
LOS displacement [range decrease →]



region\_cut = 1000/5000/7000/27000  
threshold\_snaphu = 0.12  
near\_interp = 1  
defomax = 65



LOS displacement [range decrease →]



region\_cut = 1000/5000/7000/27000  
threshold\_snaphu = 0.20  
near\_interp = 1  
defomax = 65



# Conclusions

- Work in radar coordinates.
- Remove as much phase signal as possible prior to filtering and unwrapping.
- Interferograms are filtered to reduce noise and estimate coherence.
  - Gaussian filters can be sequential for efficient decimation.
  - Goldstein filter cleans noise but can corrupt the phase.
- Snaphu is an accurate and effective phase unwrapping algorithm.
  - Unwraps everything so need to mask.
  - Fill masked areas with nearest neighbor interpolation.
  - Use defomax parameter for surface ruptures.
- Phase unwrapping errors are integer steps of  $N2\pi$ 
  - A human can usually guess  $N$
  - Many new papers on using 3-way phase closure to solve for  $N$

# Thank you

