InSAR在水土保持與坡地防災之應用

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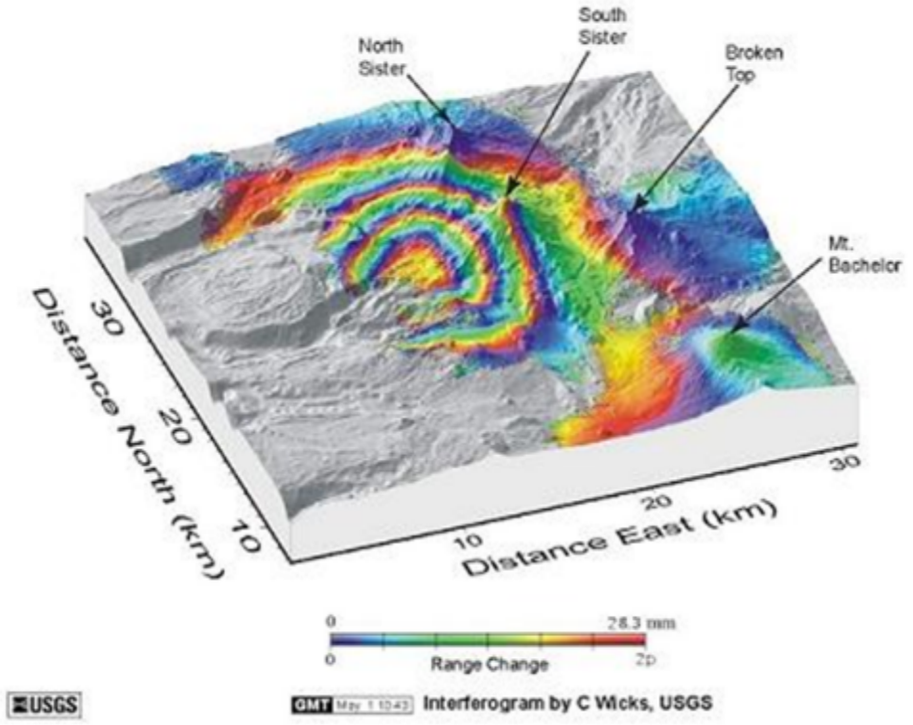
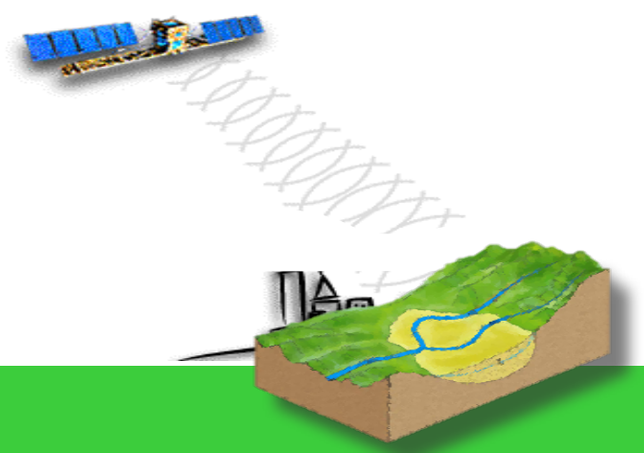
香港理工大學 張磊 研究助理教授









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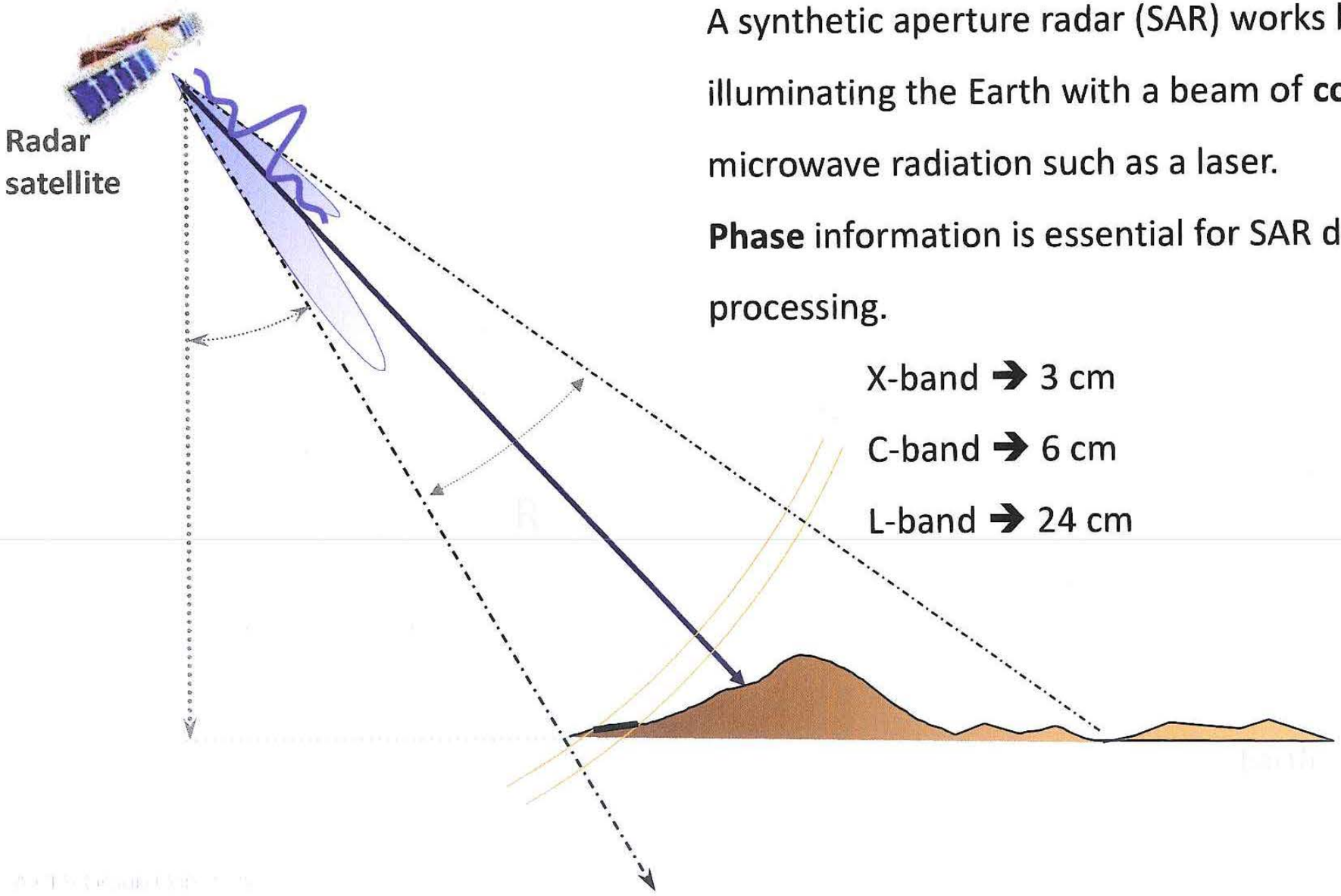
Satellite SAR: a coherent sensor



A synthetic aperture radar (SAR) works by illuminating the Earth with a beam of **coherent** microwave radiation such as a laser.

Phase information is essential for SAR data processing.

X-band ➔ 3 cm

C-band ➔ 6 cm

L-band ➔ 24 cm

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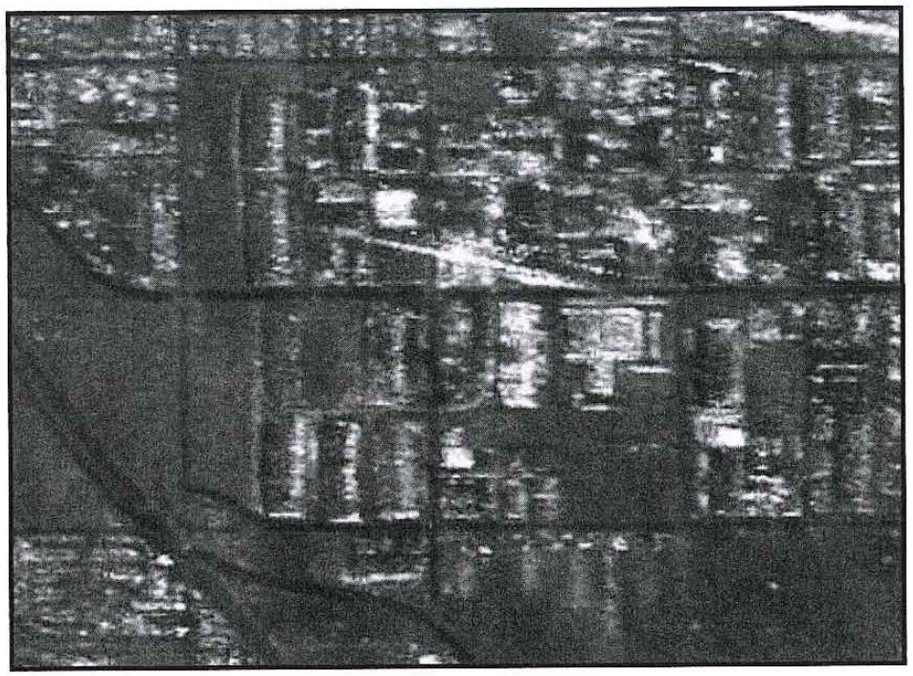
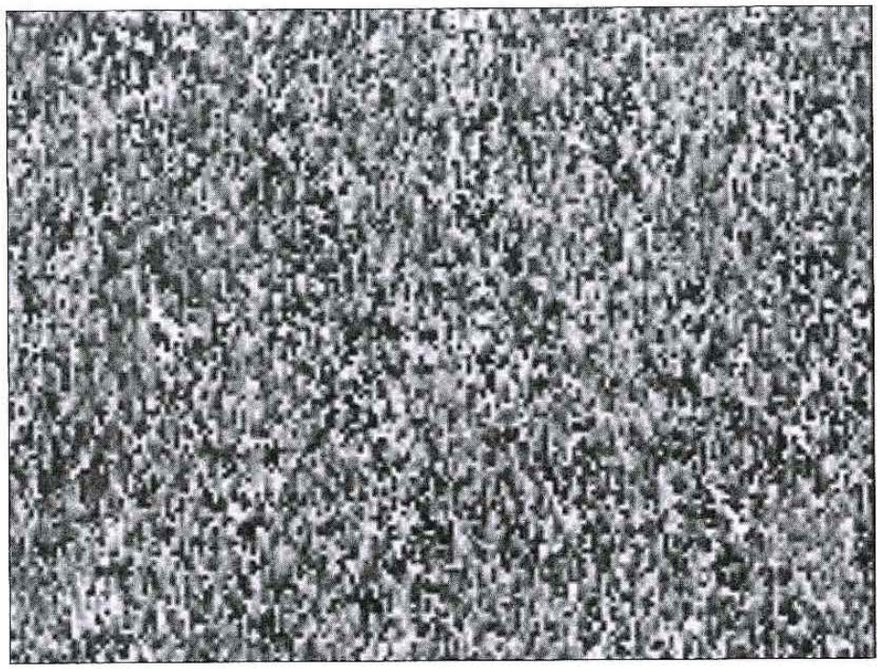
SAR data

A SAR image is a set of pixels characterized by both **amplitude** and **phase** values.

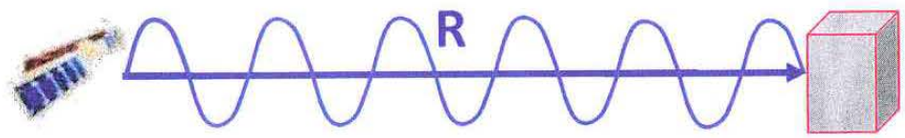


Amplitude



Phase (known modulo 2π)

The phase is related to the **sensor-target distance.**



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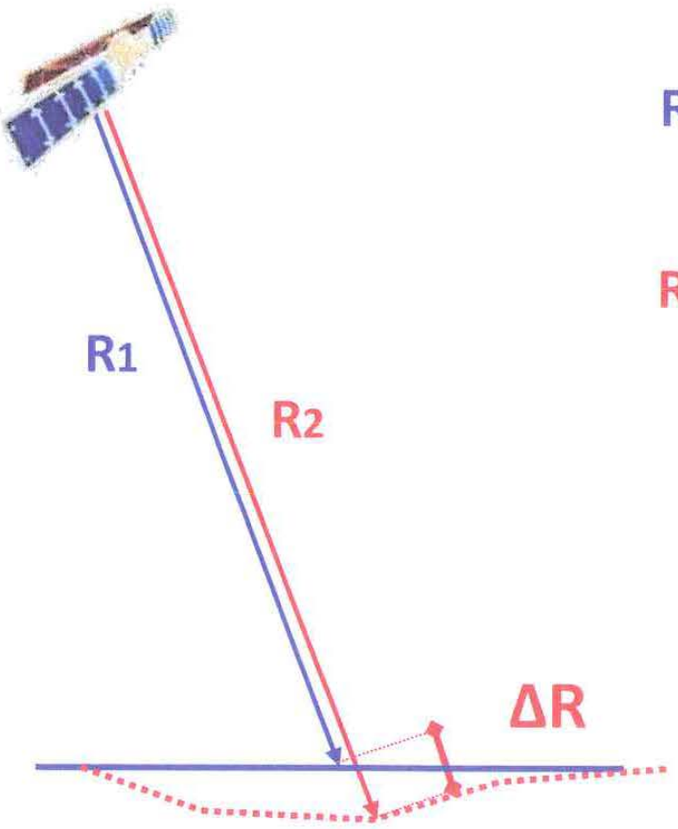
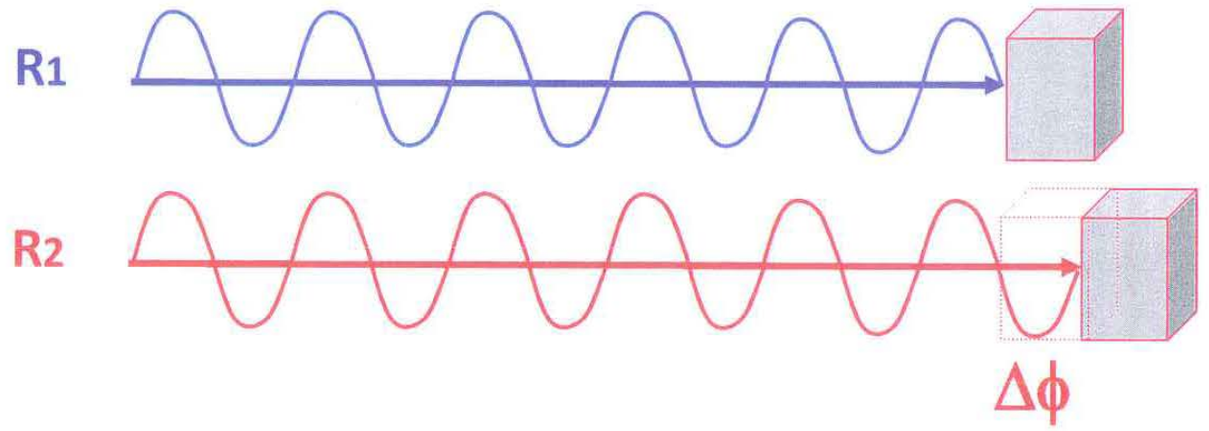
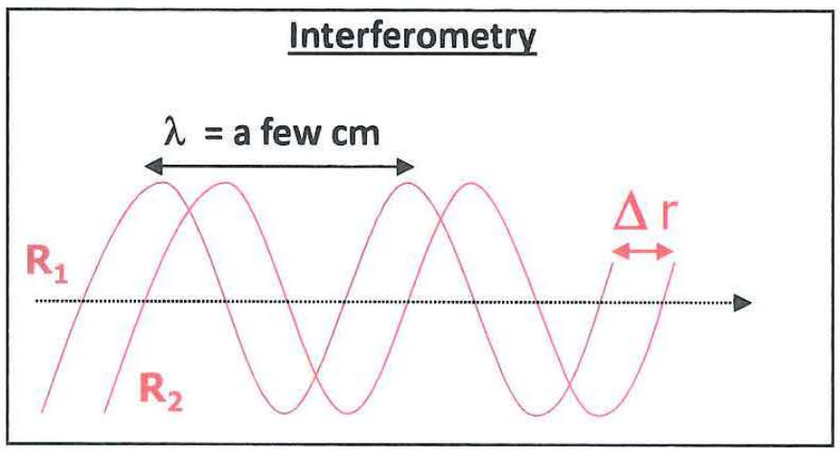
The Interferometric Concept



The *unit of length* used in InSAR is the wavelength:



$$\Delta R = c \cdot \Delta\phi$$

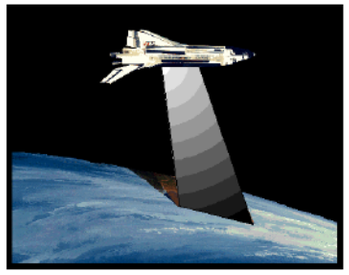


SAR data

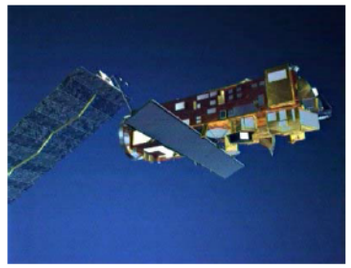
How to choose the Synthetic Aperture Radar ?

Frequency (wavelength)

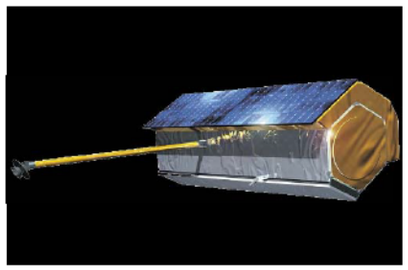
- Light interacts most strongly with objects on the sizes of the wavelength
- Wavelengths a measure of surface and subsurface scale sizes
- **L-band** greatly improves correlation



SIR-C
NASA / JPL (USA)
April 1994 (10 days)
October 1994 (10 days)
L, C-Band (Quad)



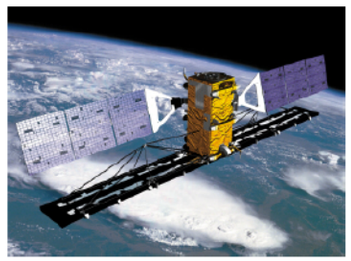
ENVISAT / ASAR
ESA (EU)
2002
C-Band (Sngl / Twin)



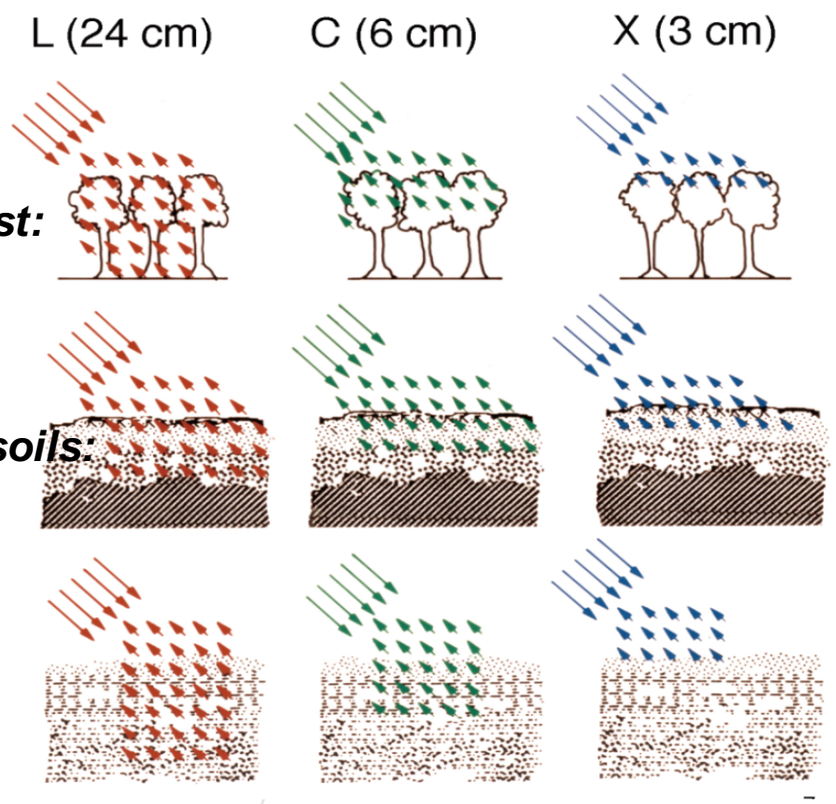
TerraSAR-X
DLR / EADS – ASTRIUM / Infoterra GmbH
June 2007
X-Band (Sngl / Twin / Quad ?)



ALOS / PALSAR
JAXA (J)
January 2006
L-Band (Sngl / Twin / Quad)



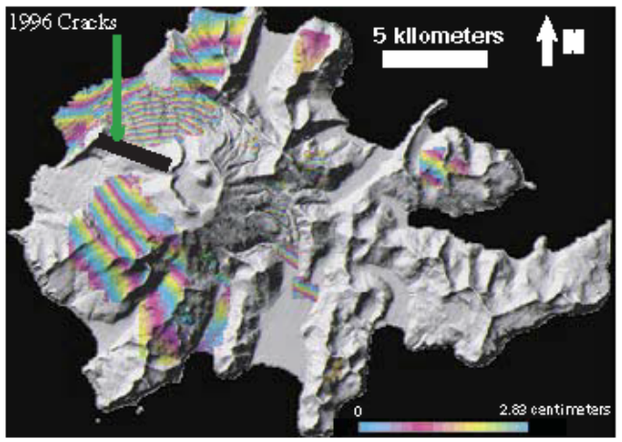
RADARSAT 2
CSA / MDA (CA)
December 2007
C-Band (Quad)

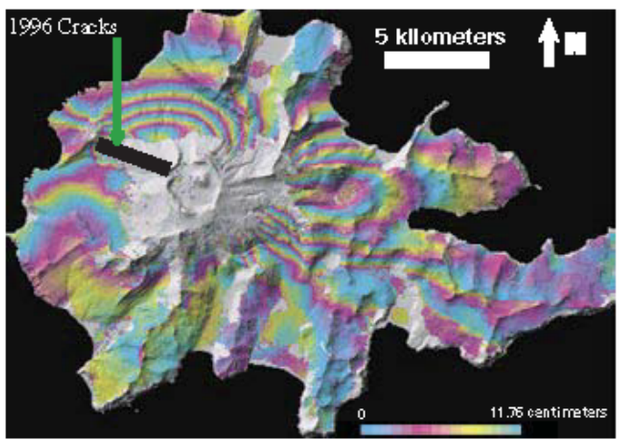


Paul A Rosen
(Jet Propulsion Laboratory, California Institute of Technology)

Pottier and Ferro, 2008
(University of Rennes1, IETR-UMR CNRS)

ERS/Radarsat (C-band) vs JERS/ALOS (L-band)

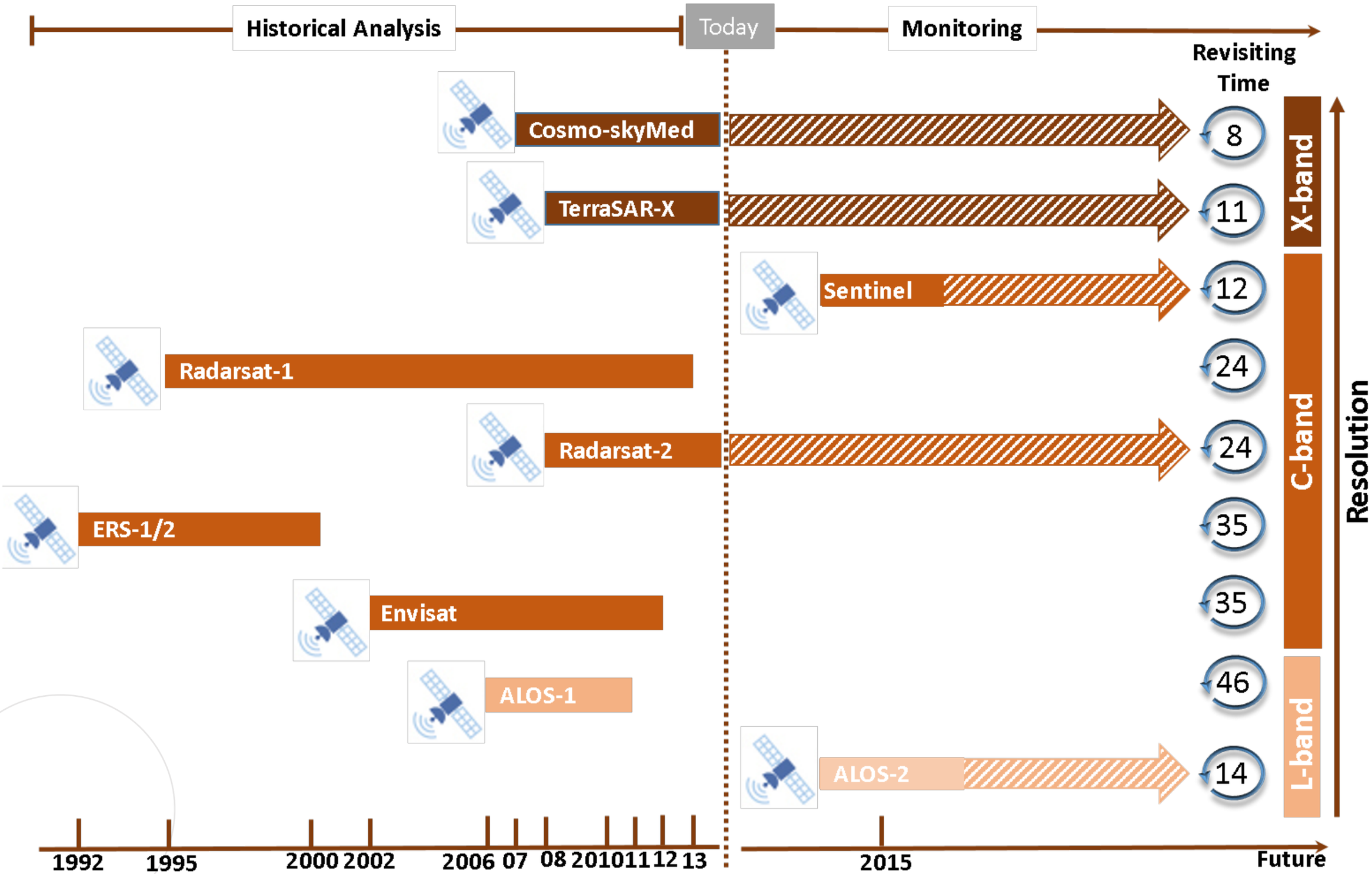




Interferogram showing deformation of Akutan Island (October 1994 ot June 1997), draped over shaded-relief map of the island (Lu et al., 2005)

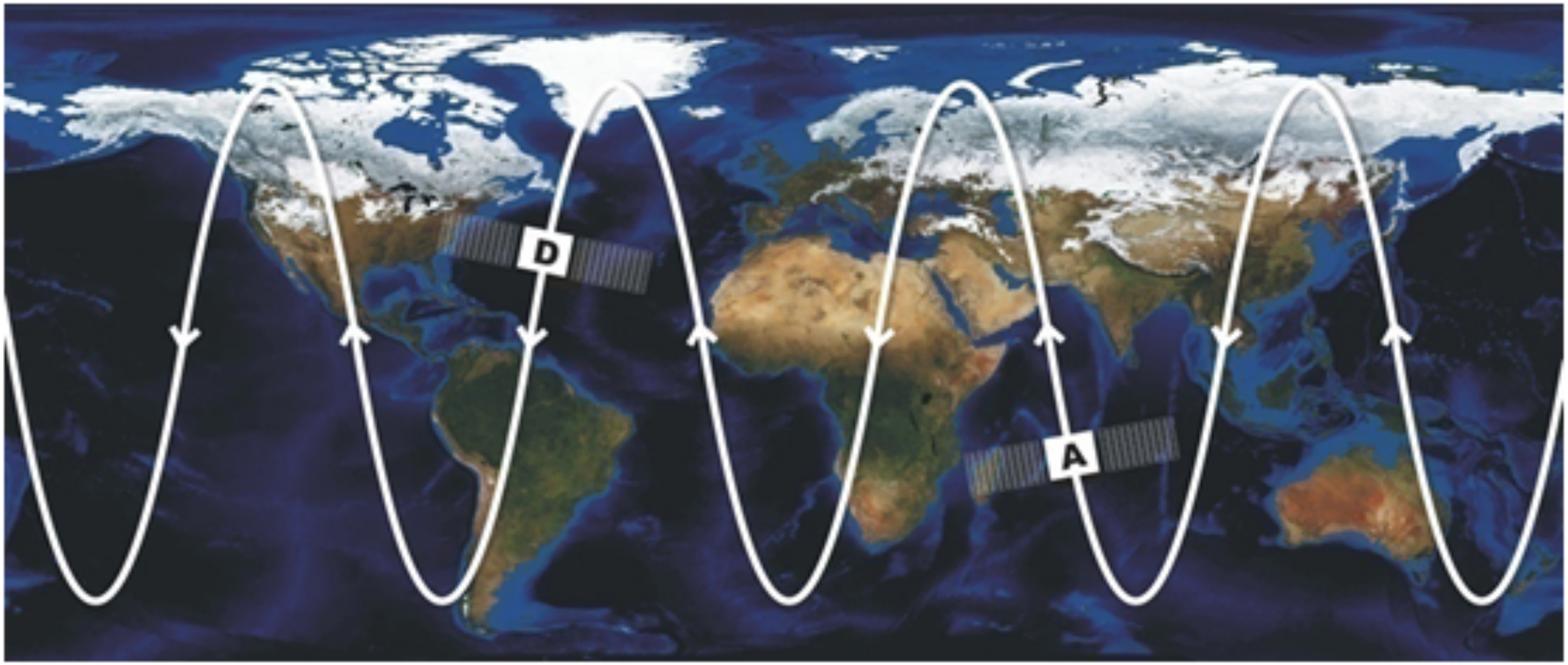
SAR data

Synthetic Aperture Radar (SAR) Satellites



SAR 衛星軌道

D: descending ； A:ascending



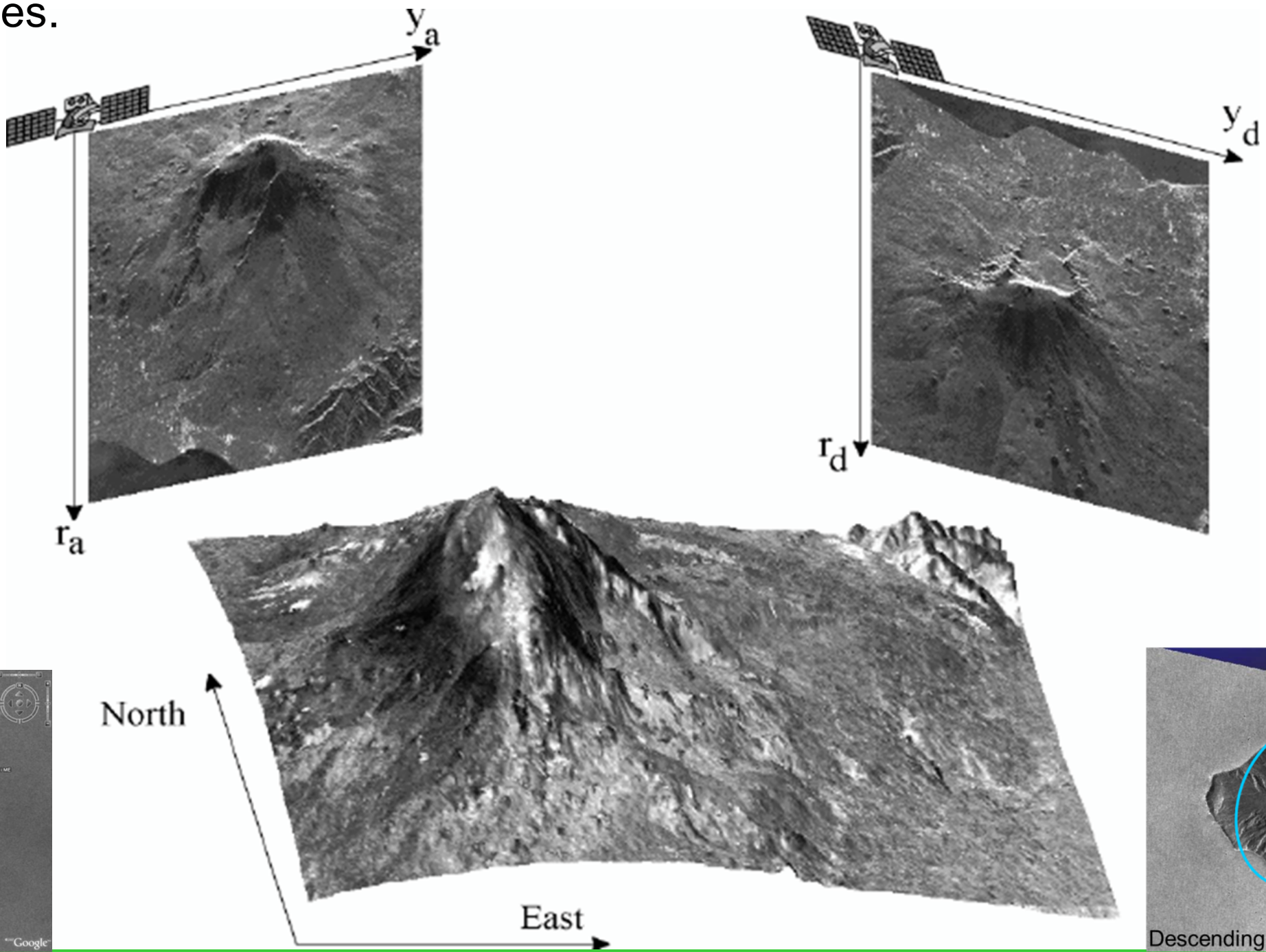
(Source: www.cgg.com)

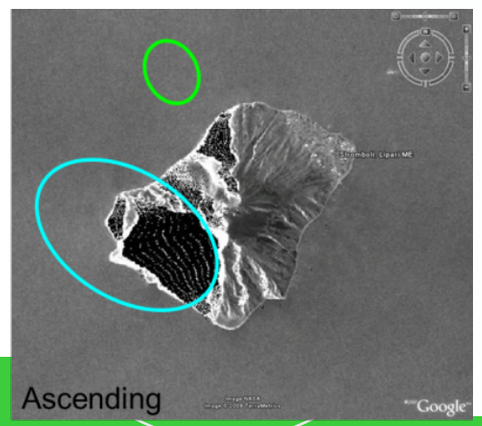
雷達訊號對南北向形變不敏感

SAR data

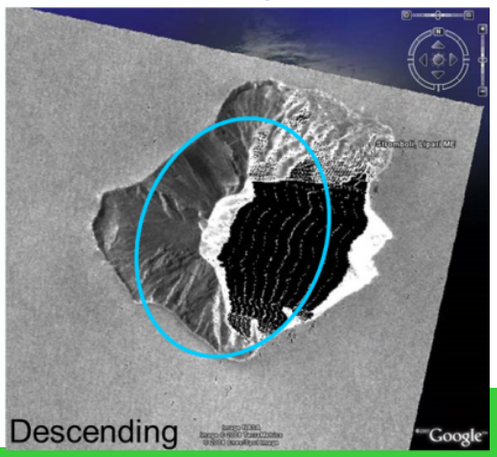
❖ Combine Ascending and descending orbits

The combination of the motion of the satellite and the motion of the earth makes it possible to look at the same area of interest from two opposite acquisition geometries.



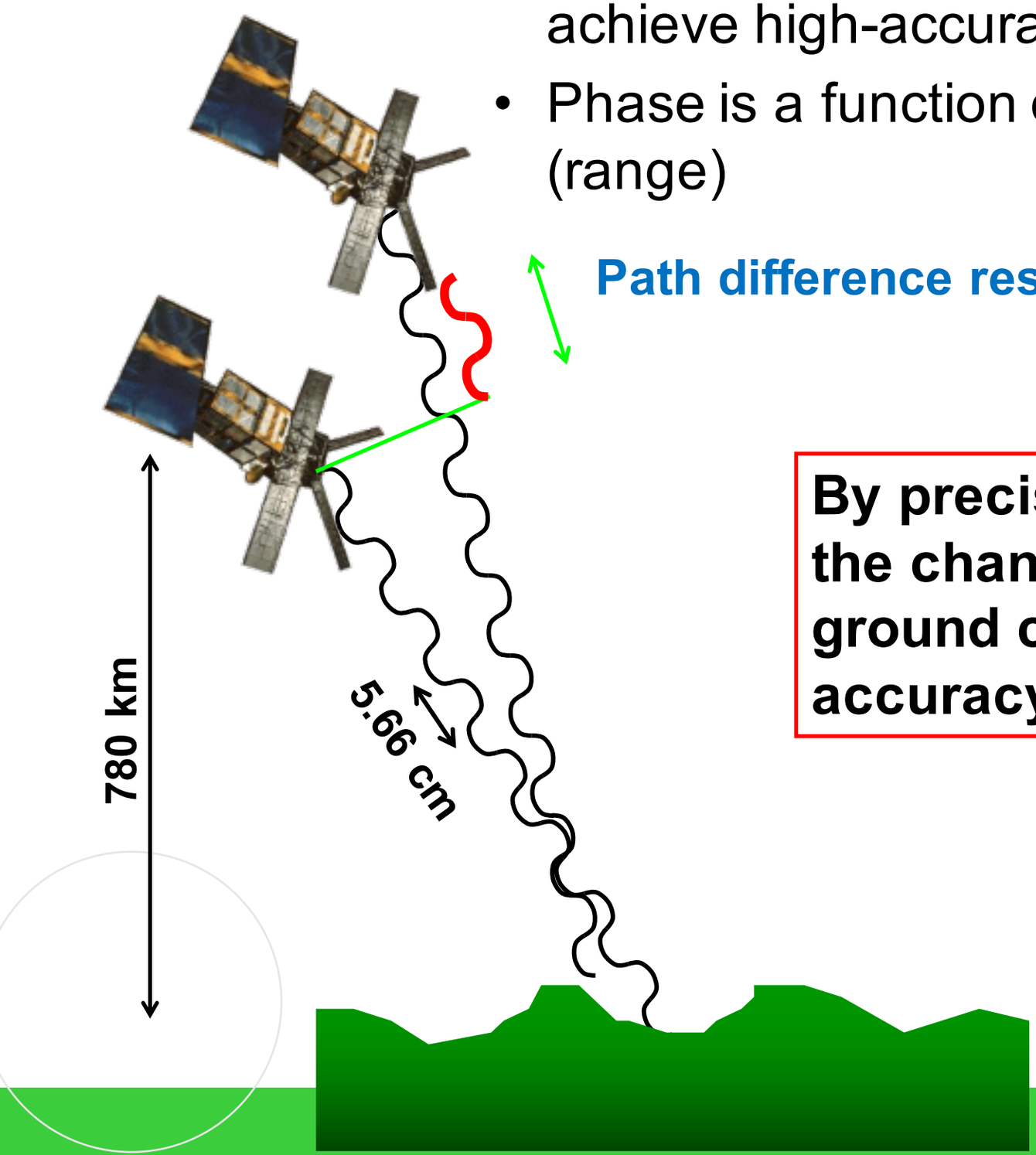


layover



InSAR原理

- InSAR utilizes phase information of radar wave to achieve high-accuracy measurement
- Phase is a function of distance from satellite to ground (range)



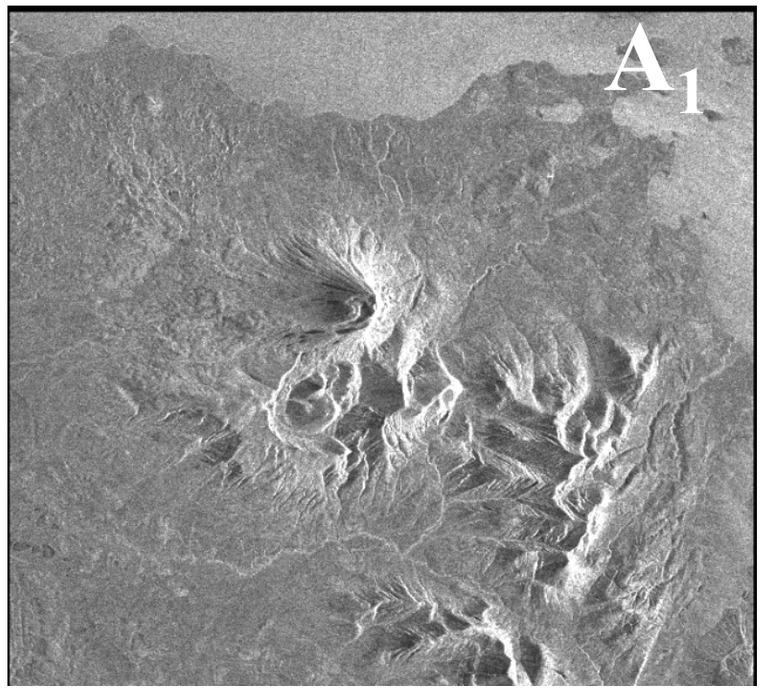
By precisely measuring the phase shift, the change in distance from satellite to ground can be calculated to an accuracy of sub-wavelength.

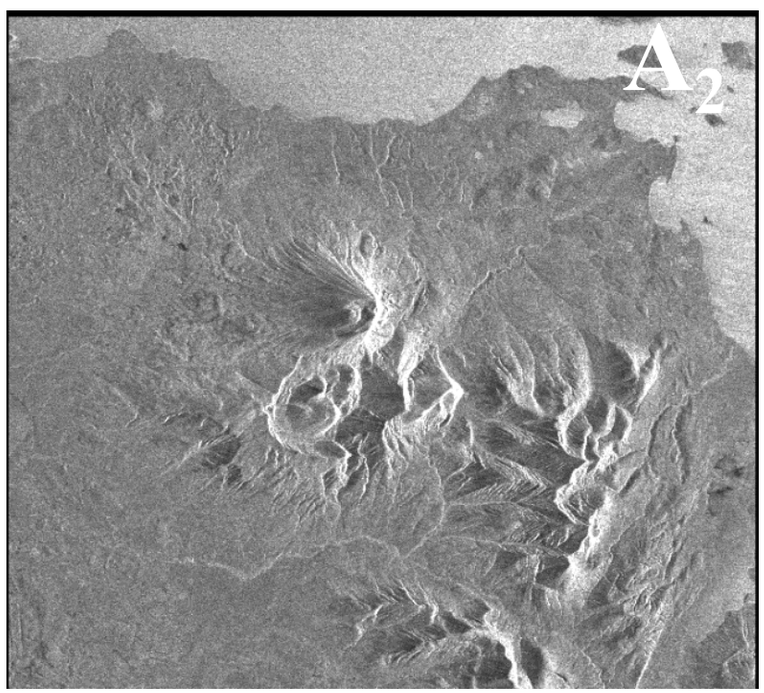
InSAR

Image 1: Oct. 4, 1995

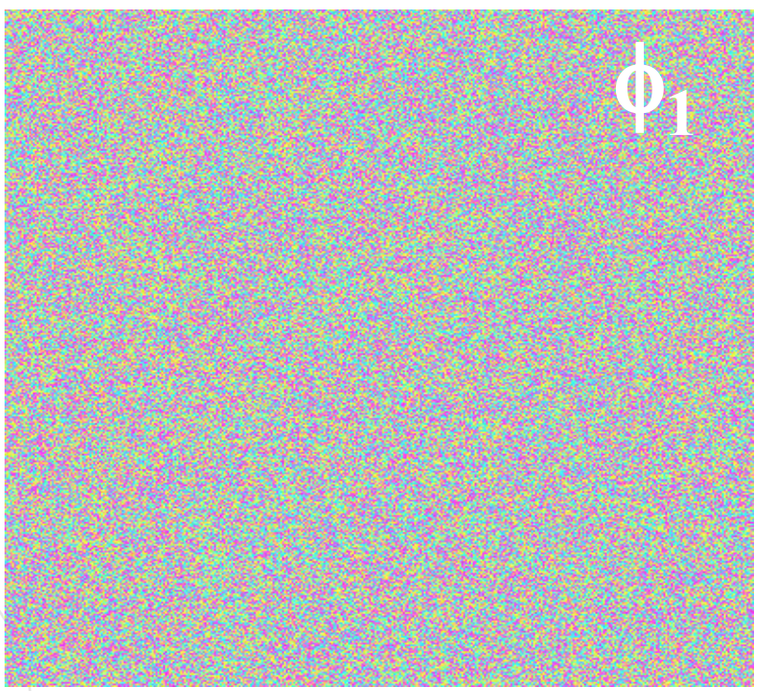
Image 2: Oct. 9, 1997

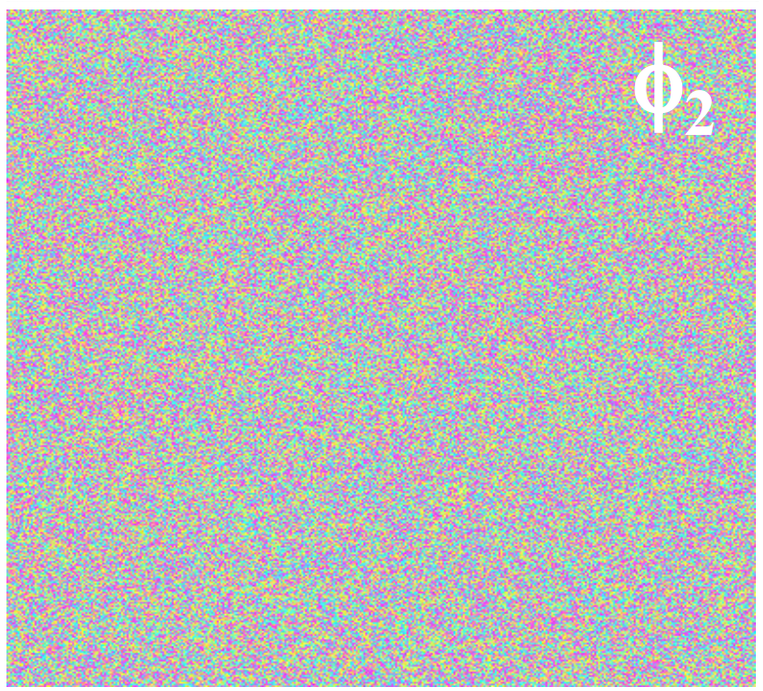
Amplitude image





Phase image



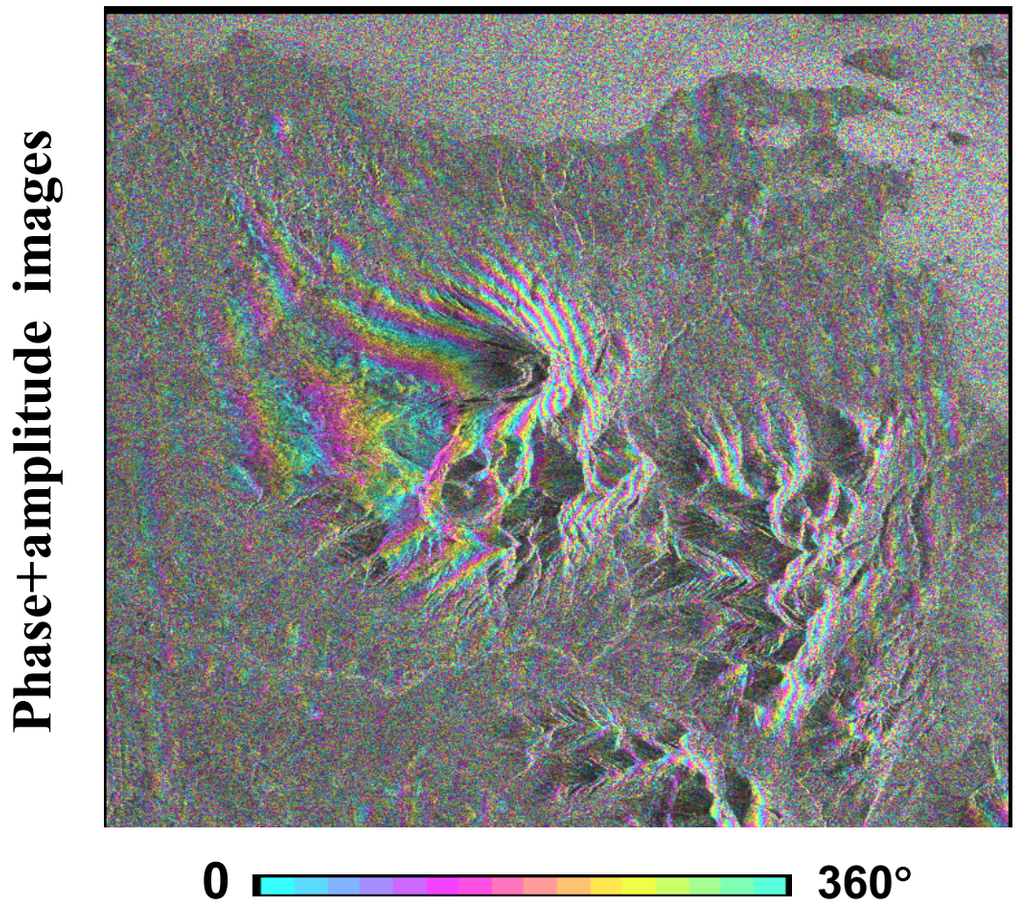


$$_1 = \frac{4}{} r_1 + _1 \qquad _2 = \frac{4}{} r_2 + _2$$

0 360°

Images are ~28 km by 25 km

$$= \quad _1 \quad _2 = \quad \frac{4 \ (r_1 \quad r_2)}{} + (\ _1 \quad _2)$$



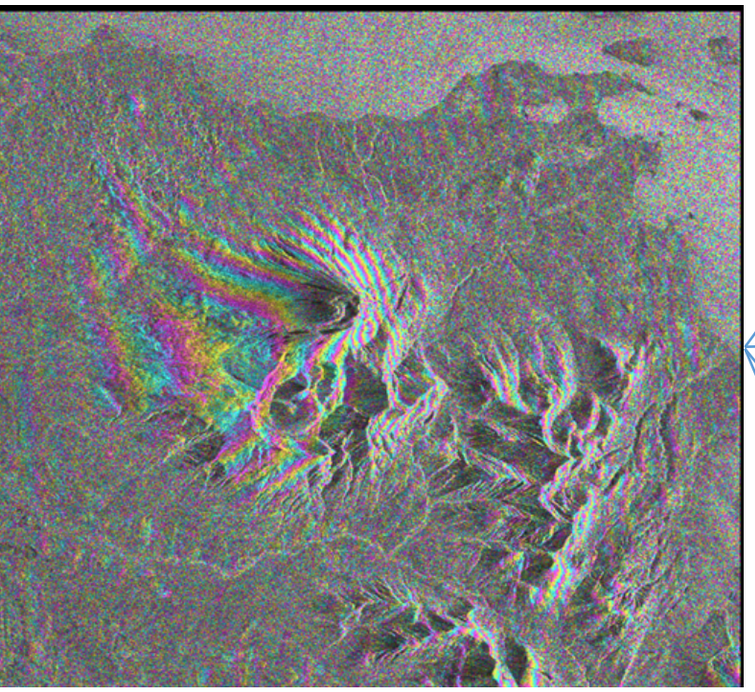
The fundamental assumption in repeat-pass InSAR is that the scattering characteristics of the ground surface remain undisturbed.

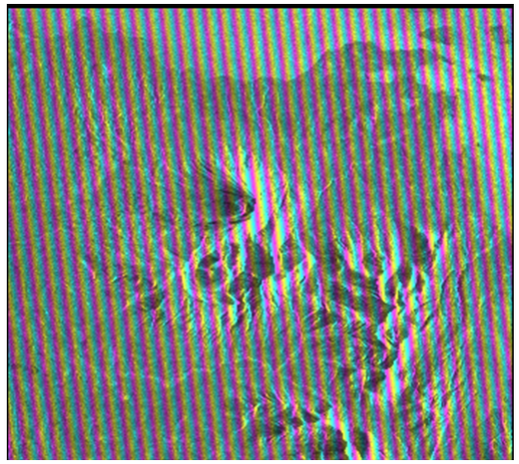
Assume $\varepsilon_1 \approx \varepsilon_2$

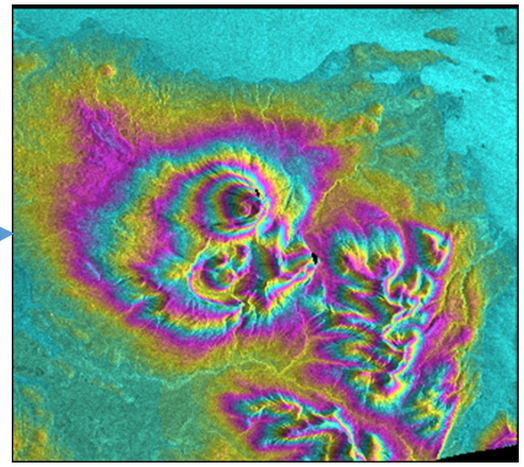
$$= \quad _1 \quad _2 = \quad \frac{4 \ (r_1 \quad r_2)}{}$$

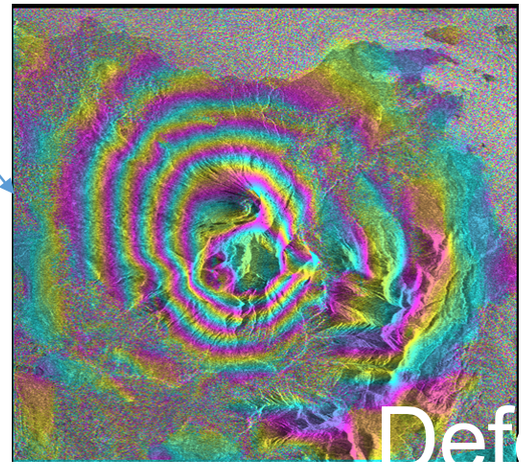
InSAR

Phase components

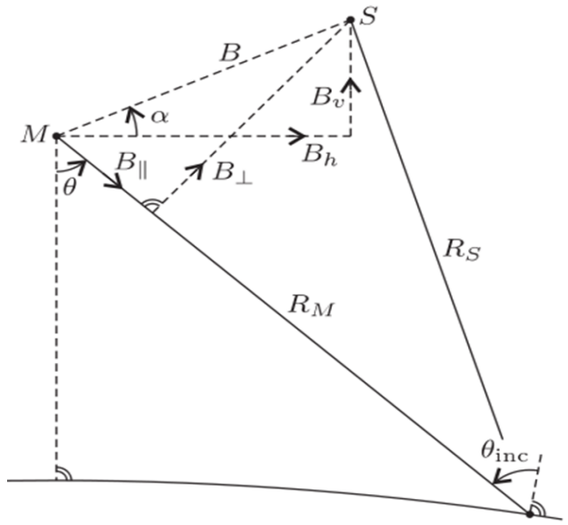


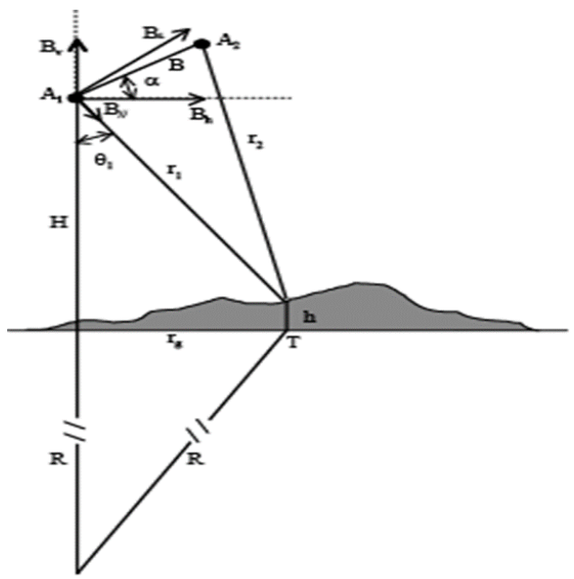


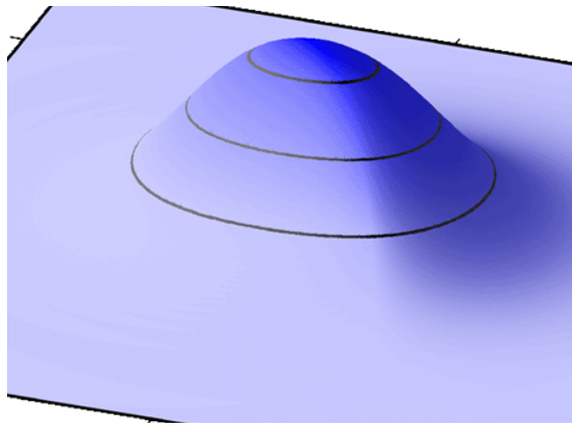




Def



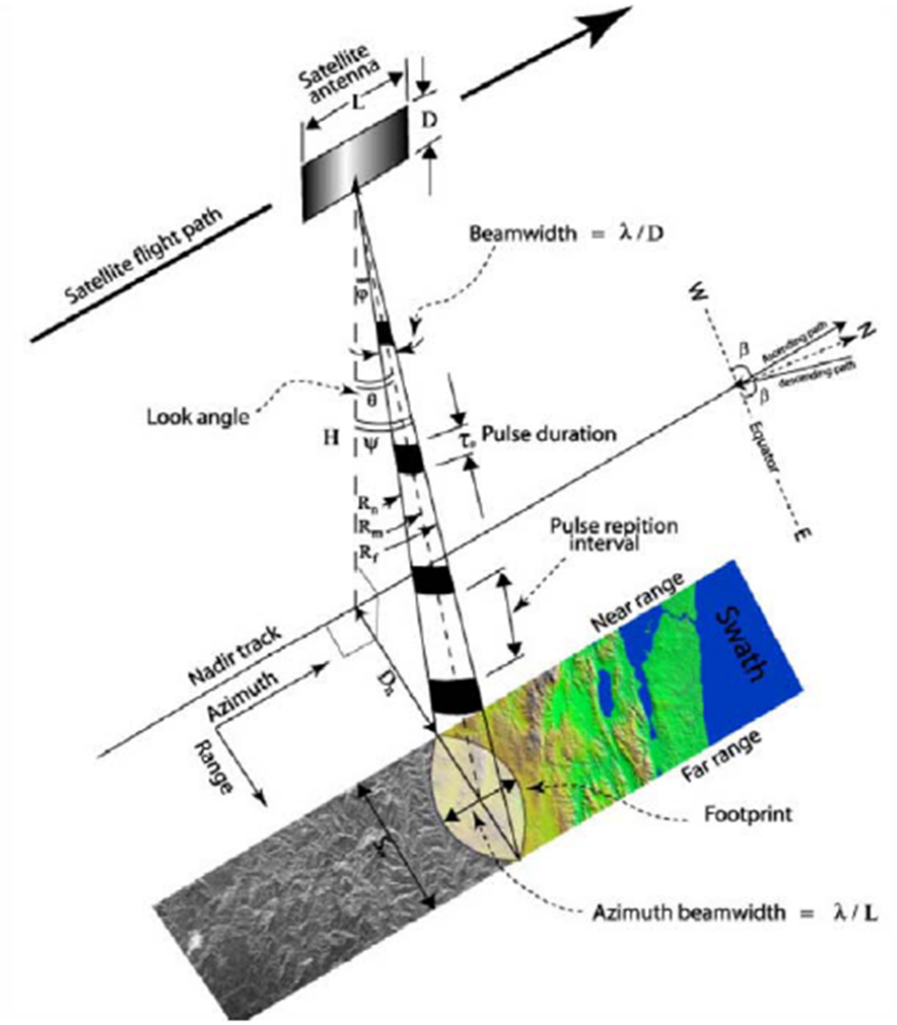




InSAR

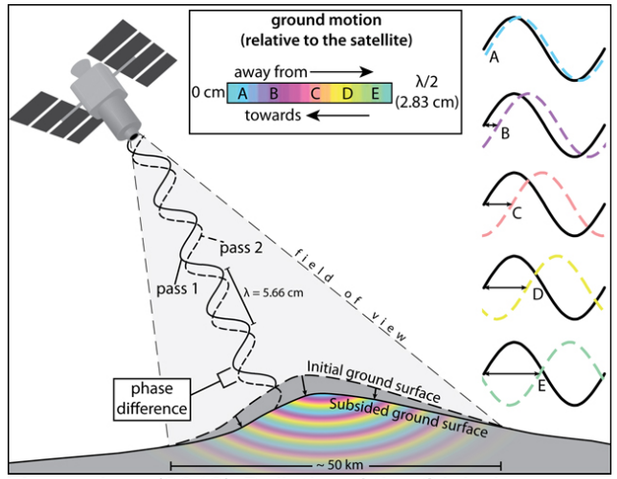
Definition of the SAR techniques

❖ **SAR**合成孔徑雷達(Synthetic Aperture Radar)：以固定天線感測器向地表發射電磁波，藉由接收物體所反射回波之強度(Strength)、振幅(Amplitude)和距離(distance) 等資訊，配合都卜勒偏移原理(Doppler Shift)進行幾何修正，得到地表三維資訊。

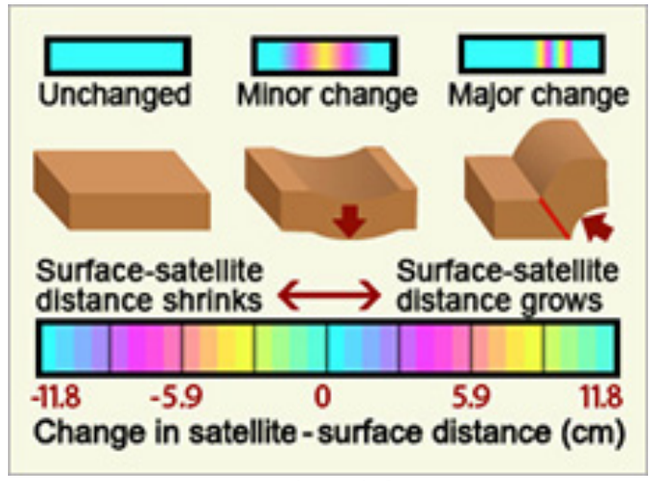


Paolo trivero and Walter Biamino (2010) Observing marine pollution with Synthetic Aperture Radar, ISBN 978-953-7619-97-8

❖**InSAR**干涉合成孔徑雷達(Interferometric SAR)：利用兩張不同時間同一地區之SAR影像，回復影像對之間的相位差(Unwrapping) 取得數值高程地形模型(DEM)或是干涉圖(Interferogram)。



Mauna Loa (2012) Bulletin of the Global Volcanism Network, vol. 37, no. 5



Masayuki Yamanaka (2011) Saving Lives With Satellites. JAXA.

❖ **D-InSAR**差分干涉合成孔徑雷達(Differential InSAR)：同一地區兩幅不同時期干涉圖，利用差分處理將地形效應去除後，得到地表變形量。

❖ **PS-InSAR**永久散射體差分干涉雷達(Persistent Scatterers InSAR)：根據不同時間序列之SAR影像，萃取地表反射性、同調性良好的散射點(Persistent Scatterer, PS)，提供高相關性且長時間穩定之相位資訊。

Phase measurement

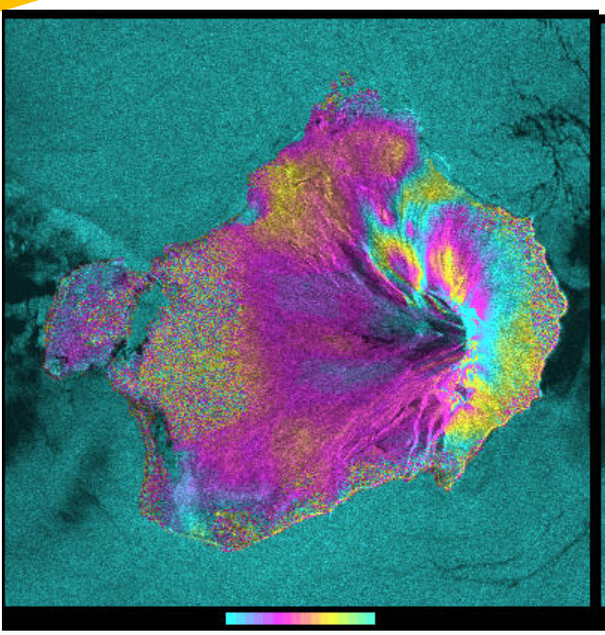
For a pixel (l,m) in the ith differential interferogram

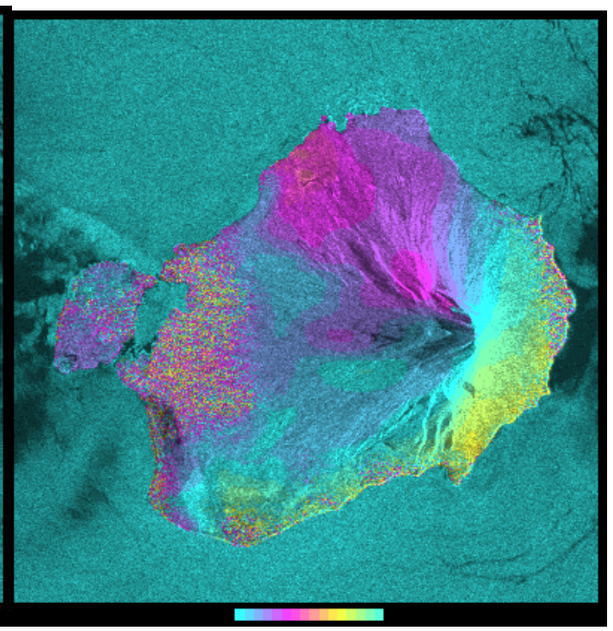
$$\overset{i}{}_{l,m} = \overset{i}{}_{topo,l,m} + \overset{i}{}_{defo,l,m} + \overset{i}{}_{atmo,l,m} + \overset{i}{}_{orbit,l,m} + \overset{i}{}_{noise,l,m} + N \quad 2$$

- $\overset{i}{}_{topo,l,m}$: DEM Error Term
- $\overset{i}{}_{defo,l,m}$: **Deformation**
- $\overset{i}{}_{atmo,l,m}$: Atmospheric Artifact Term
- $\overset{i}{}_{orbit,l,m}$: Orbit Error Term
- $\overset{i}{}_{noise,l,m}$: Noise
- N: Phase Ambiguity → Phase unwrapping error

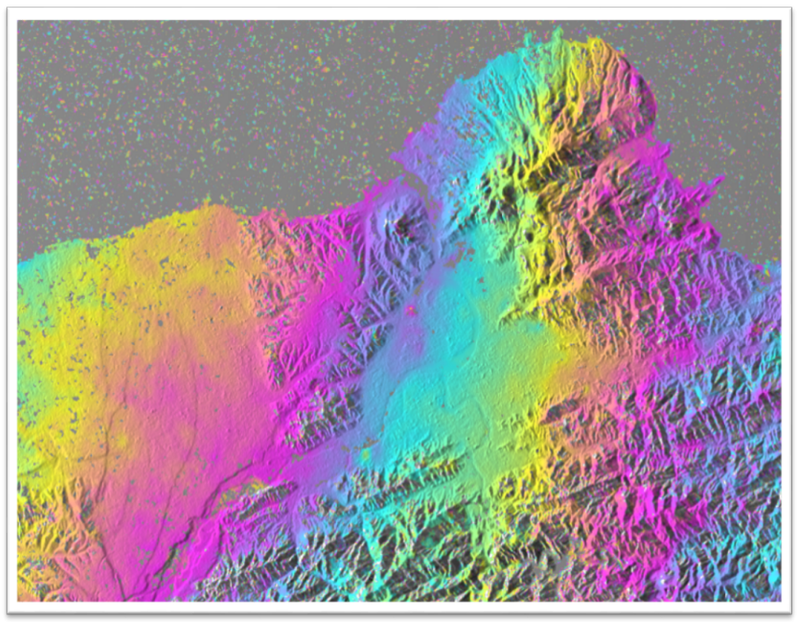
Accuracy of DInSAR measurement: centimeter to several centimeters

InSAR

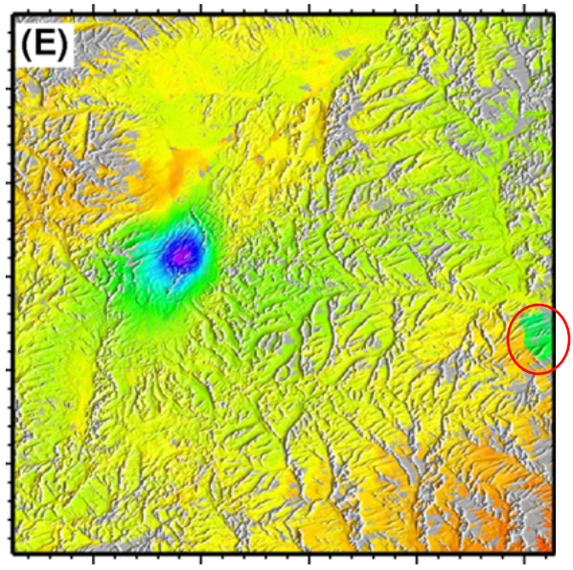




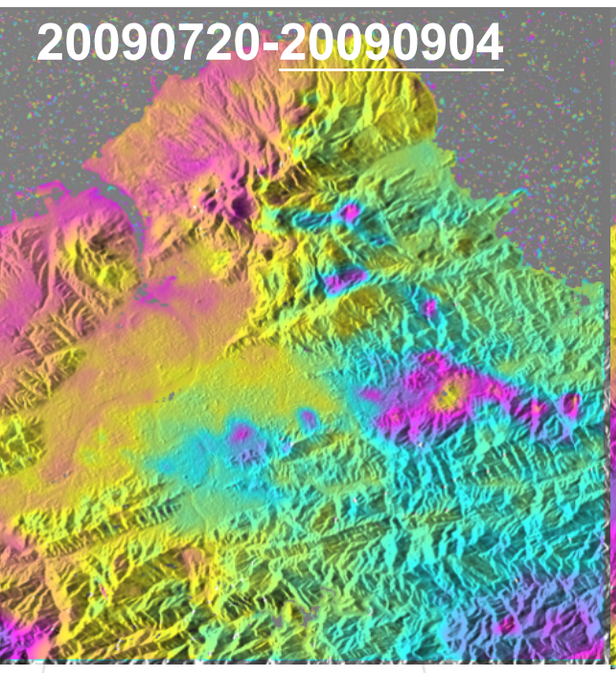
DEM error

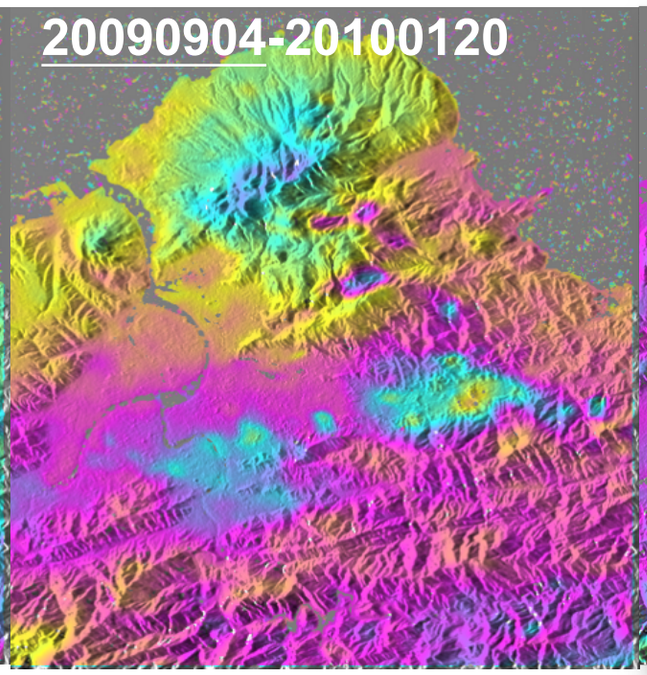


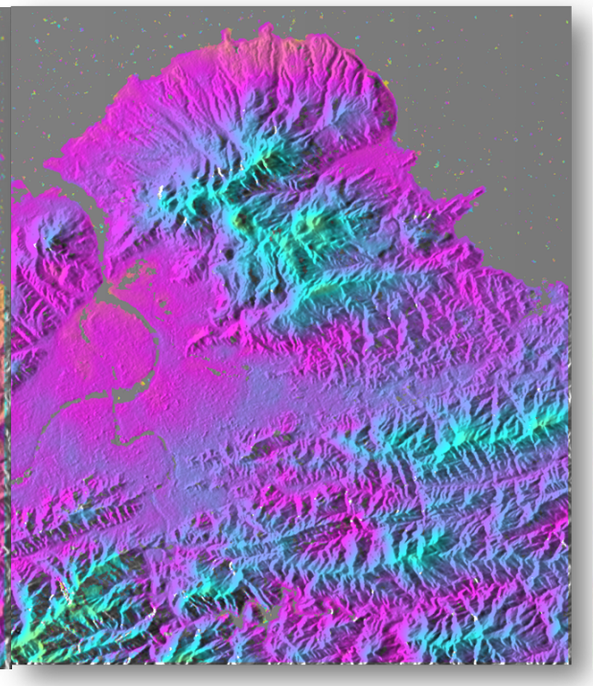
Orbit error



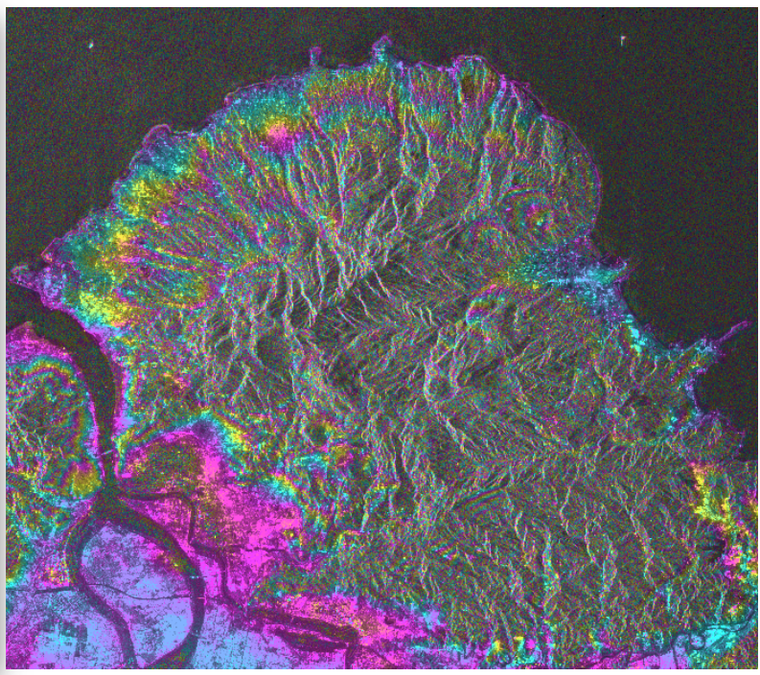
Unwrapping error







Atmospheric artifacts



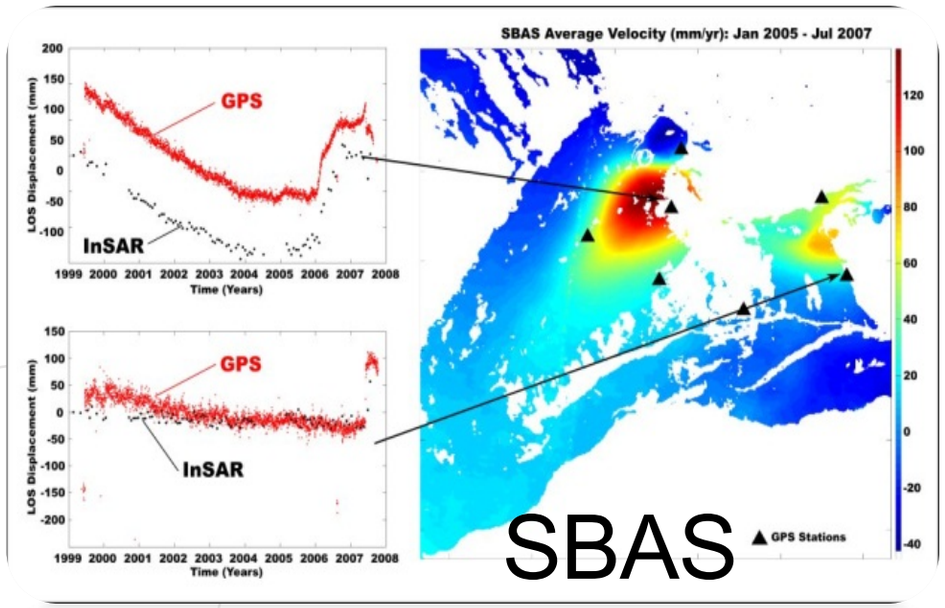
Noise

Multi-temporal InSAR

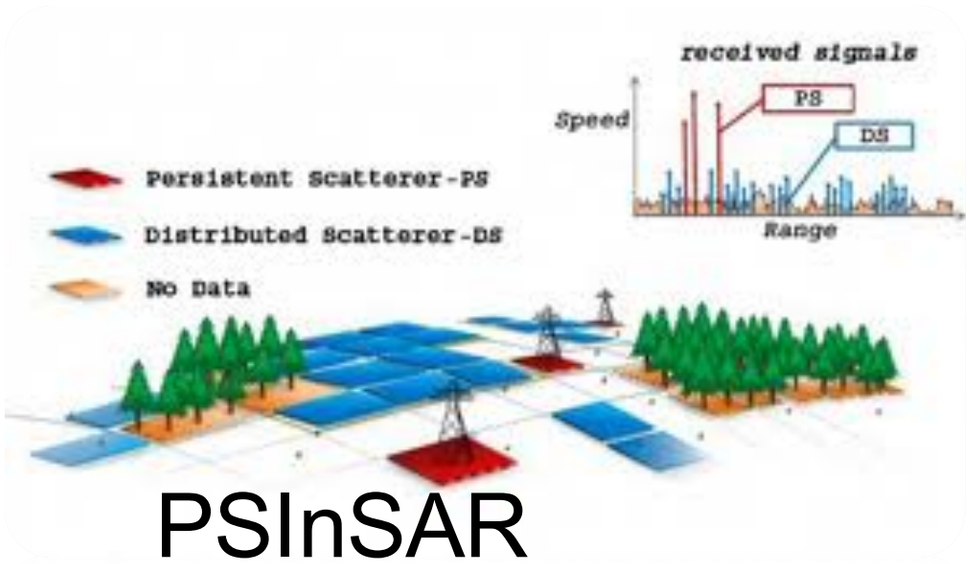
Data utilization: A stack of SAR images over the same area
Products: Refined DEM; linear deformation rate and time series

Overcome the limitations of conventional InSAR by

Using coherent points ------> the noise term
Taking the DEM error as a parameter -----> DEM error term
Point pair as basic observation + filtering ----> APS and orbit error



SBAS (IREA)



PSInSAR (TRE)

現有MTInSAR技術的缺陷

- 相關點的選取依賴於閾值，閾值的確定依賴於用戶的經驗
- 均需要解算模糊度，然後解算成功率難以保證
- 難以分離長波長形變信號及軌道誤差
- 缺乏有效的精度評定方法

Techniques	Interferogram type	Observation type	Observation with ambiguities	Point selection	Parameter solver
PSInSAR	Single-master	Arc (point pair)	Yes	Amplitude dispersion index	Model coherence maximization
STUN	Single-master	Arc (point pair)	Yes	Signal to clutter ratio	Weighted integer least squares
StaMPS	Single/multi-master	Arc (point pair)	Yes	Phase stability	3D unwrapping
SBAS	Multi-master	Point	Yes	Coherence	Minimum norm least squares
CPT	Multi-master	Arc (point pair)	Yes	Coherence & amplitude dispersion index	Model coherence maximization

TCPInSAR

○提出新的相關點選取方法，以克服現有方法的局限

○設計新的參數估計策略，以解決模糊度難以精確求定的問題

○開發新的聯合估計模型，可以同時解算多種參數，以實現信號和誤差的精確分離.

○探索評定InSAR測量精度的方法

○InSAR及GPS資料的集成

TCP-InSAR

Zhang, L., Ding, X.L, Lu, Z., Jung, H.S., Hu, J., Feng, G.C. (2014), A novel multi-temporal InSAR model for joint estimation of deformation rates and orbital errors, *IEEE Trans. Geos. Rem. Sens.*, 52(6):3529-3540.

Zhang, L., Ding, X.L, Lu, Z. (2011) Ground settlement monitoring based on temporarily coherent points between two SAR acquisitions, *ISPRS Journal of Photogrammetry and Remote Sensing*, 66(1):146-152.

Zhang, L., Ding, X.L., and Lu, Z. (2011), Modeling the PSInSAR time-series without phase unwrapping, *IEEE Trans. Geos. Rem. Sens.*, 49(1):547-556.

Zhang, L., Ding, X.L., and Lu, Z. (2011), Deformation rate estimation on changing landscapes using Temporarily Coherent Point InSAR, Fringe2011, Italy.

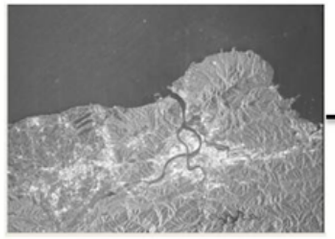
Zhang, L., Ding, X.L., and Lu, Z. (2013), Fusion of GPS and InSAR Measurements by Constrained Least Squares: an Alternative Way for the Suppression of Atmospheric Artifacts, 3rd IWIDF, Changbaishan, Jilin.

TCPInSAR

- TCPInSAR 可以識別多類相關點（包括永久散射體和分散式散射體）
- 可以提供大區域高精度形變速率和形變序列產品
- 可以可靠分離長波長形變信號和軌道誤差
- 可以在無需DEM的情況下，從高解析度資料中提取形變信號

TCP-InSAR

處理後原始影像



1.計算影像間
基線資訊

水平基線　時間基線
各影像對時間　垂直基線

20061231-20070215	1273	1736.7068	46
20061231-20070818	1628	2267.7417	230
20061231-20071003	1913	2292.3064	276
20061231-20080103	1960	2472.4997	368
20061231-20080520	2540	3335.6417	506
20061231-20080705	1311	1412.2969	552
20061231-20080820	-139	-521.4834	598
20061231-20081005	241	338.1482	644
20061231-20090105	582	761.0128	736
20061231-20090708	474	641.5214	920
20061231-20090823	1571	1783.5357	966
20061231-20091008	1362	1959.1132	1012
20061231-20100108	1524	2045.3355	1104
20061231-20100223	1897	2583.4527	1150
20061231-20100711	2047	2611.1396	1288
20061231-20100826	2233	2981.8876	1334
20061231-20101011	2359	3183.0815	1380
20061231-20101126	2397	3154.6131	1426
20061231-20110226	2880	3877.5104	1518
20070215-20070818	355	531.0840	184
20070215-20071003	639	555.7228	230
20070215-20080103	686	735.8763	322
20070215-20080520	1266	1599.1595	460

2.篩選影像對

篩選後未使用影像

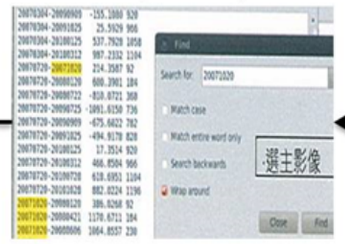
```
**** threshold used*********
perpendicular baseline:      1200 (m)
minmum interval:             46 (day)
maxmum interval:             1200 (day)
*****************************************
total image pairs: 68 shortbaseline
total images selected: 16 images
all images: 17 images_ori
images not being used

20070117
*****************************************
```

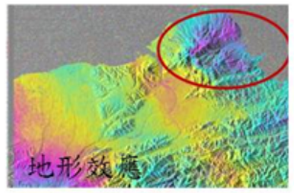
3.統一轉換格式

將FBD統一格式
轉為FBS

選擇主影像



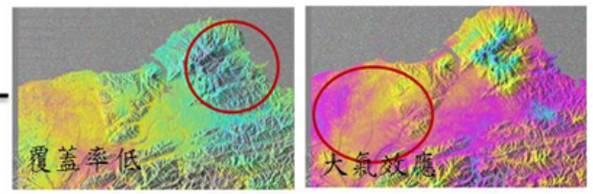
剔除有問題影像

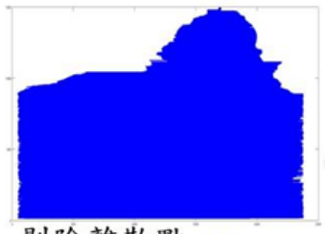


4.空間對位配準

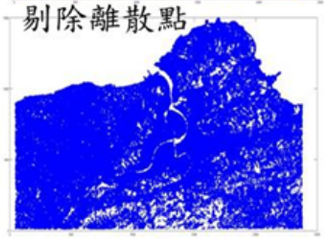
5.計算相位差

6.篩選TCP



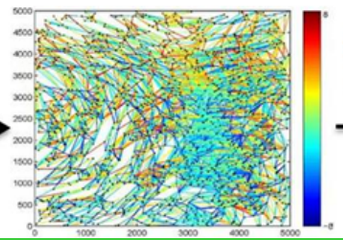


剔除離散點



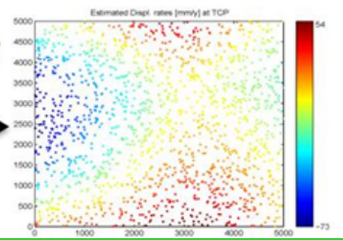
7.相位重建

三角網定義的鄰近點(相位資料)



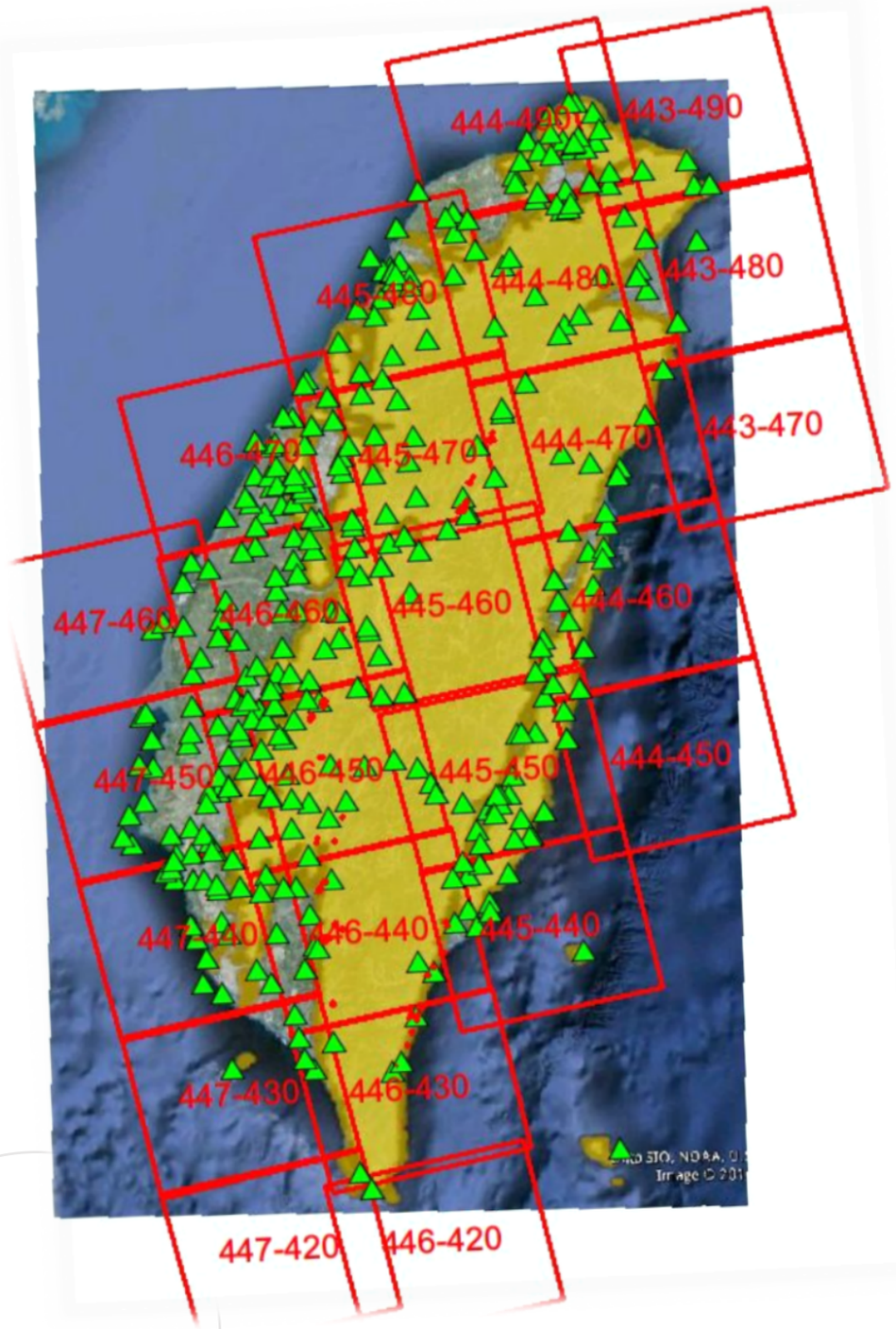
8.解算TCP平均
變化量

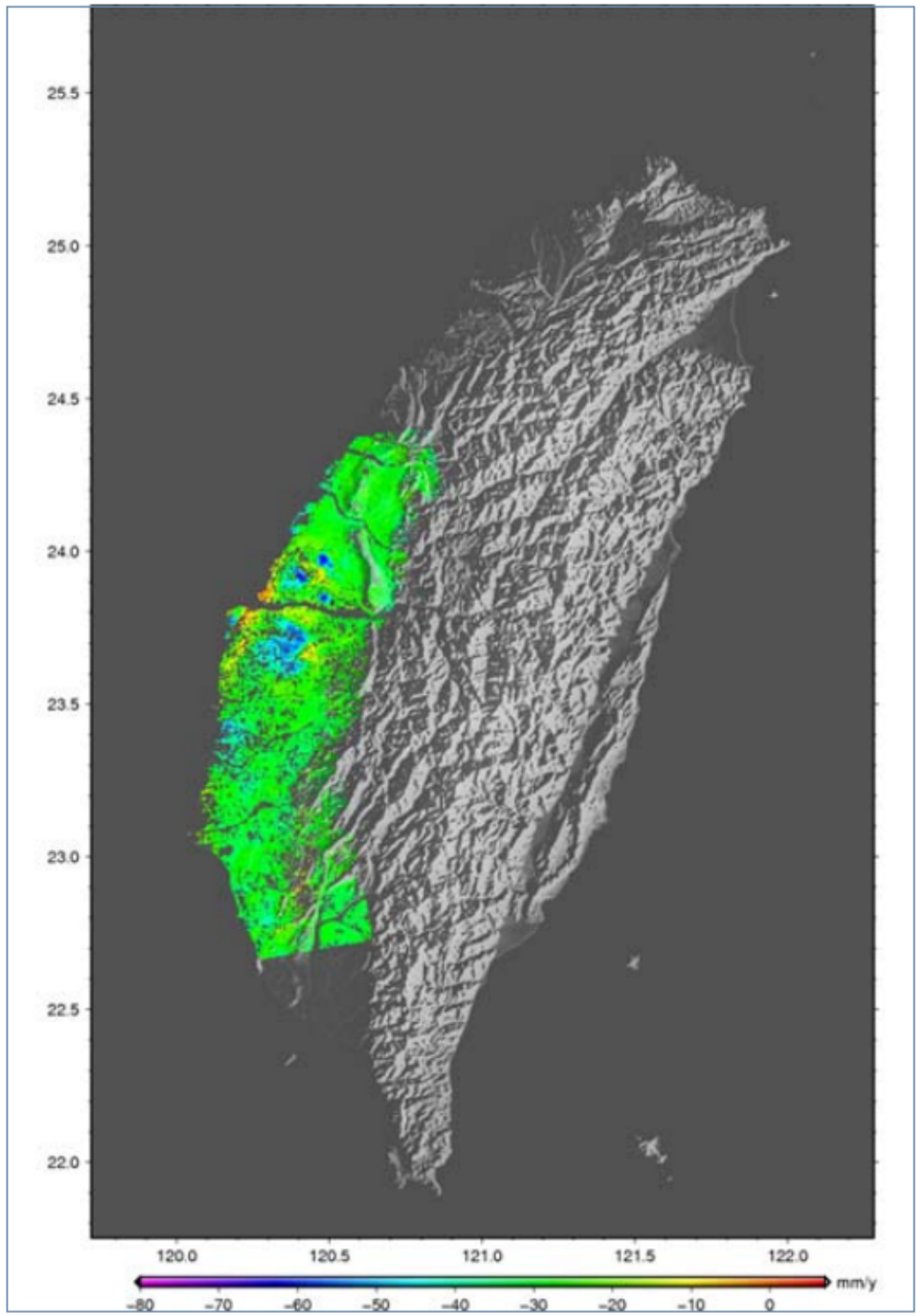
解算出地表位移資訊(平均速率)



Application

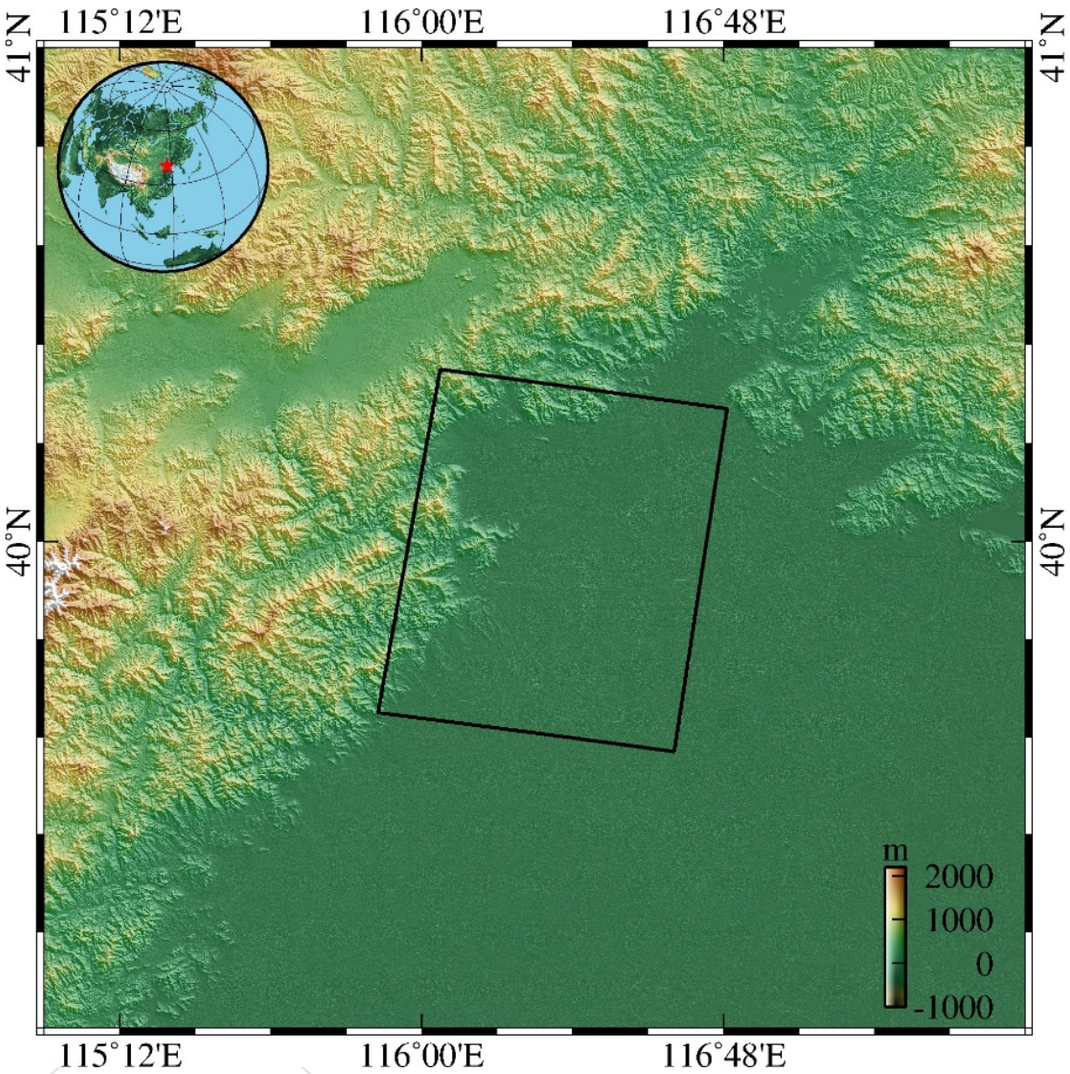
Subsidence

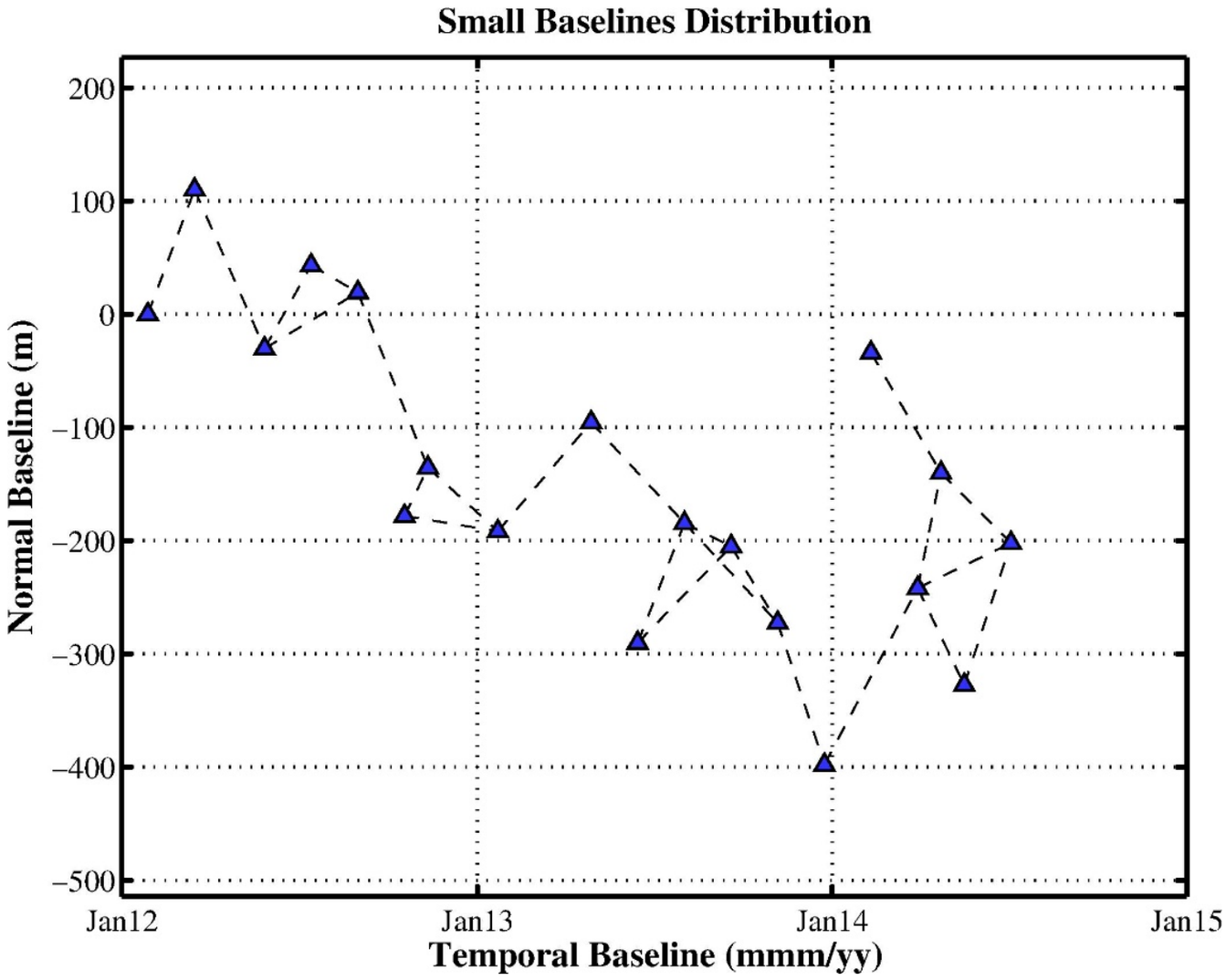




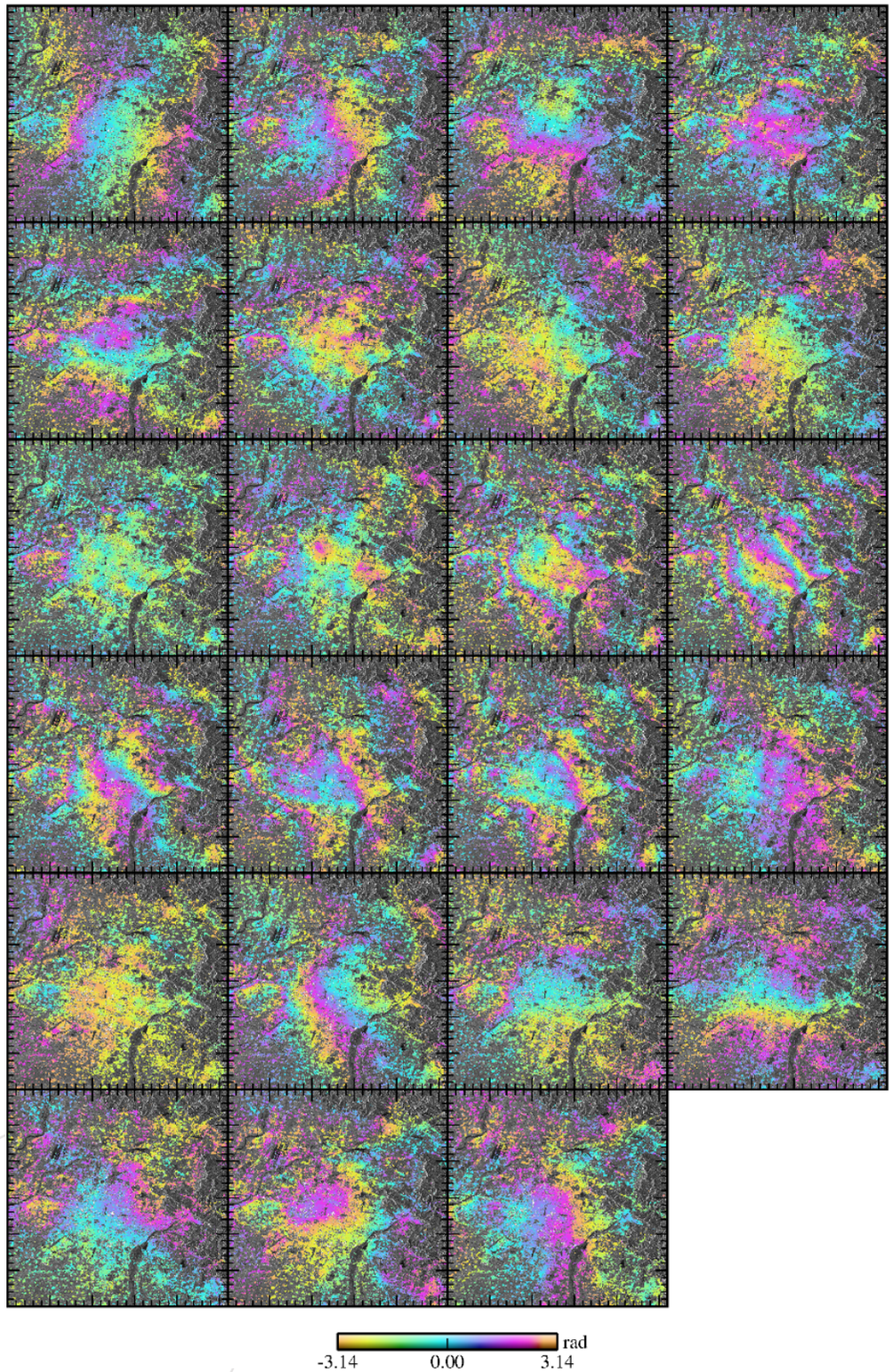
Application

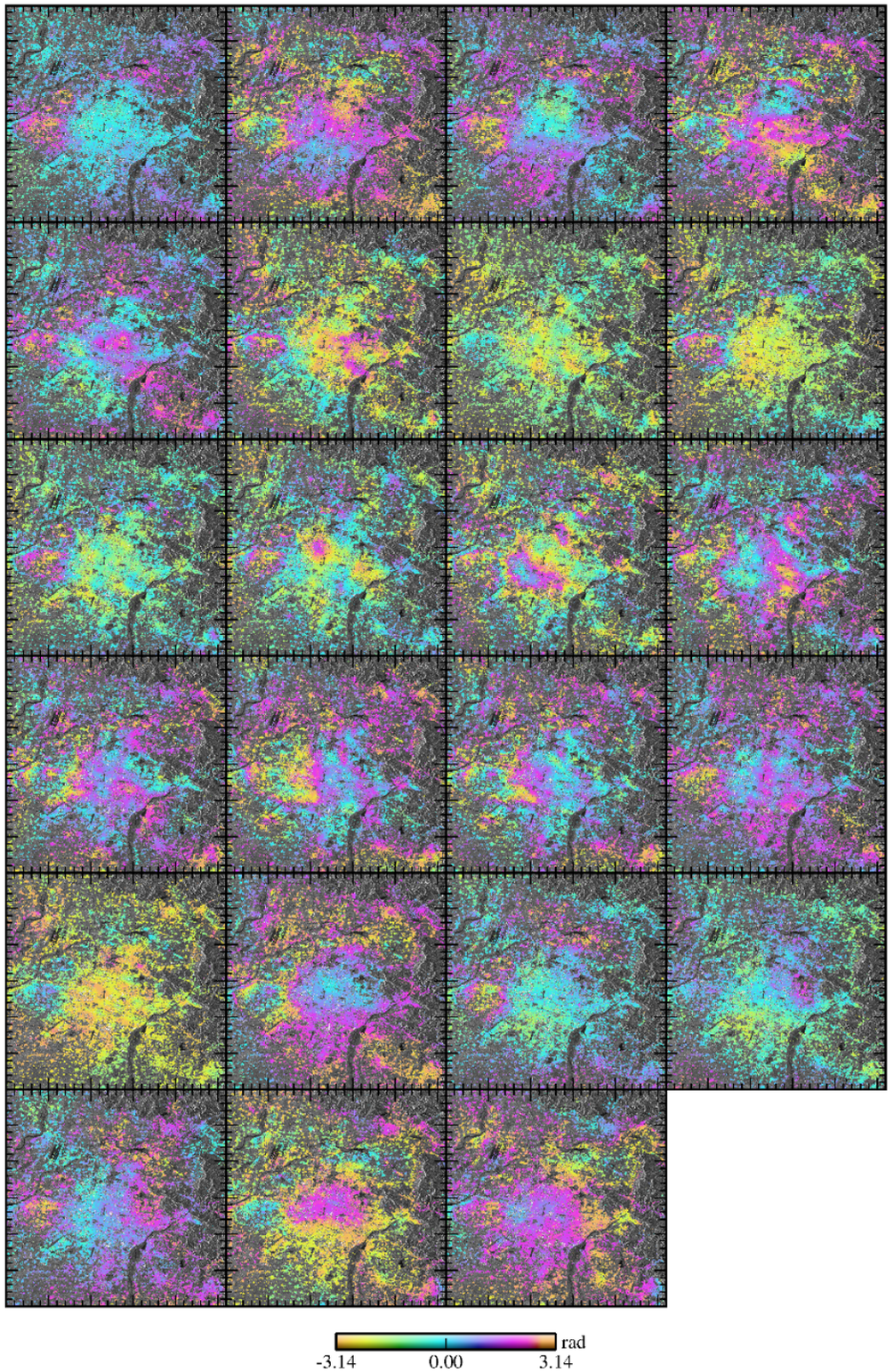
Radarsat-2: 20120128-20140704





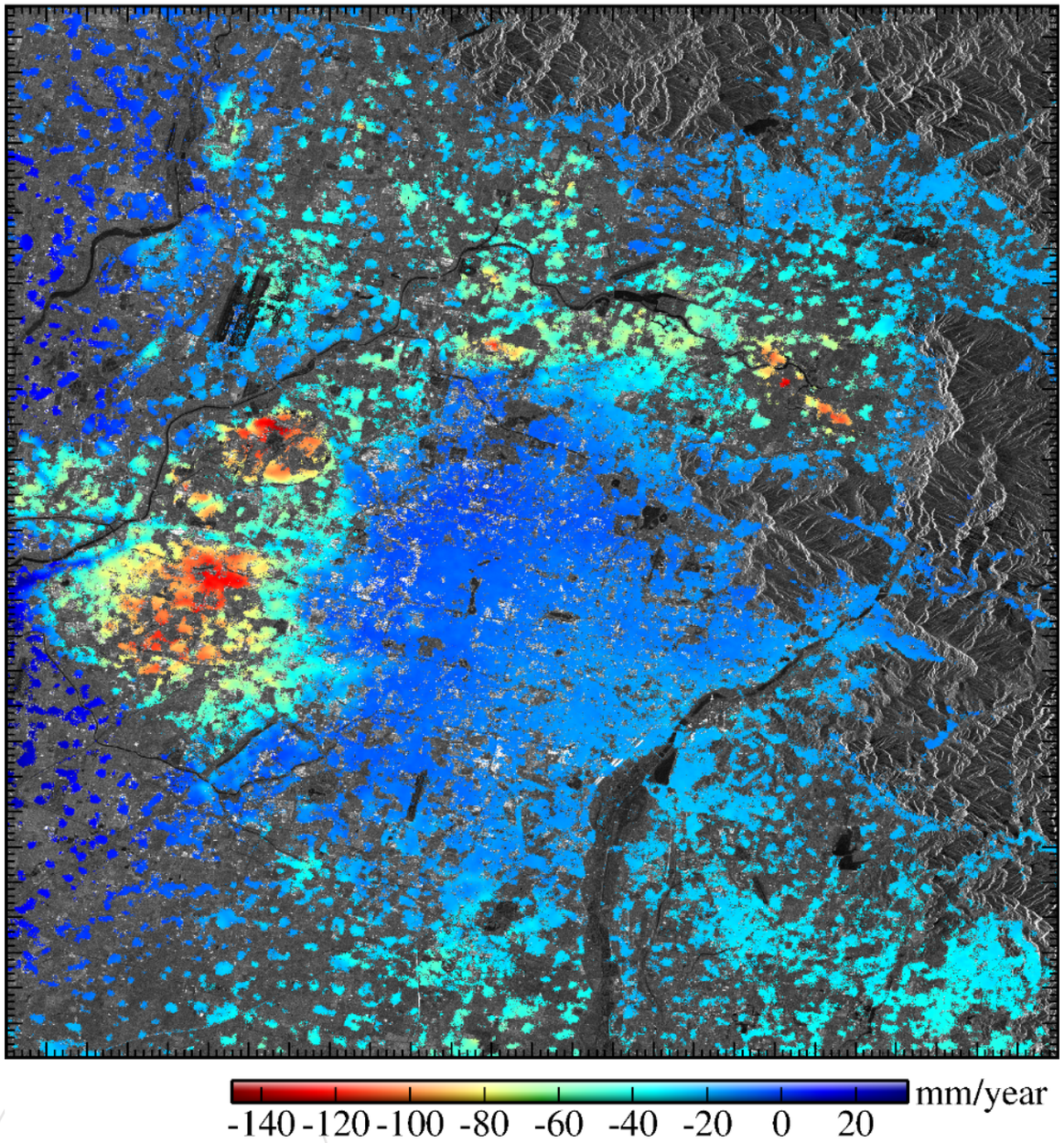
Application



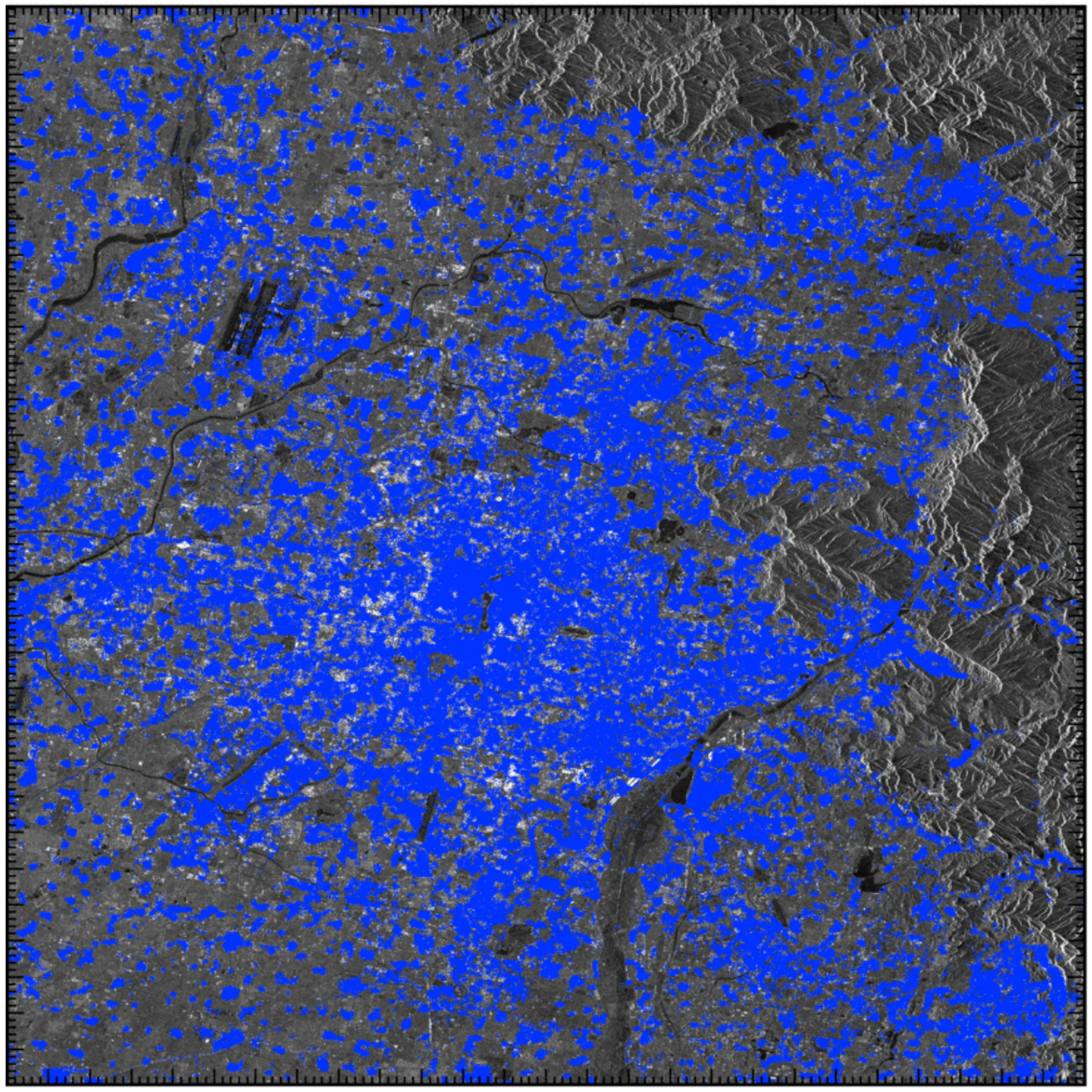


Application

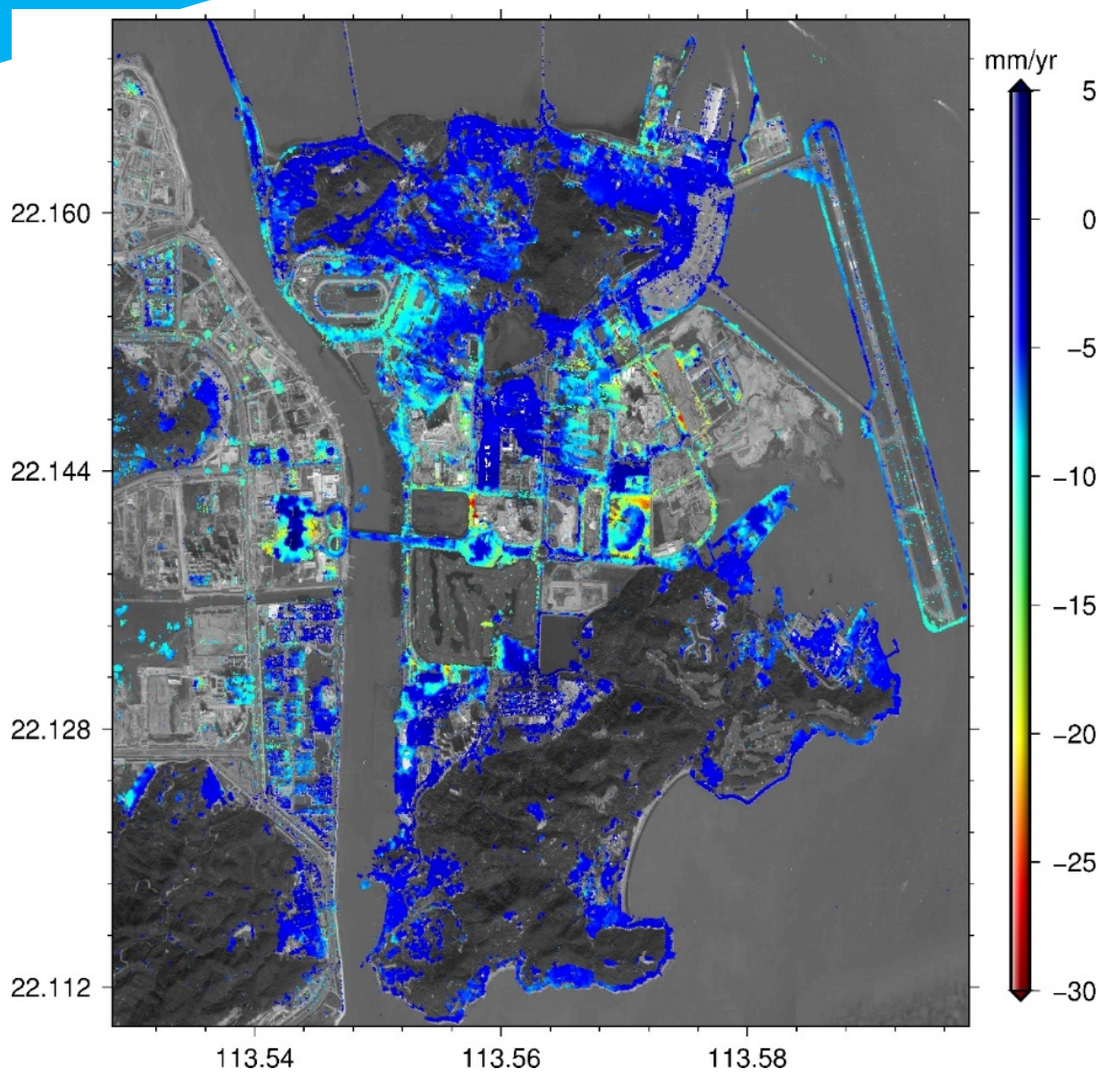
Deformation_Rate

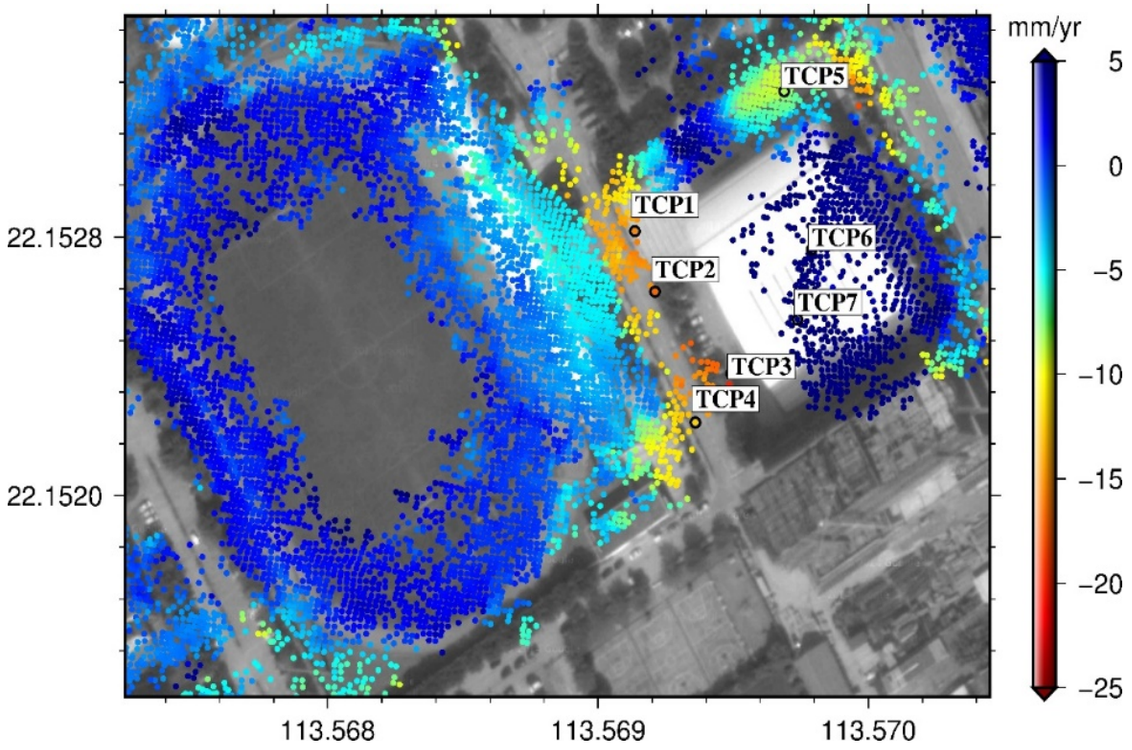


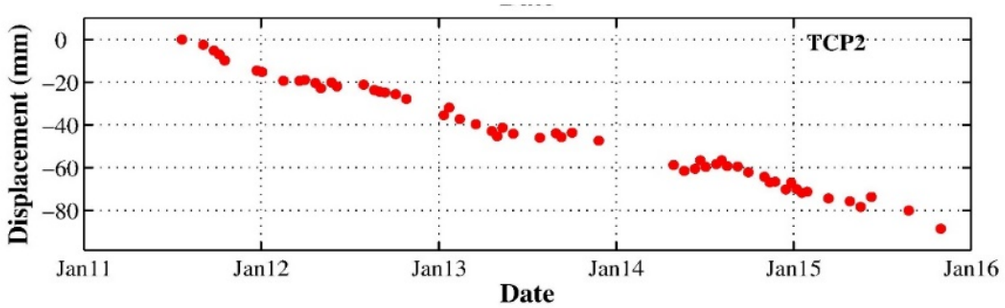
SLC20120128

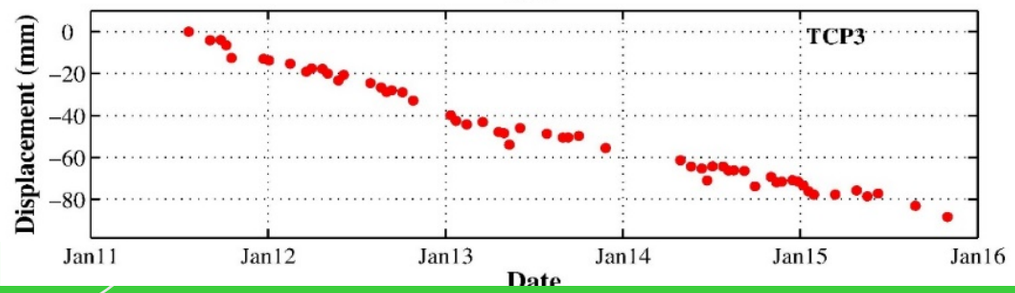


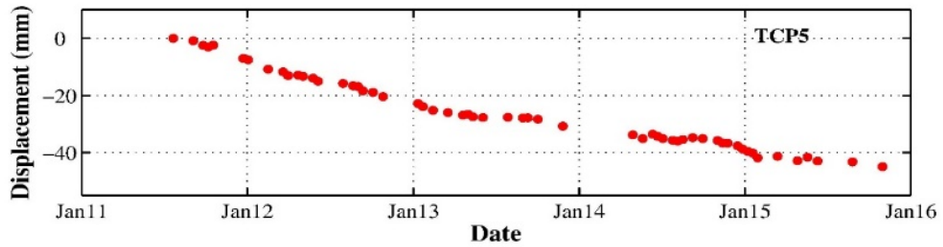
Application

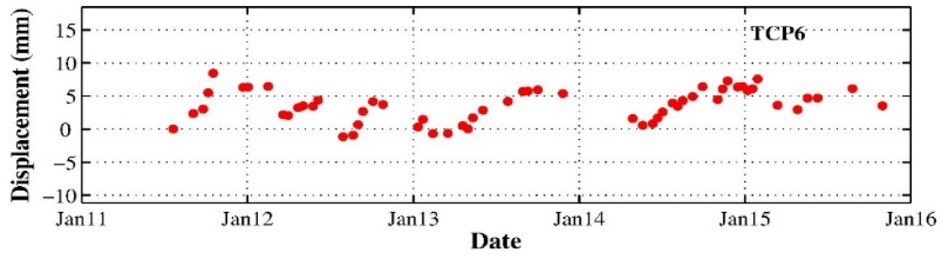


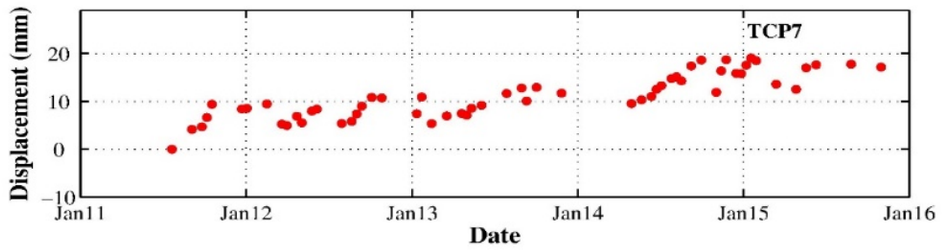




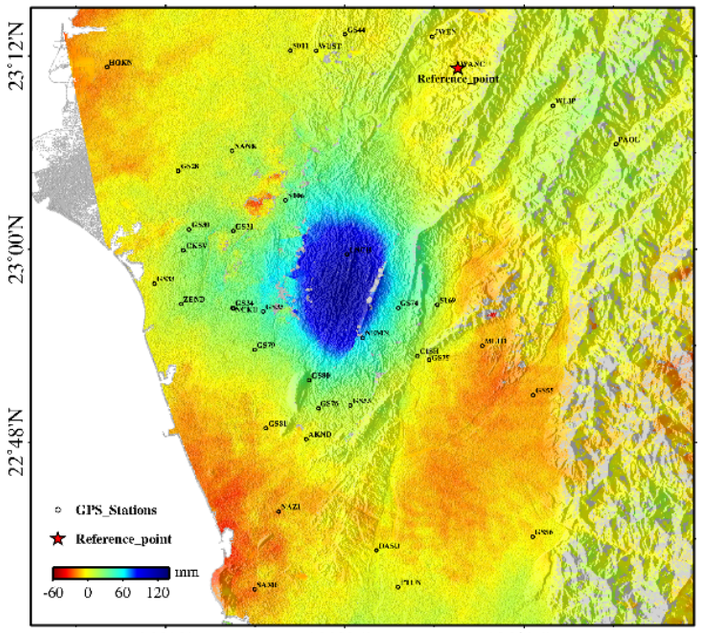


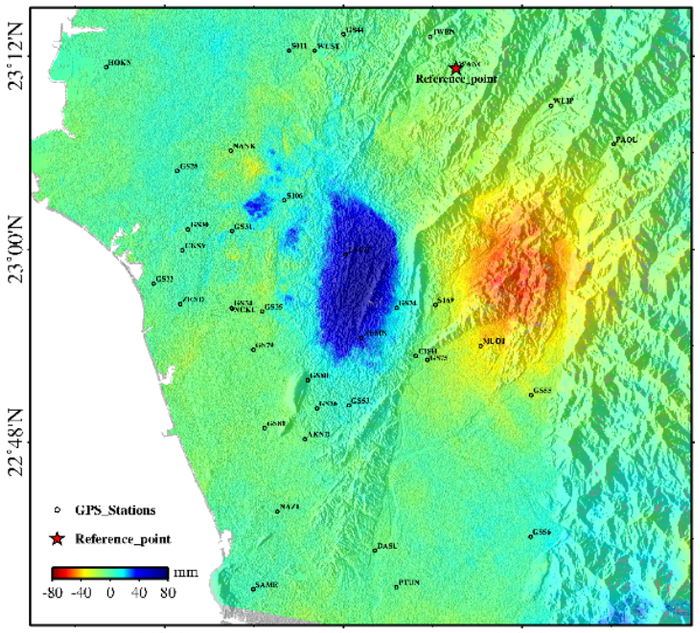


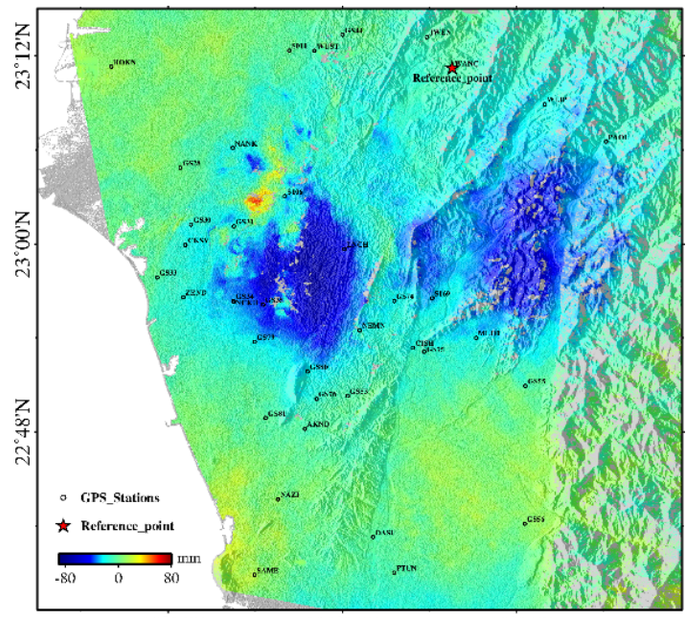


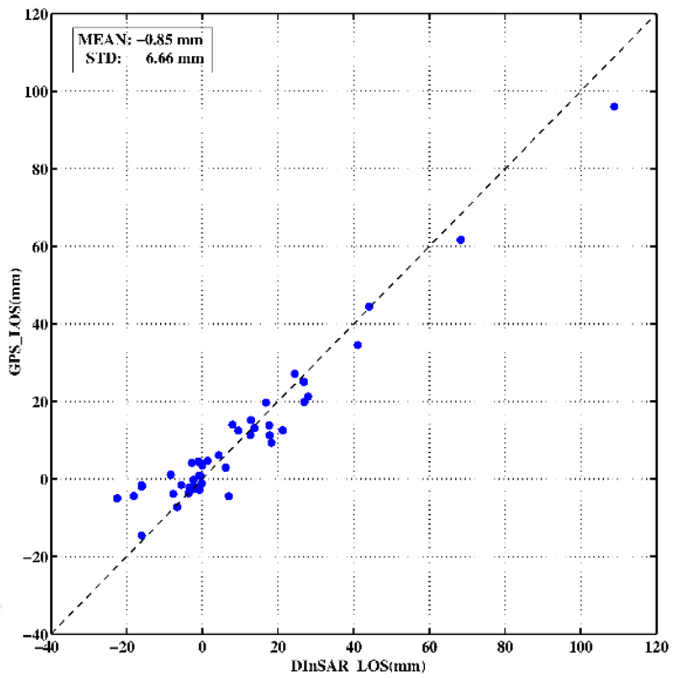


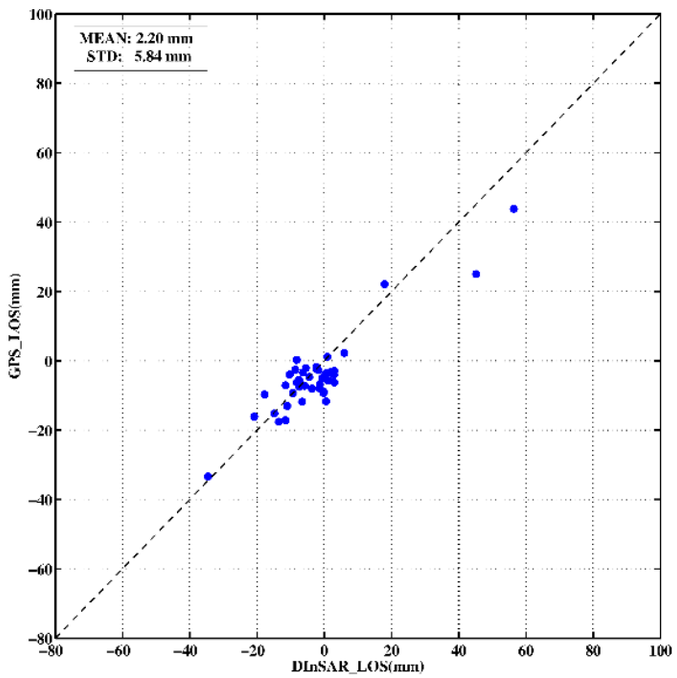
Application

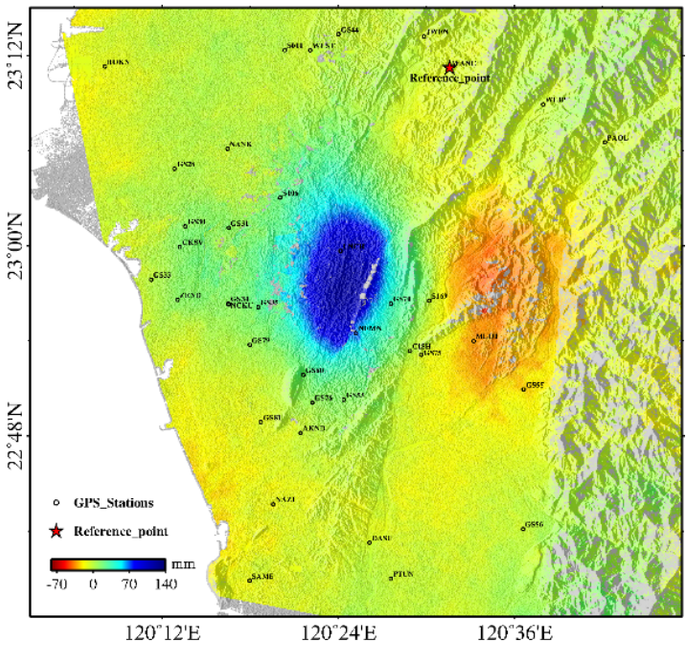












Application

Okmok

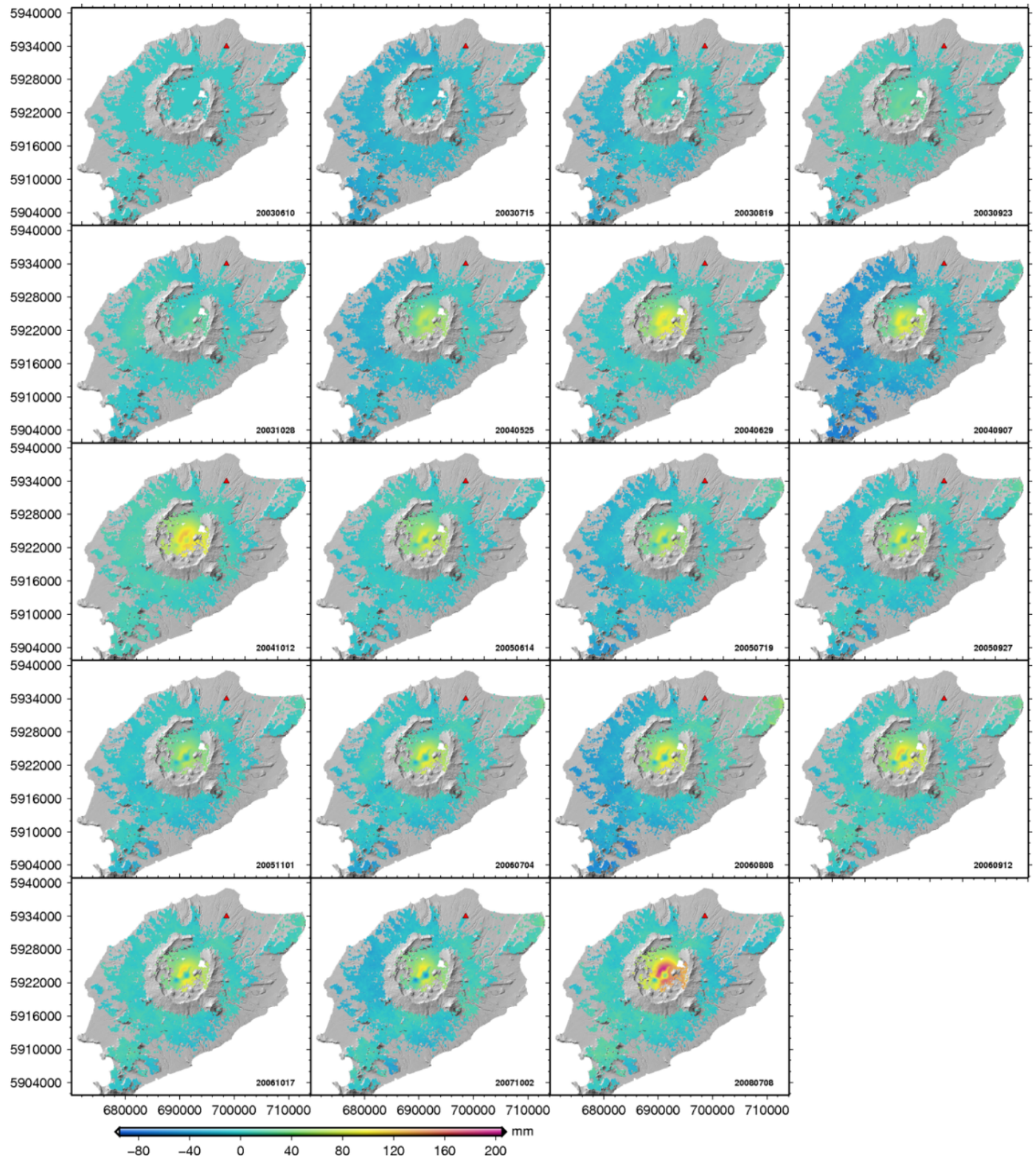
Okmok火山形變序列

20030610

↓

20080708

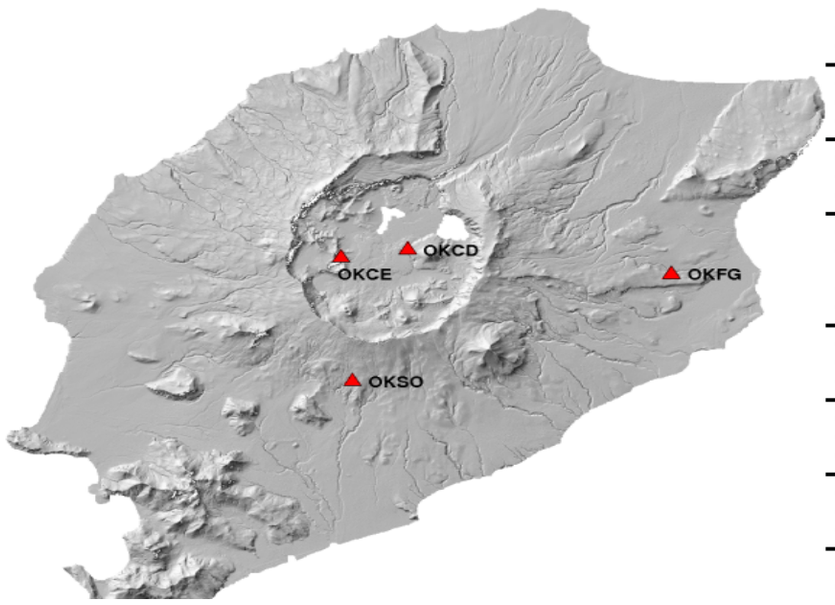
爆發時間:
20080712

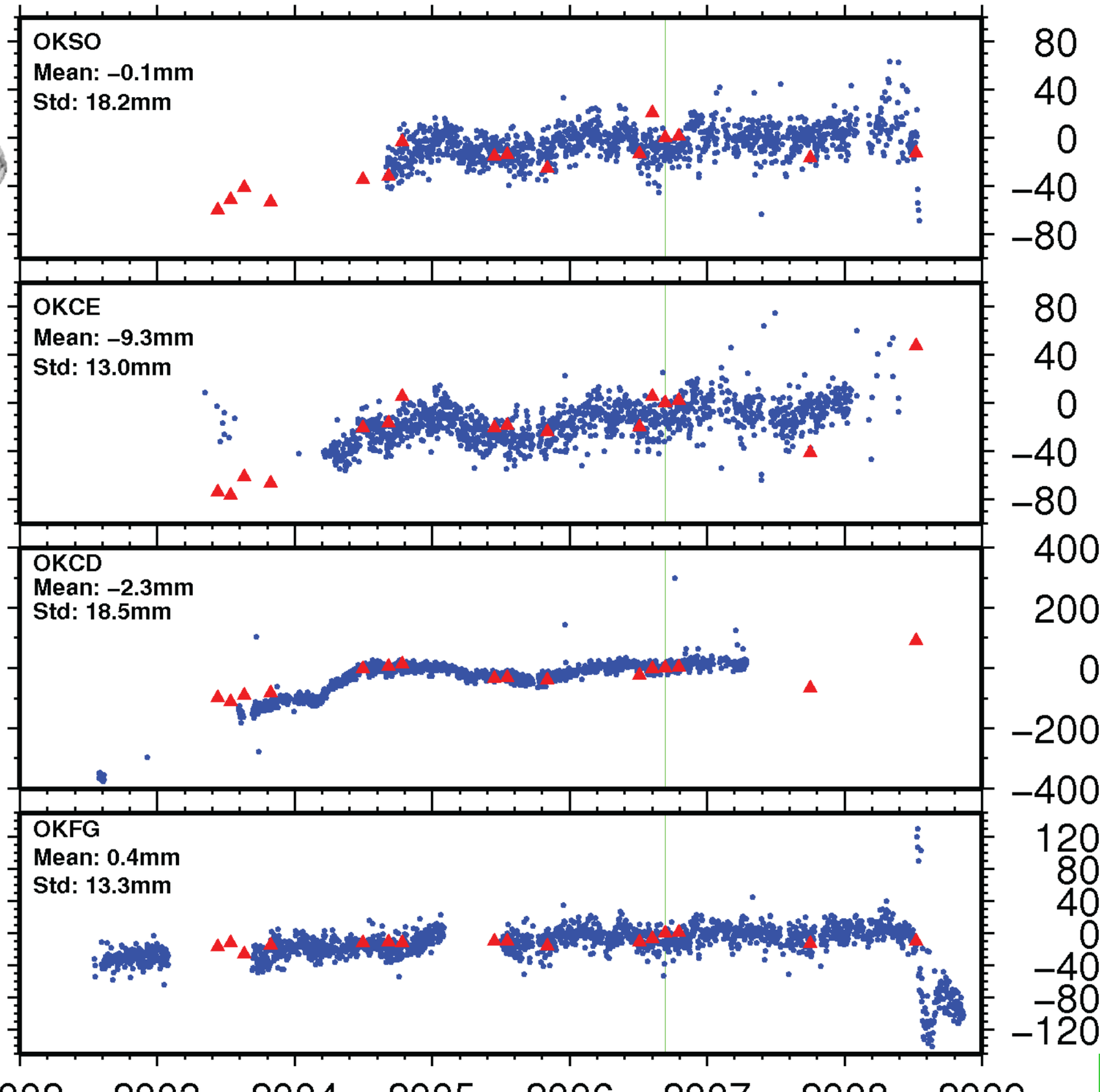


Zhong Lu and Daniel Dzurish(2014), InSAR imaging of Aleutian Volcanoes: Monitoring Volcanic Arc from Space

Application

Tianjin

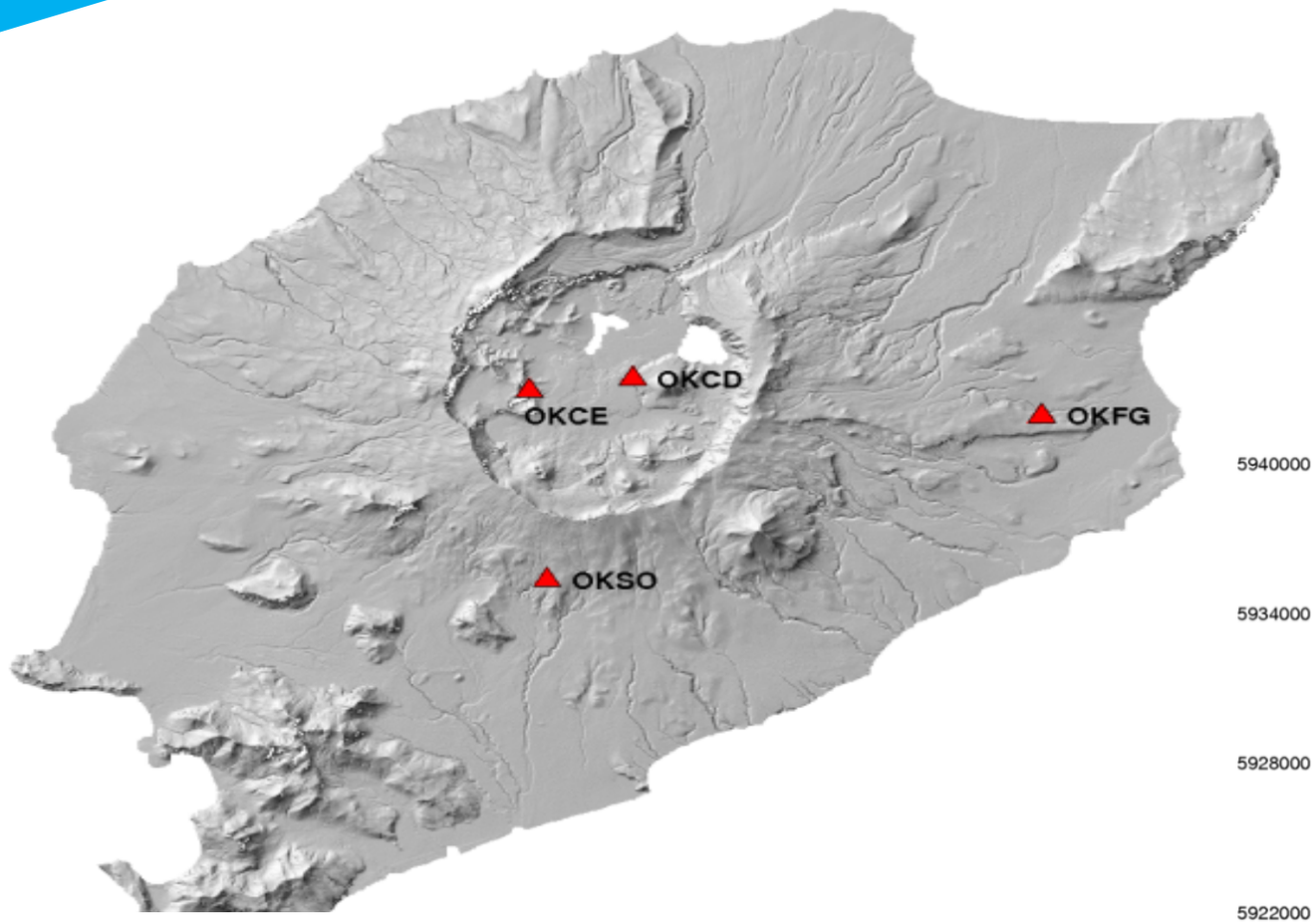




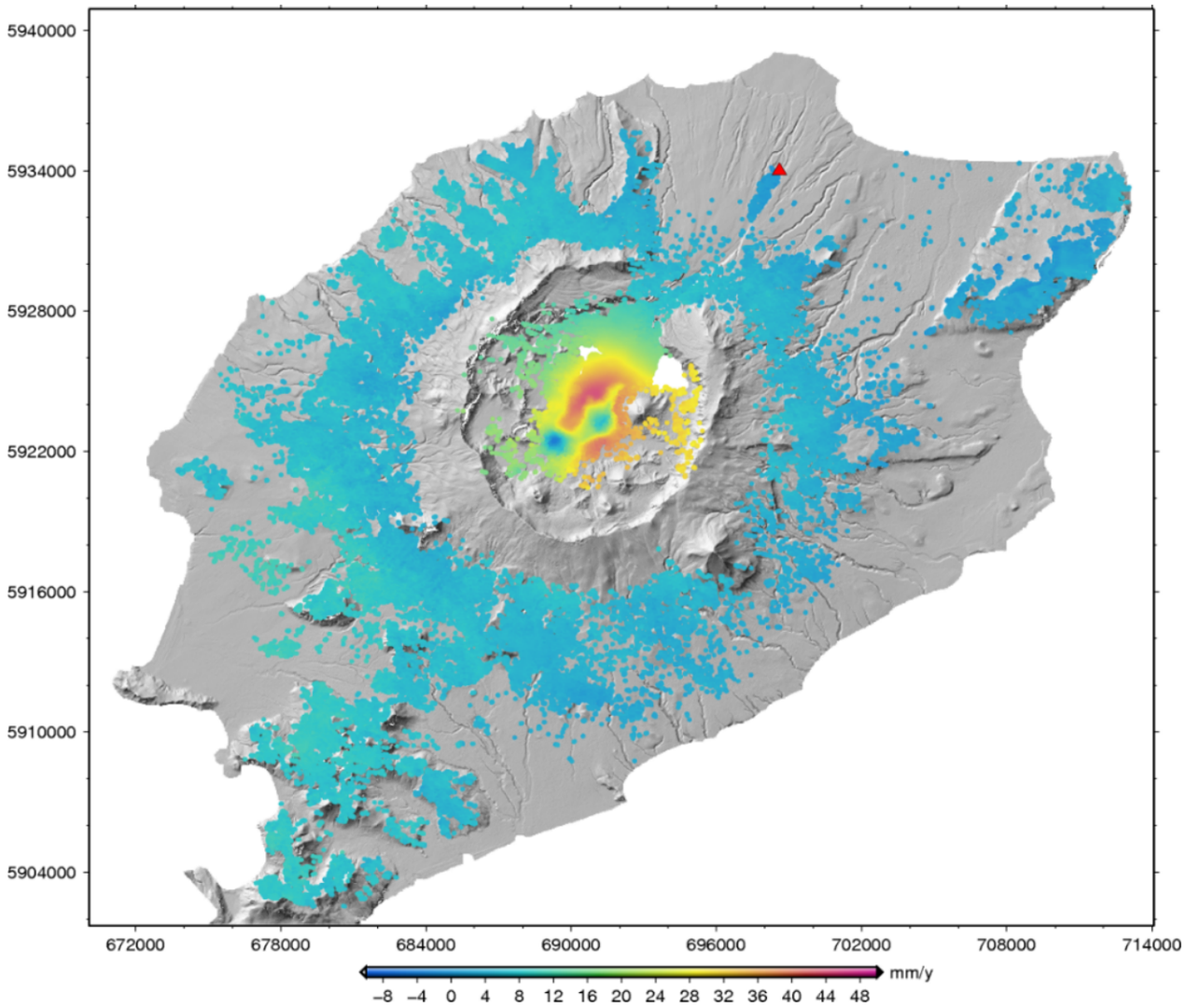
與GPS資料的比較

Application

Okmok



形變速率



This work is funded by the Soil and Water Conservation Bureau," Monitoring and Analysis of Ground Deformation in Large-Scale Potential Area Using SAR Satellite Imagery", 106 -11.10.2-S2.

Thanks for your attention