

Detecting Topographical Change around the Summit of Mt. Merapi by InSAR Technique

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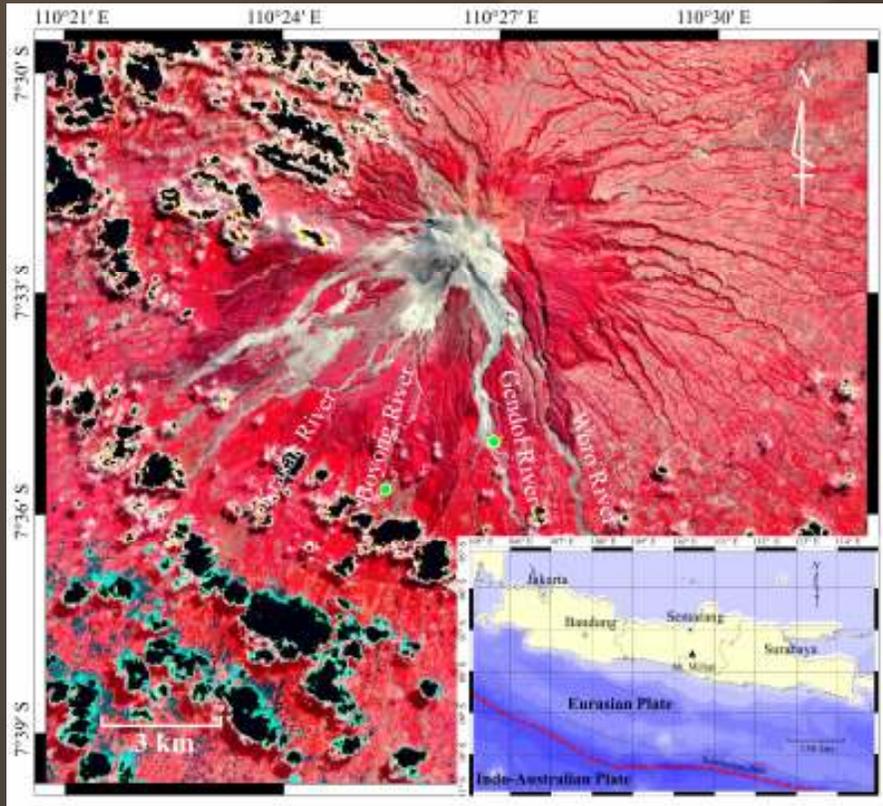
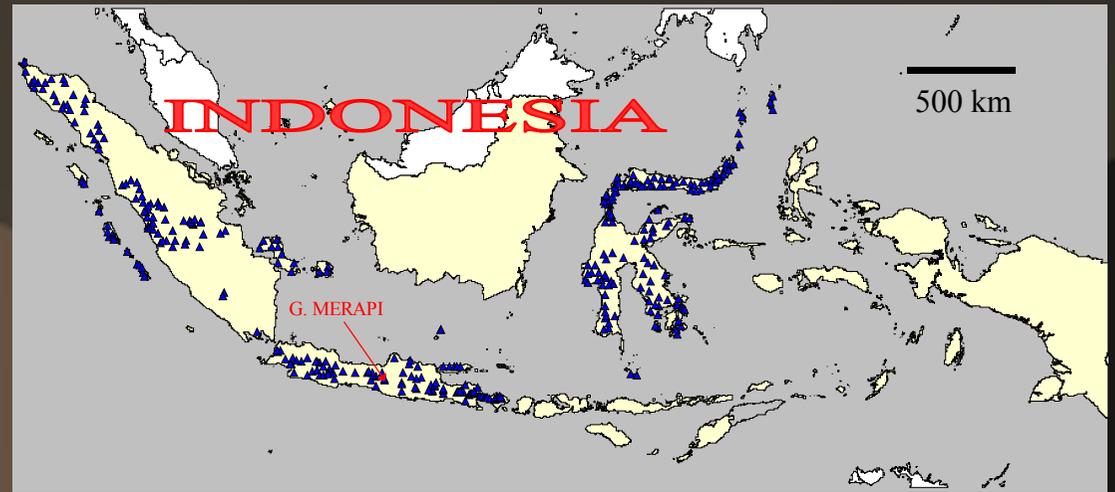
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Introduction

Study area:

Mt. Merapi located in Central Java, Indonesia is one of 129 the most active volcanoes in Indonesia.



Objectives:

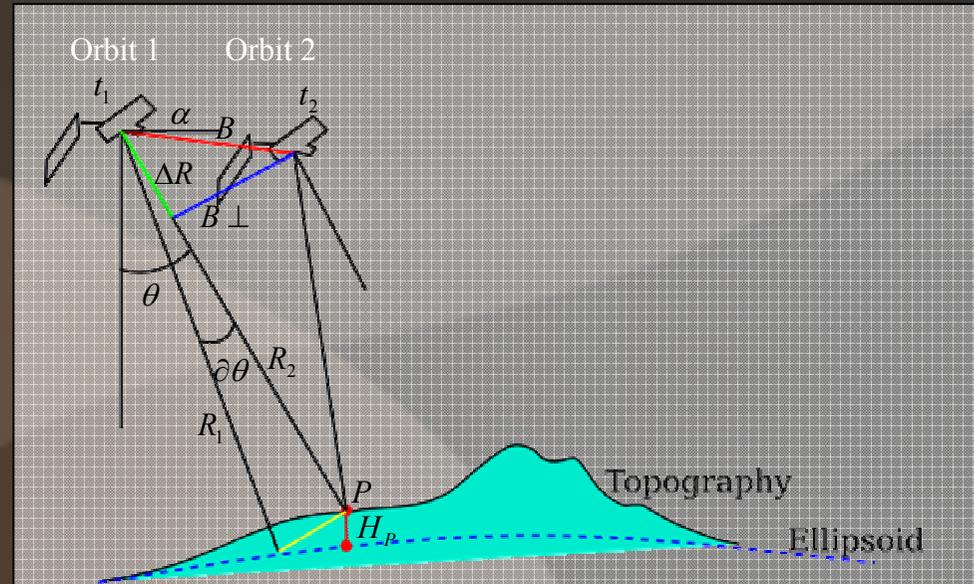
- To obtain topographical change around the summit
- To identify the change related with magma ascent and/or lahars generation
- To characterize surface change in the time of lava dome growth

ASTER image of Mt. Merapi for Band 3,2,1 in R,G,B and the subduction zone in the southern part.

InSAR Processing

overview

- Image pair from two scenes time (t_1 and t_2).
- Perpendicular baseline (B_{\perp}) affected to phase different.
- Complex multiplication.
- Phase different for each pixel ($\partial \phi_p$) including topography (D_p) and Deformation (H_p) effect.
- Deformation effect is larger than topographic effect.



$$y_1 = |y_1| e^{j\phi_1}$$

$$y_2 = |y_2| e^{j\phi_2}$$

$$y_1 y_2^* = |y_1| |y_2| e^{j(\phi_1 - \phi_2)}$$

$$\partial\phi_p = \phi_{1p} - \phi_{2p}$$

$$\partial\phi_p = -\frac{4\pi}{\lambda} \left(D_p - \frac{B_{\perp}}{R_{1p} \sin \theta} H_p \right)$$

InSAR Processing Common Problem

1. Low coherence;

Distance between two satellites (Baseline): The long baseline leads the low correlation.

Time Interval between two observations.

2. Atmosphere condition;

Delay caused by water vapor in the atmosphere: The difference of the water vapor conditions in two observations produces the extra phase pattern.

3. Large changes of the earth surface;

Too large deformation caused high decorrelation between two data, e.g. eruption of an active volcano.

4. Orbital ambiguity;

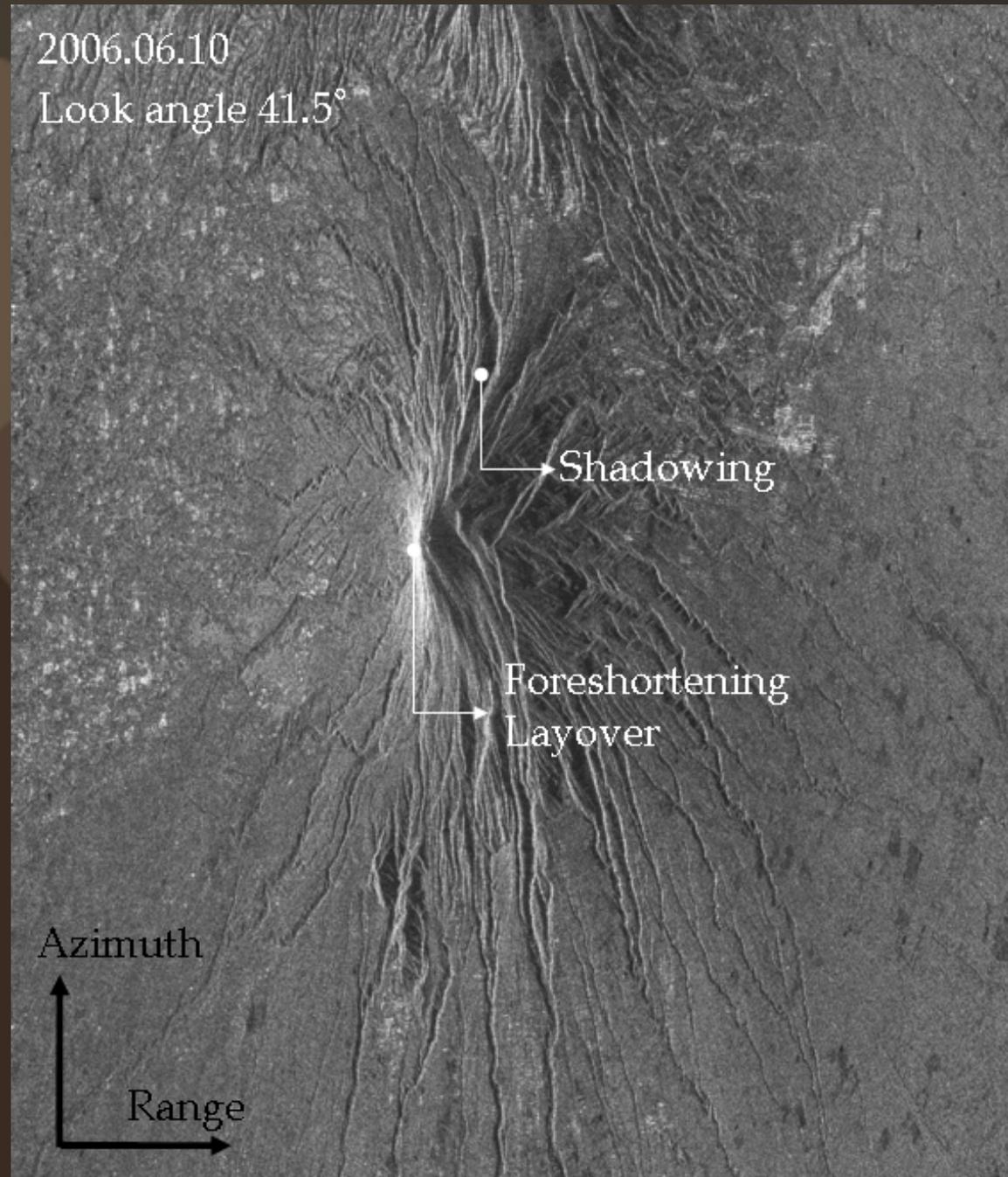
The fringes aligned toward to spacecraft direction (azimuth).

ALOS-PALSAR

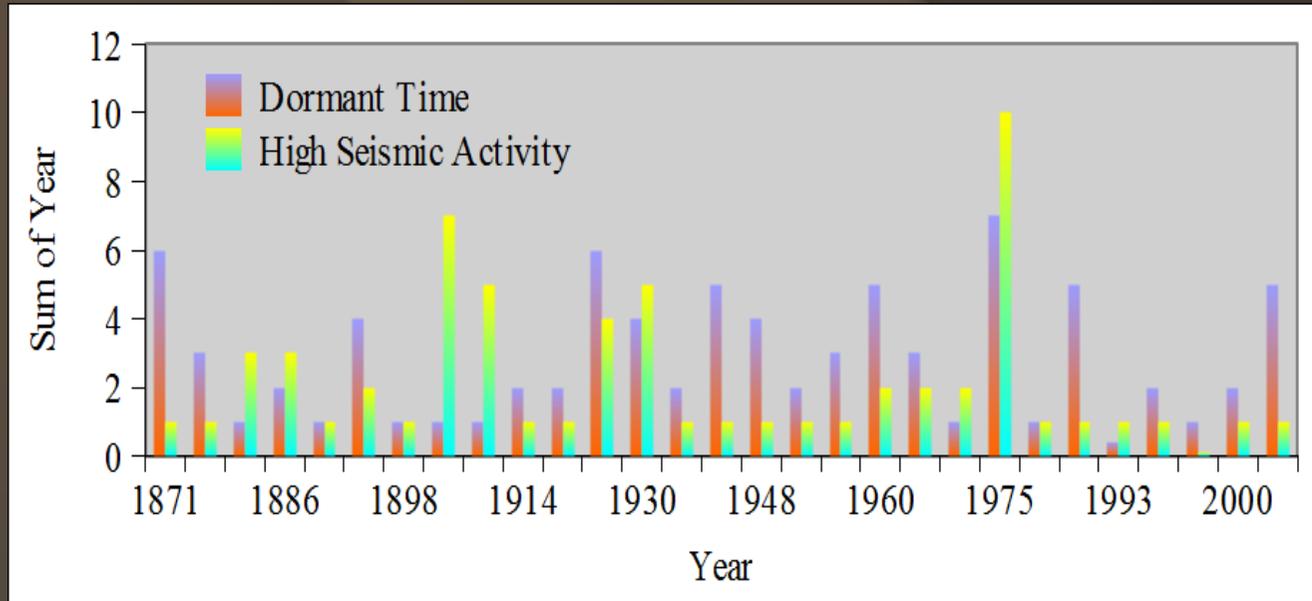
Radar signal return to the receiver depend on:

- Slope
- Roughness
- Dielectric constant

Intensity image showing the geometry distortion caused by off nadir angle view

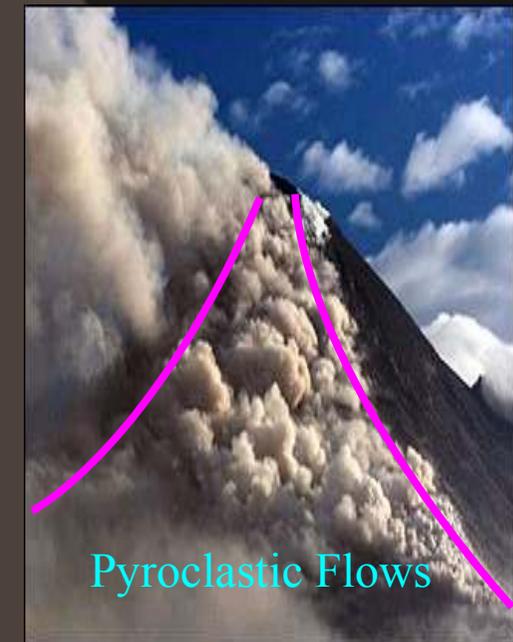


The History of Mt. Merapi Eruption Period

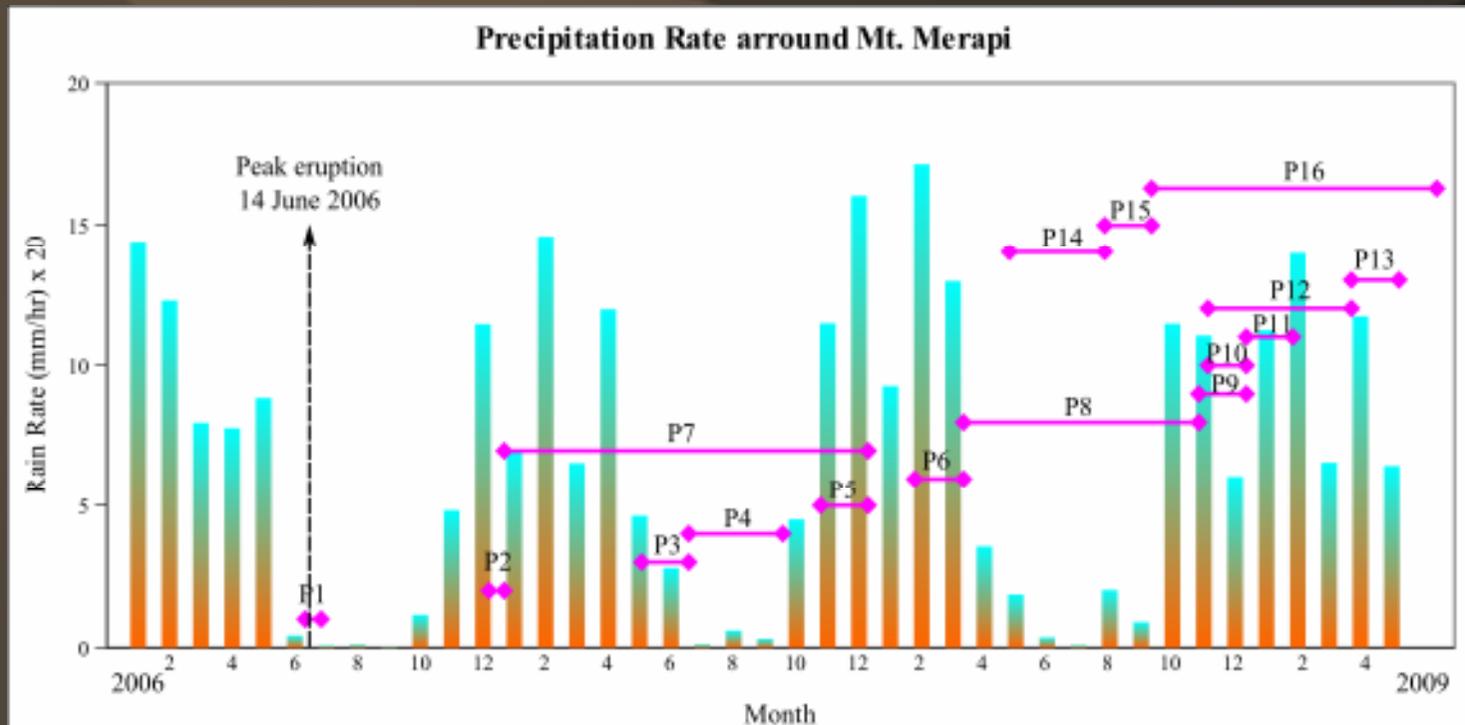


The latest eruption
on May-June 2006

Mt. Merapi has short intervals of eruptions characterized by dome explosion and accompanied large amount of pyroclastic flow deposits (source: VSI, 2008).



Pair Line of ALOS/PALSAR 2006-2009



Three years observation data of ALOS/PALSAR were combined by a monthly precipitation rate with grid size $0.25^{\circ} \times 0.25^{\circ}$ from Tropical Rainfall Measuring Mission (TRMM) data covered around the summit of Mt. Merapi

Overview of Sigma-SAR Software

ALOS/PALSAR Level 1.0 in JAXA Format

SAR Imaging+Calibration

- *Select a machine*
- *Input full directories*
- *SAR Imaging (InSAR)*
- *Sensor selection*
- *Processing algorithm selection*

InSAR Processing Software

- *Co-registration*
 - *Interferometry 1st trial*
 - *Slant range tuning*
 - *Interferometry 2nd trial*
 - *D-InSAR (prepare co-registration)*
 - *Orbit tuning*
- Atm. Corr:*
- 0: *coarse*
 - 1: *detailed*
 - 2: *no*
 - 3: *self_correction (DDTM)*
- *Filtering*
 - *Geocoding*

An Inconsistency...?

Master and Slave Position
change automatically
when running the program

Slave Image is Older than Master

```
tansa09@tansa09-desktop: /media/MERAPI/InSAR_2009/data_FBS
File Edit View Terminal Tabs Help
tansa09@tan... x tansa09@tan... x tansa09@tan... x tansa09@tan... x tansa09@tan... x
114e+01
sdB=1.223025e-06 sdh=8.370436e-07 sdvh=9.628405e-09

k1= 1
dB0=5.048406e-04 dh0=2.599973e-04 dvh0=1.445312e-05 poff=-1.077812e+00 std=4.629
349e+01
sdB=1.223026e-06 sdh=8.370435e-07 sdvh=9.628481e-09
r_0=2.044487e-02 r_1=2.830481e-02 r_2=3.698922e-03

k1= 2
dB0=5.047843e-04 dh0=2.599650e-04 dvh0=1.445216e-05 poff=-1.077742e+00 std=4.629
349e+01
sdB=1.223026e-06 sdh=8.370435e-07 sdvh=9.628481e-09
r_0=1.114367e-04 r_1=1.242382e-04 r_2=6.675011e-05

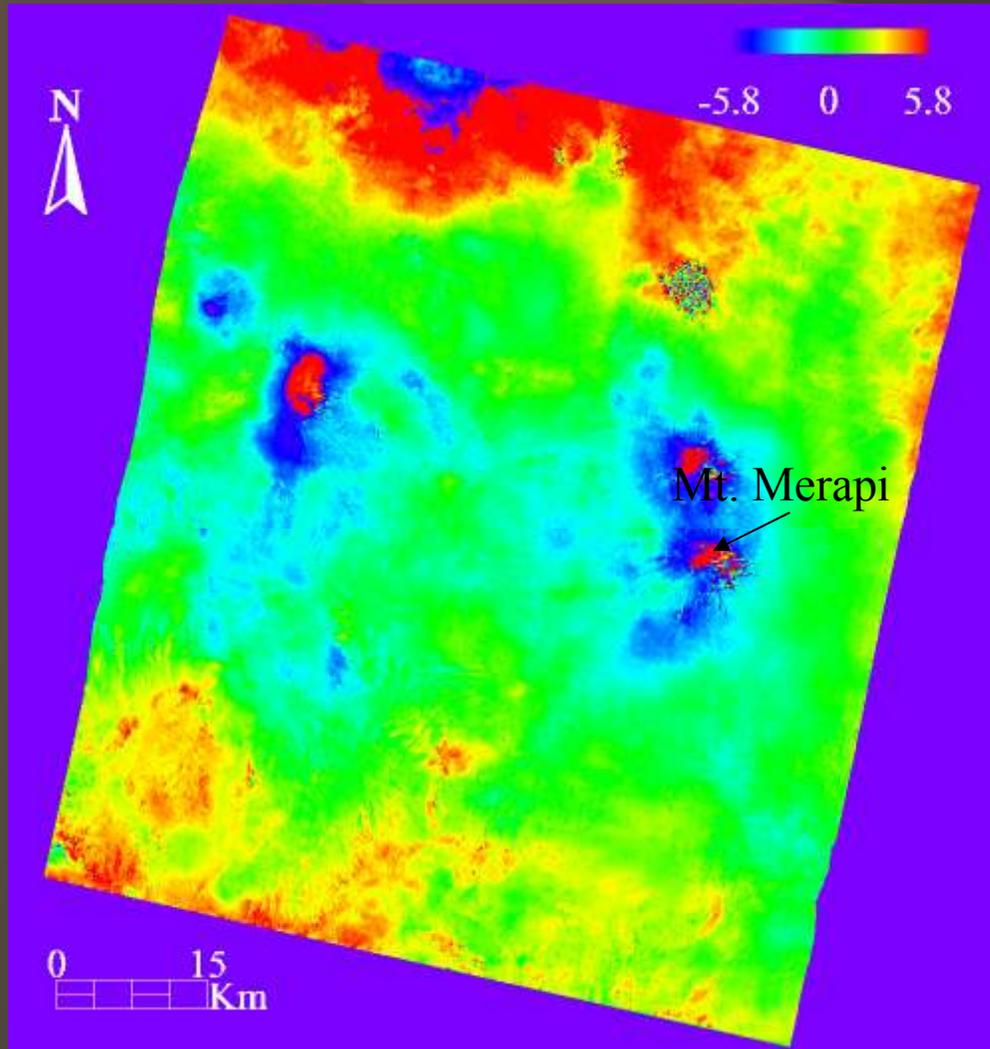
k1= 3
dB0=5.047849e-04 dh0=2.599655e-04 dvh0=1.445215e-05 poff=-1.077745e+00 std=4.629
349e+01
sdB=1.223026e-06 sdh=8.370435e-07 sdvh=9.628481e-09
r_0=1.244451e-06 r_1=2.033153e-06 r_2=3.887928e-07
std= 4.629349e+01(deg)
  0 10207 8.928976e+02 drse=-0.00707 Bp= 0.15954
 1000 10207 8.928976e+02 drse=-0.00902 Bp= 0.15586
1.280008e+02
HHHHH : p10_atm/
Filtering.....
.....
 2048 1.00000000e+07 3.42058500e+06 4096
 1024 1.00000000e+07 3.35098600e+06 2048
jB=0 jE=1728
1.268558e+02 -1.691525e-03 6.552995e+00
start address=0 end address=2552
1:1.306600e+02 -2.639978e-03 0.000000e+00 2532 6.512846e+00
2:1.254130e+02 9.830948e-03 -5.013274e-06 2532 6.196508e+00
2.016493e+02
Hello db=5.047849e-04 dh=2.599655e-04 ddh=1.445215e-05
-2.930397e+03 6.367104e+03 -9.749865e+02
-2.930463e+03 6.366962e+03 -9.750270e+02
r_m=7.076570e+03 r_s=7.076475e+03 th=1.056777e-03(deg)
dr=-9.513365e-02 re=6.377729e+03 dth=4.281515e-03(deg)
slave is right of master
d1=1.117114e-01 d2=-5.547229e-02 d3=-2.648525e-02 nr=1.275072e-01
B=1.275072e-01 dh=-9.513365e-02 re=6.377729e+03 dth=4.281515e-03(deg) rs=1.00000
0e+00
-2.906176e+03 6.363210e+03 -1.069088e+03
-2.906234e+03 6.363071e+03 -1.069129e+03
r_m=7.07669e+03 r_s=7.076575e+03 th=1.005426e-03(deg)
dh=-9.437163e-02 re=6.377647e+03 dth=4.294250e-03(deg)
slave is right of master
d1=-1.053539e-01 d2=-5.231010e-02 d3=-2.494526e-02 nr=1.202417e-01
B=1.202417e-01 dh=-9.437163e-02 re=6.377647e+03 dth=4.294250e-03(deg) rs=1.00000
```

```
tansa09@tansa09-desktop: /media/MERAPI/InSAR_2009/data_FBS
File Edit View Terminal Tabs Help
tansa09@tansa09-... x tansa09@tansa09-... x tansa09@tansa09-... x tansa09@tansa09-... x
7 : USGS DEM 60 meter Alaska
3
select the Filter 0 : no-filter
          1 : G-W filter

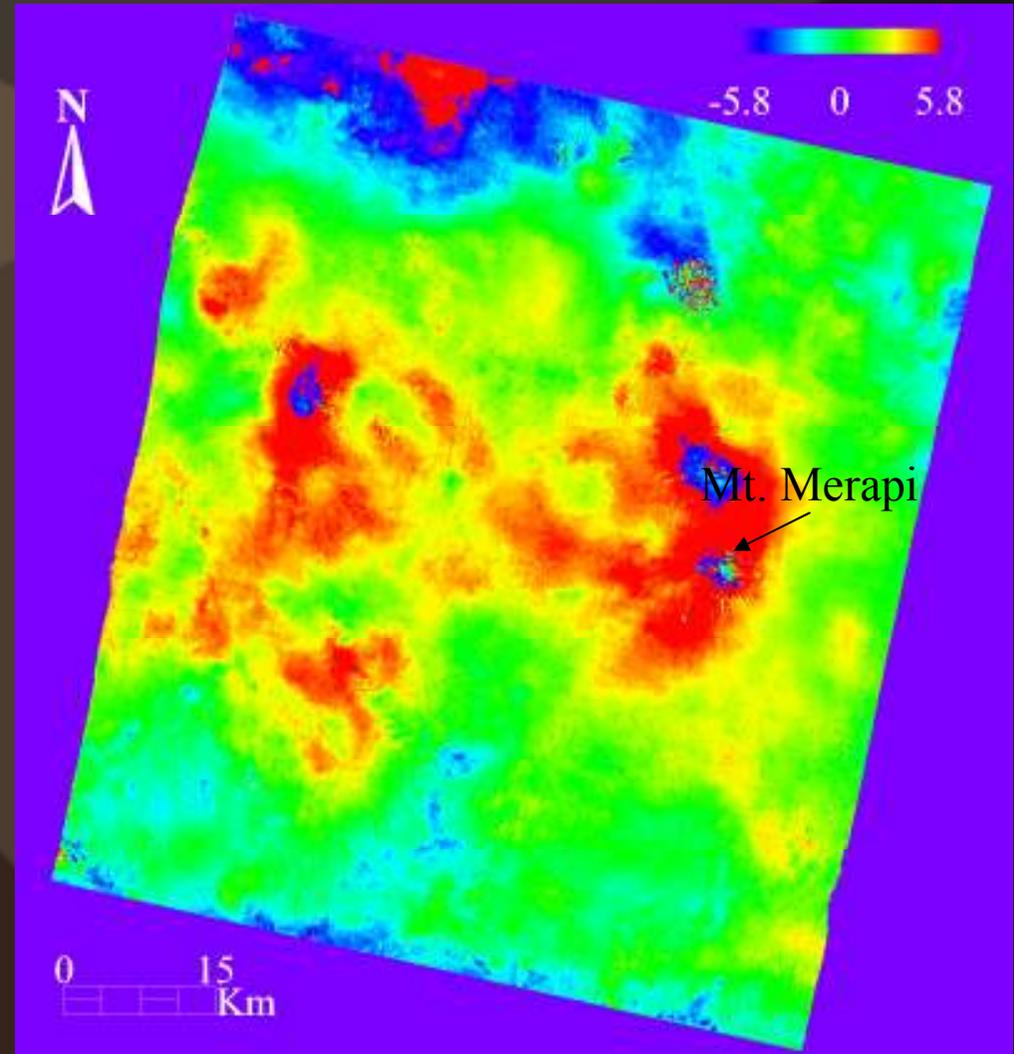
0
-2.931208e+03 6.366711e+03 -9.751637e+02
-2.931067e+03 6.366920e+03 -9.750835e+02
r_m=7.076576e+03 r_s=7.076695e+03 th=-1.913651e-03(deg)
dr=-1.188097e-01 re=6.377729e+03 dth=7.121356e-03(deg)
slave is left of master
d1=2.023370e-01 d2=1.004691e-01 d3=4.780636e-02 nr=2.309107e-01
B=2.309107e-01 dh=1.188097e-01 re=6.377729e+03 dth=7.121356e-03(deg) rs=-1.00000
0e+00
p4/result/sar.dtma_HH_HH p4/result/sar.ddtma_HH_HH
3 1 3.000000e+00
errx=1.353371e-01 : tndata= 927/( 1428)
erry=1.695540e-01 : tndata= 927/( 1428)
9.996210e-01 -6.112055e-05 1.290093e+00
2.723409e-04 1.000049e+00 3.330375e+01
GRS80
lonmin=1.096651e+02 latmin=-8.056918e+00
lonmax=1.108890e+02 latmax=-6.963983e+00
3:1.096651e+02 -8.056918e+00 1.108890e+02 -6.963983e+00
-9109
-7110
 109 -9
 110 -7
nlon=2 nlat=3
lon0=1.090000e+02 lat0=-9.000000e+00 lon3=1.090000e+02 lat3=-6.000000e+00
30:1.090000e+02 -9.000000e+00 1.110000e+02 -6.000000e+00
SRTM30 e100n40 icase=0
1.090000e+02 -9.000000e+00 1.110000e+02 -6.000000e+00 DTM-GSI/SRTM30/e100n40.HDR
BYTEORDER M
LAYOUT BIL
NROWS 6.000000e+03
NCOLS 4.800000e+03
NBANDS 1.000000e+00
NBITS 1.600000e+01
BANDROWBYTES 9.600000e+03
TOTALROWBYTES 9.600000e+03
BANDGAPBYTES 0.000000e+00
NODATA -9.999000e+03
ULXMAP 1.000042e+02
ULYMAP 3.999583e+01
XDIM 8.333333e-03
YDIM 8.333333e-03
nlon=241 nlat=361
lon0=1.090000e+02 lat0=-9.000000e+00 lon3=1.090000e+02 lat3=-6.000000e+00
300:1.096651e+02 -8.056918e+00 1.108890e+02 -6.963983e+00
310:0
icase=0
```

Master and Slave Image Position

P3 slave is right of master

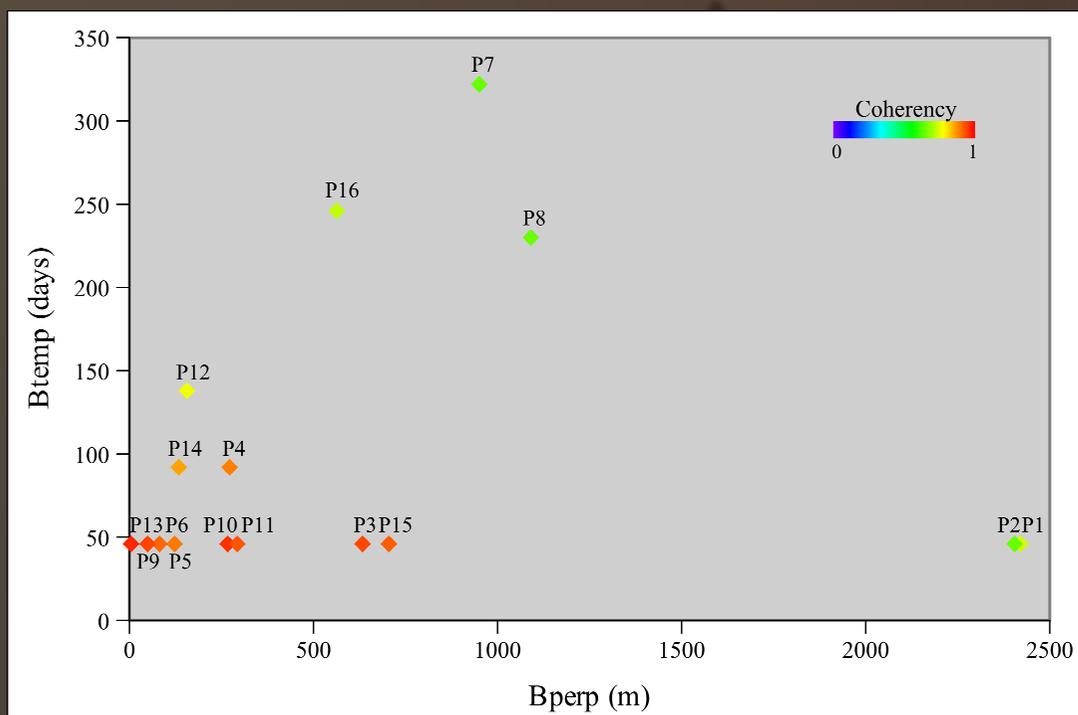
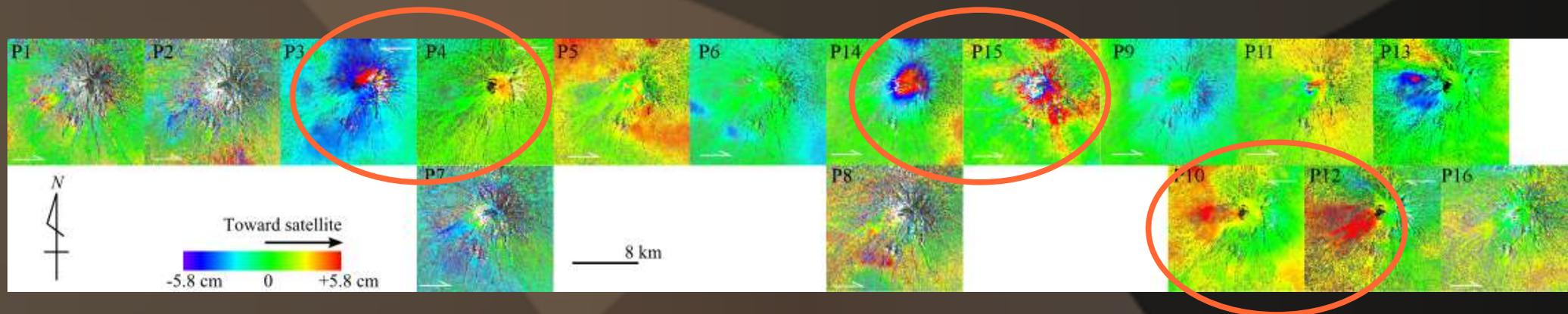


P3 slave is left of master



In particular case the Sigma-SAR change the master and slave position.
The examination of log report is needed to know their correct position.

The Interferograms Generated from ALOS/PALSAR

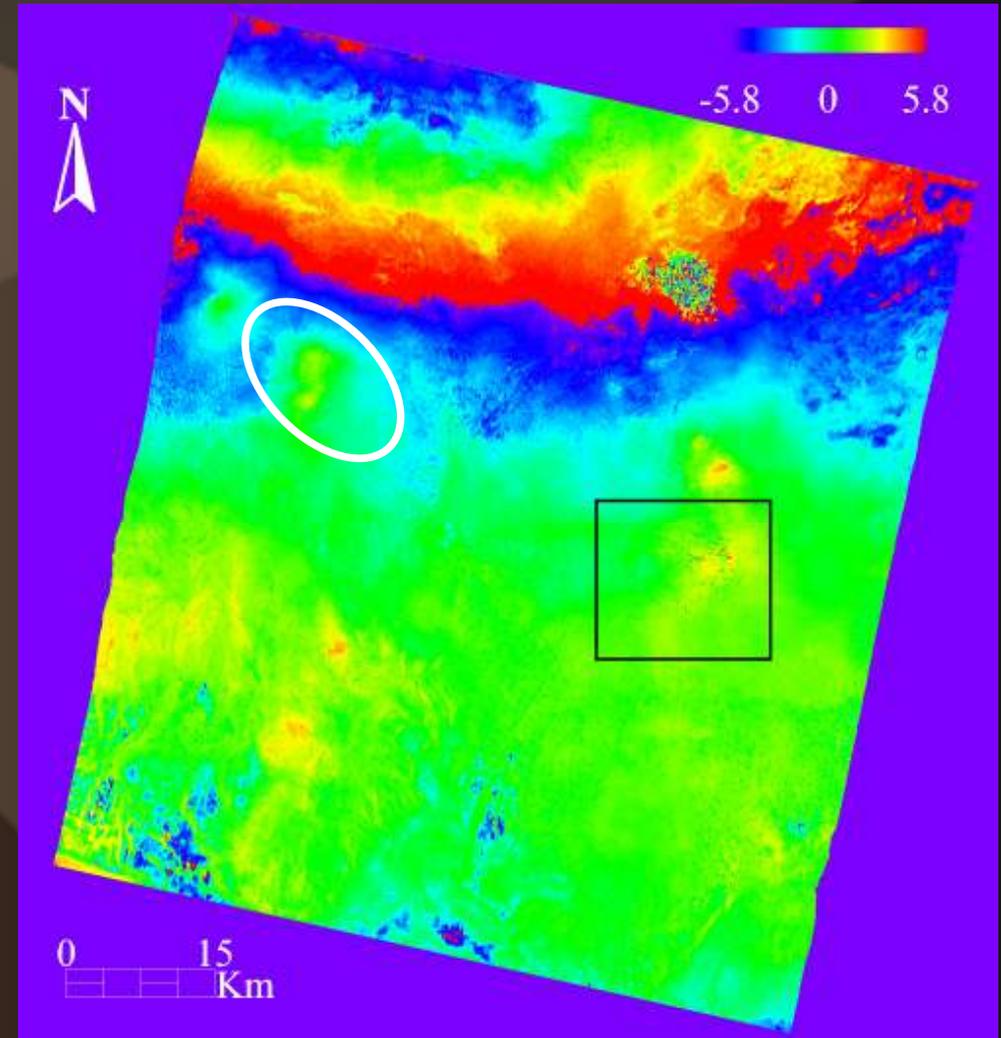
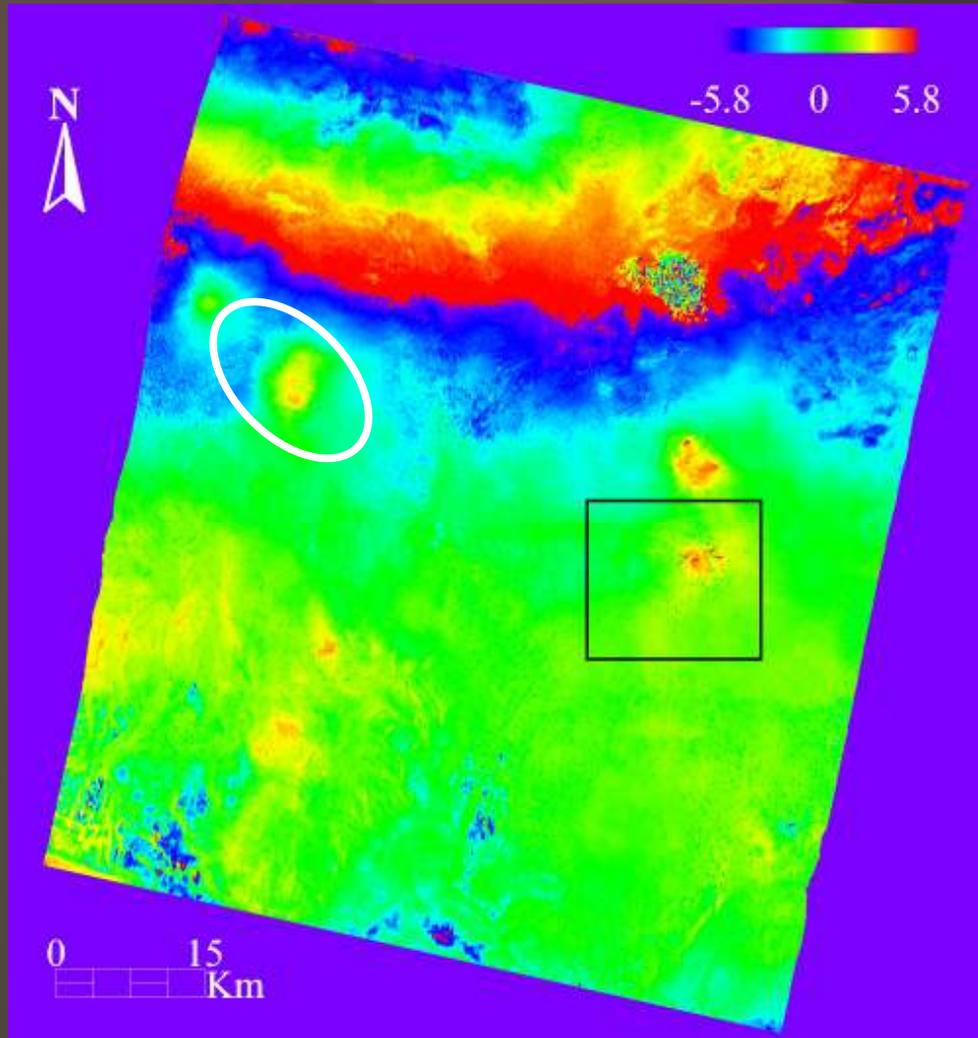


- The Interferograms were generated after removing the topographical and orbital error.
- Two typical patterns are notable: the ground surface is changed about 10 cm in the radar's line of sight to the surface at the eastern flank and the western flank from the summit.
- Baseline and coherence condition of ALOS/PALSAR is getting better in recent time.

Atmospheric Effect

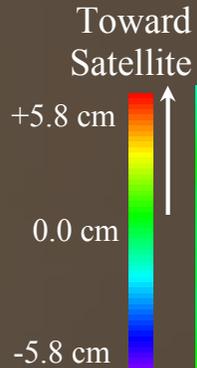
P4 sar.ddtmaf_g

P4 sar.ddtmaf_g

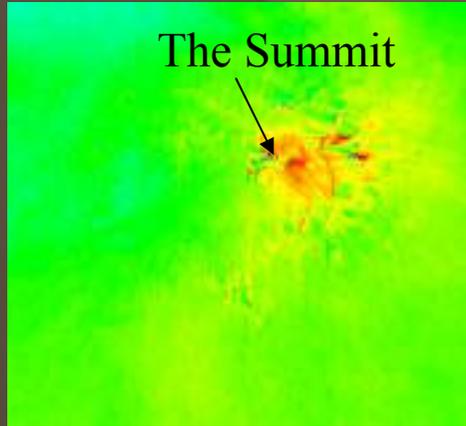


The effect of atmospheric delay can be seen by the difference before (left) and after (right) atmospheric correction.

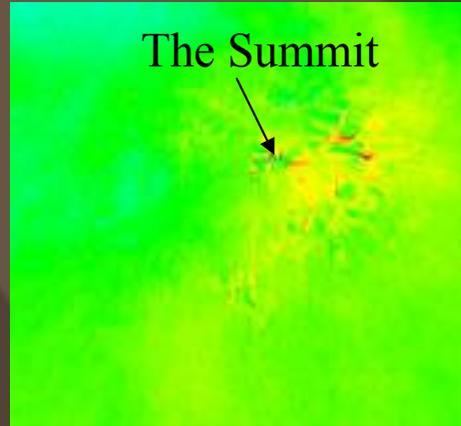
Profile Before and After Atmospheric Correction



Before

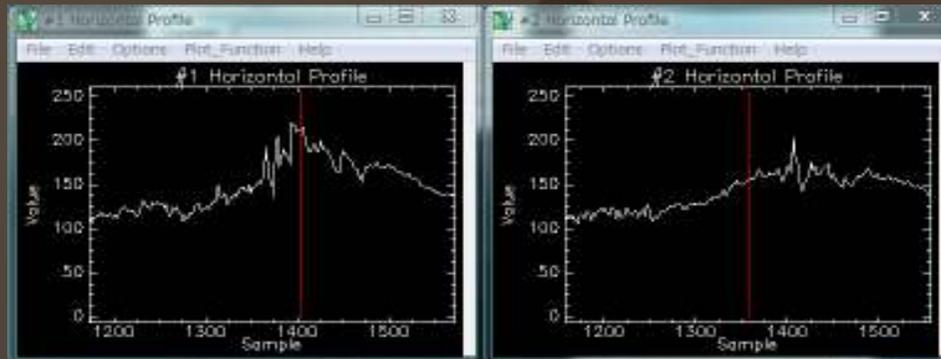


After



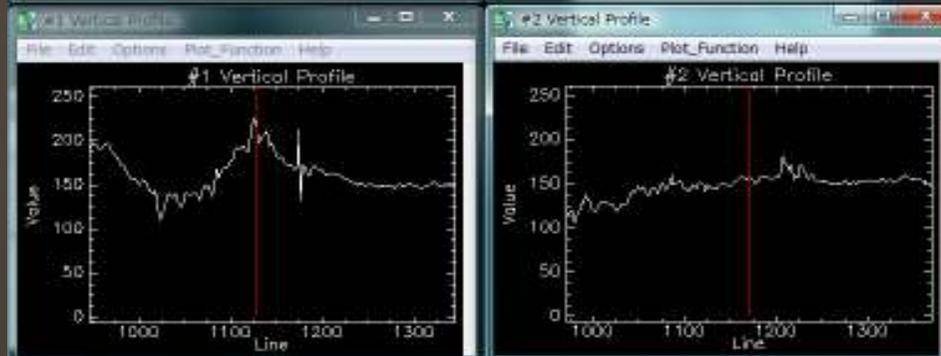
The deformation signals on the left image are contaminated by atmospheric delay that may lead to the mis-interpretation.

A



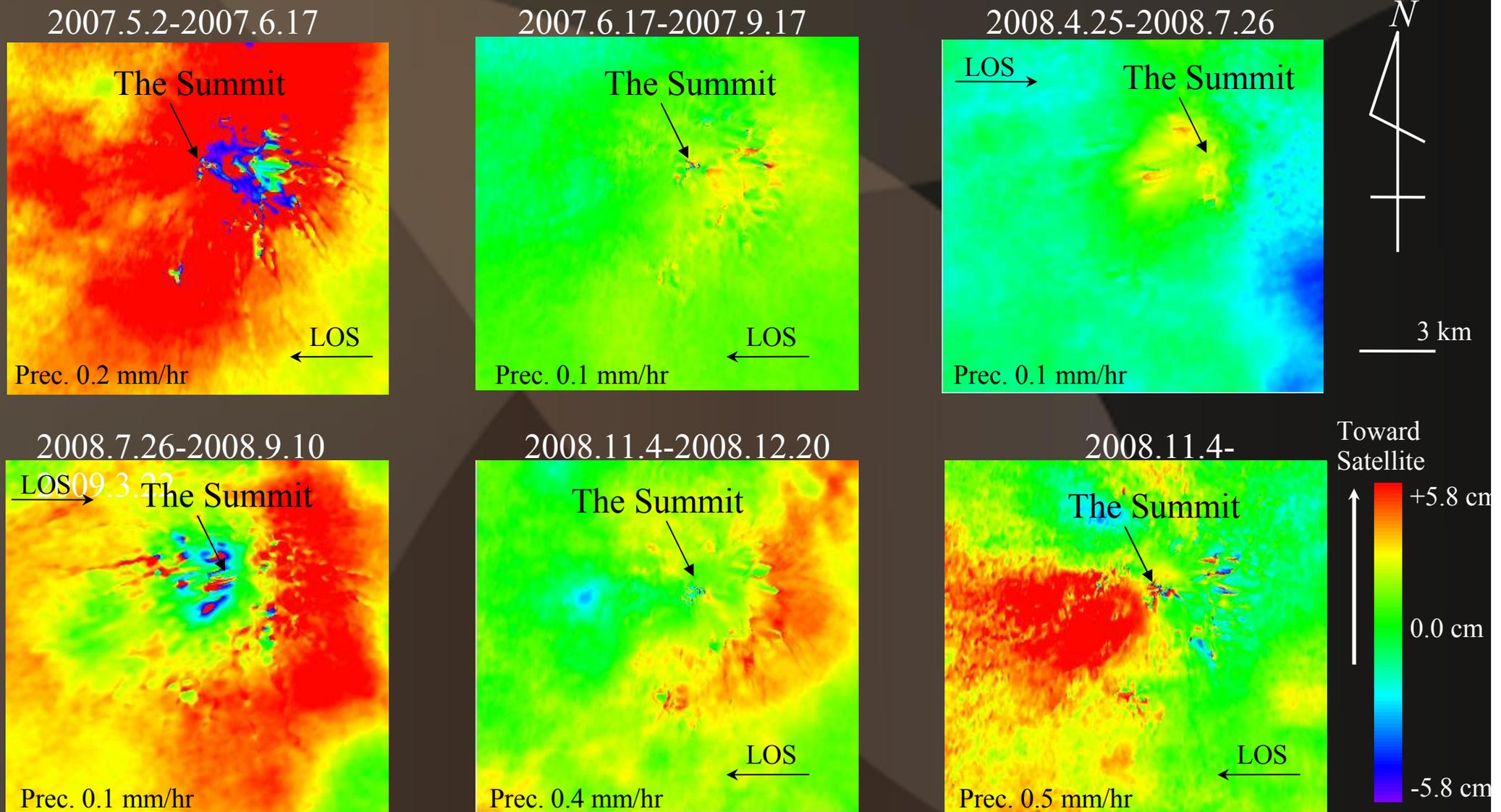
Interferogram profile for the west-east (A) and north-south (B) direction before and after atmospheric correction.

B



The profiles are supposed to be the topographical change around Mt. Merapi

Topographical Change of Mt. Merapi



The fringe pattern with low precipitation at the eastern flank is supposed to be related with magma ascent to the shallow reservoir and the western flank is caused by lahars generation due to high precipitation in rainy season.

Conclusion

- The topographical changes around Mt. Merapi might be caused by two factors: internal factor related with magma ascent and external factor related with lahars in rainy season.
- The precipitation data can be used to estimate the lahars generation, however the high precision GPS measurement is important to validate the topographical change related with magma ascent .
- The ground surface is uplifted about 10 cm in the radar's line of sight to the surface at the eastern flank and the western flank from the summit.
- The pattern at the eastern flank is supposed to be related with magma ascent to the shallow reservoir and the western flank is caused by lahars generation in rainy season.

Acknowledgments

The ALOS/PALSAR data level 1.0 were provided by PALSAR Interferometry Consortium to Study our Evolving Land and Surface (PIXEL). The raw SAR data were processed using JAXA/SIGMA-SAR (M. Shimada, 1999).