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THE ESA/MOST DRAGON IV PROJECT: DETECTION AND INTERPRETATION OF TIME EVOLUTION OF COSTAL ENVIRONMENTS THROUGH INTEGRATED DINSAR, GPS AND GEOPHYSICAL APPROACHES.

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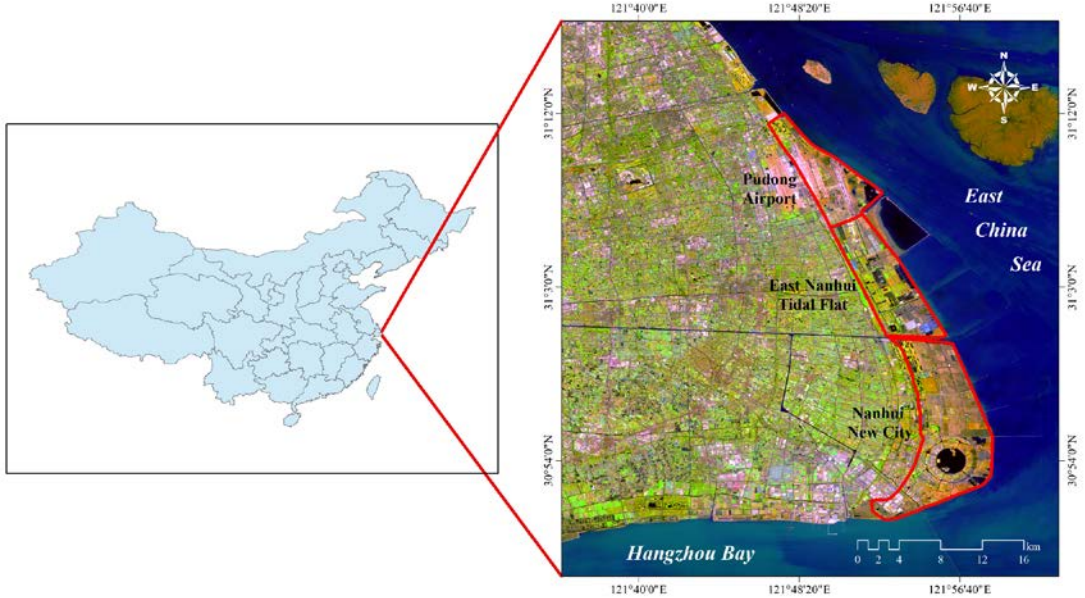
Summary

- Recent InSAR Results Achieved on Shanghai area
- Insights on present state of deformation of Shanghai
- About Sea Level Rise: Experiments
- InSAR Results on Pearl River Delta
- Future Achievements

Shanghai Area

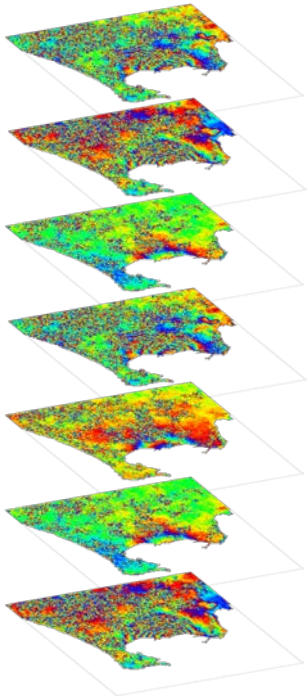


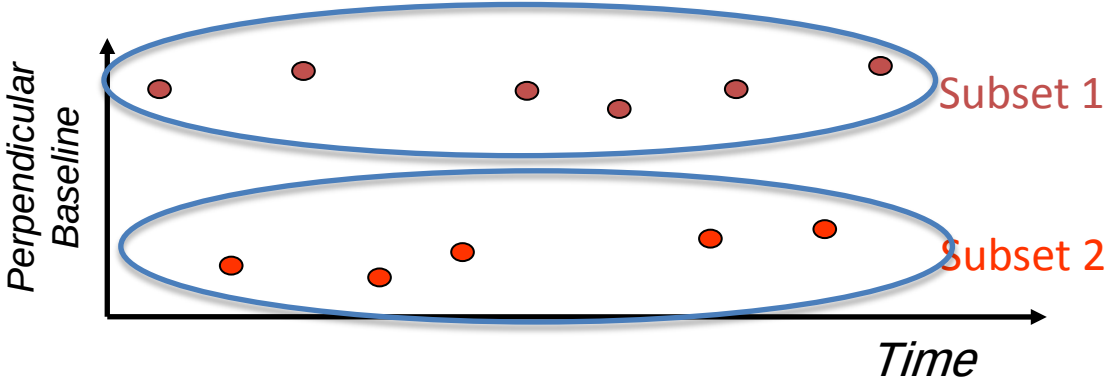
A sentinel-2 image, collected on March 2017,showing the study area.

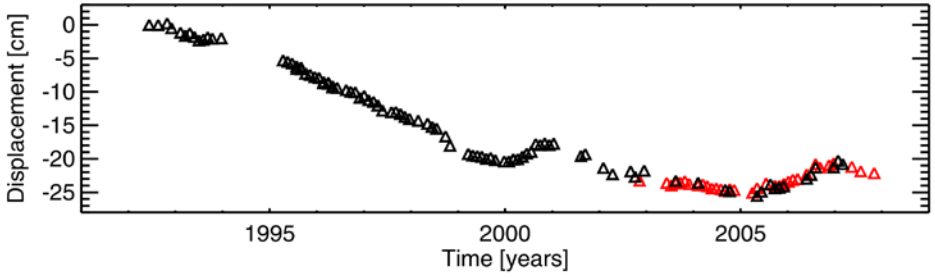
Reclaimed area in east coast of Shanghai:

- Located in the east coast of Shanghai, (121.75~122.0E, 30.85~31.20N);
- Mainly including Nanhui New City, East Nanhui Tidal Flat, and Pudong International Airport.

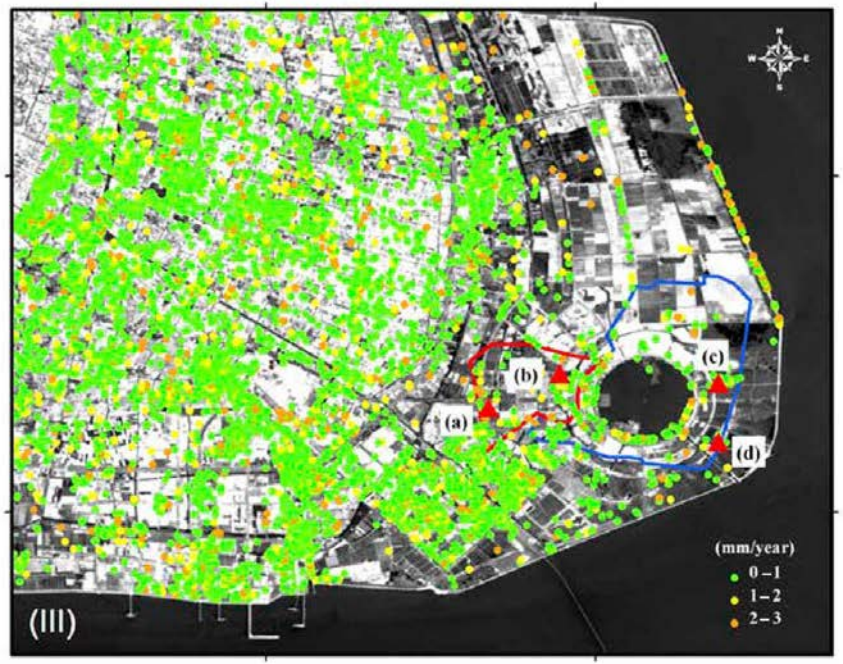
The Small BAseline Subset InSAR Technique: Example

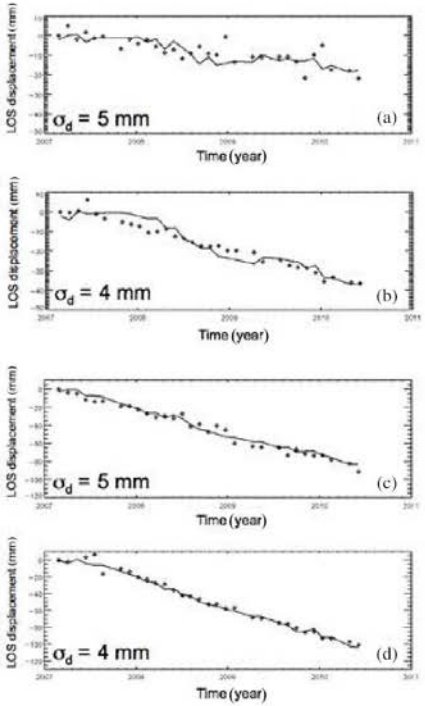






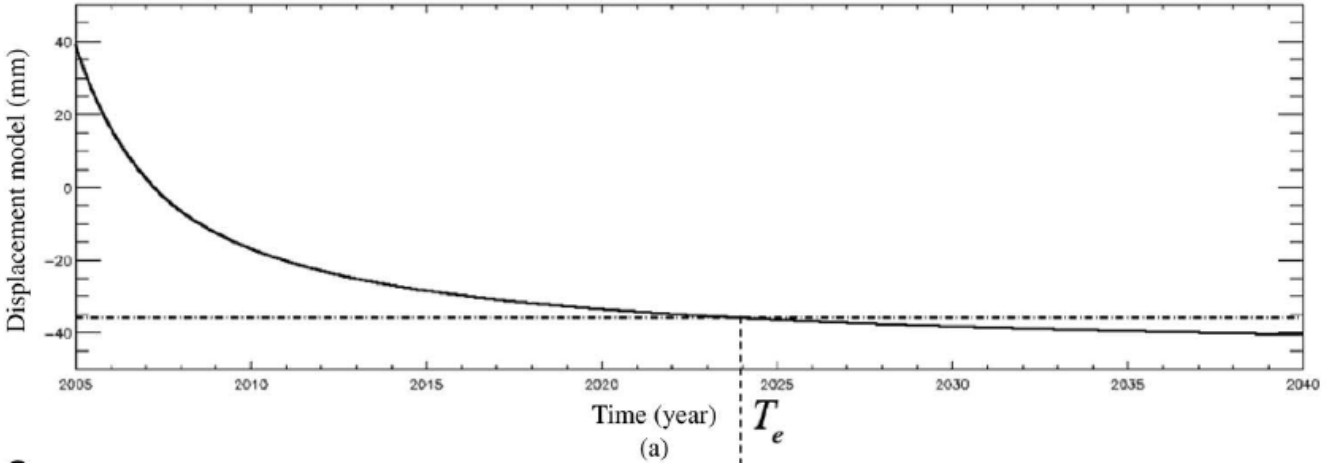
PS-SBAS Intercomparison Analyses on Shanghai





2007-2010
ASAR/ENVISAT
SAR DATA
WERE INDEPENDENTLY
PROCESSED

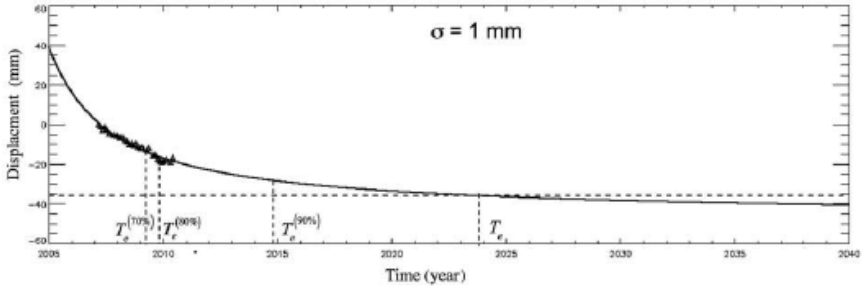
Deformation of Reclamation Platforms: A Model



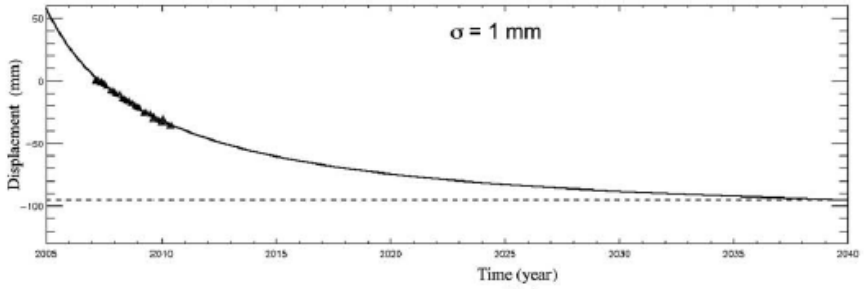
$$s_{CMT}(t) = S_m \frac{(t-\delta)^{\lambda}}{k^{\lambda} + (t-\delta)^{\lambda}}$$

InSAR Results: Shanghai

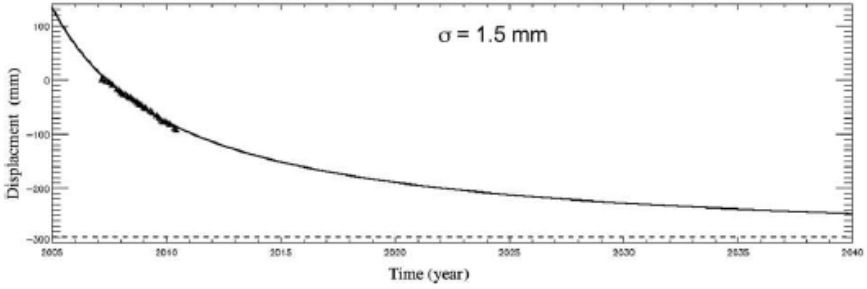
Deformation of Reclamation Platforms in Shanghai



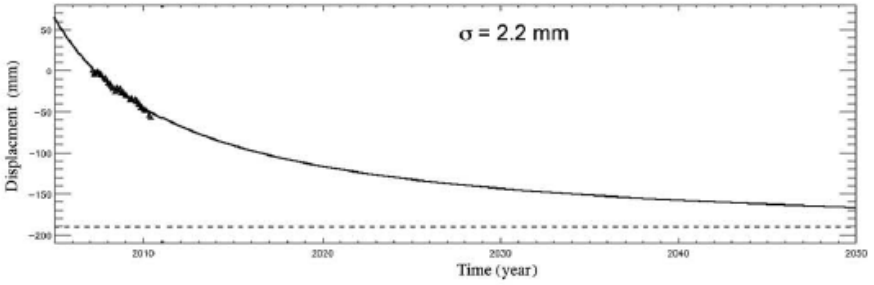
(a)



(b)

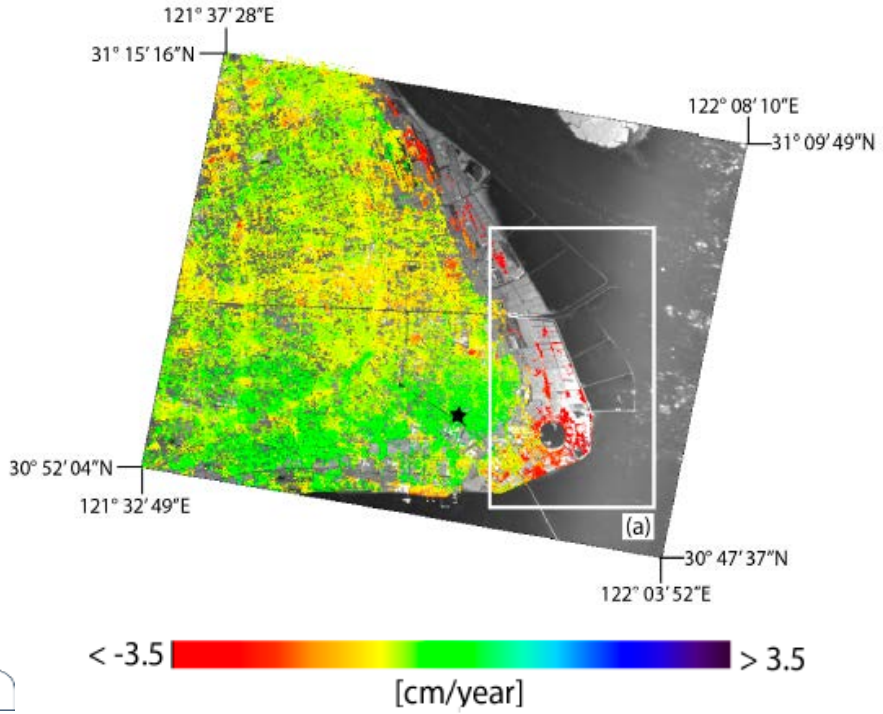


(c)



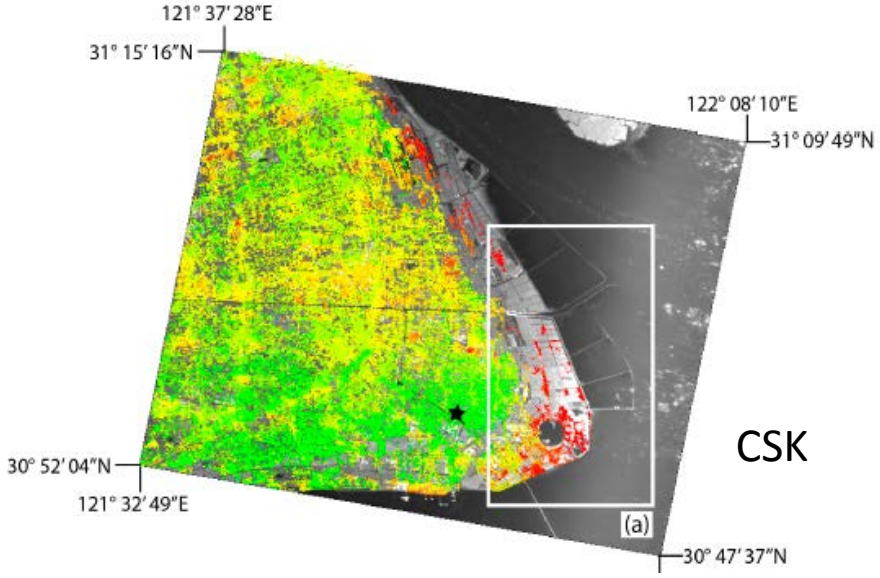
(d)

2014-2016 SBAS InSAR Result Using COSMO-SkyMED data

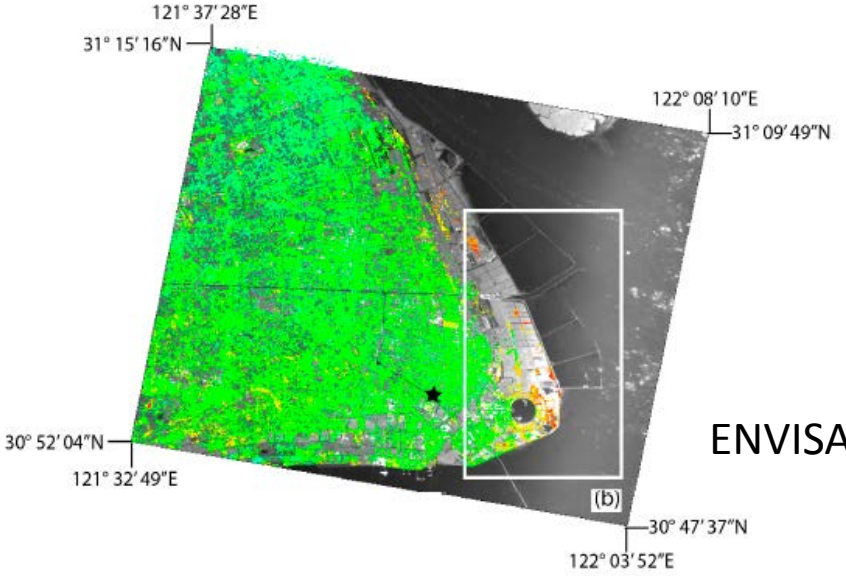


- The east coastal areas are with rapid ground subsidence.
- Lingang New City and the Pudong International Airport are both built on reclaimed areas.
- The maximum subsidence rate is 35mm/year.

On Combining COSMO-SkyMed and ENVISAT data



CSK



ENVISAT

Time-Gapped ENVISAT and COSMO-SkyMed Data

- ENVISAT data span the time interval between Febr. 2007 and March 2010
- CSK data are from March 2014 to March 2016

$$\mathbf{T}_1 = [T_{1,1}, T_{1,2}, \ldots, T_{1,Q_1}] \text{ and } \mathbf{T}_2 = [T_{2,1}, T_{2,2}, \ldots, T_{2,Q_2}]$$

- A Model has been used to combine the ENVISAT and CSK time-series

$$\mathbf{m} = \mathbf{m}(\mathbf{T}, S, k, \lambda, \delta) = S\frac{(\mathbf{T}-\delta)^{\lambda}}{k^{\lambda} + (\mathbf{T}-\delta)^{\lambda}}$$

Time-Gapped ENVISAT and COSMO-SkyMed Data

- LOS Time-series are firstly converted into vertical time-series

$$\mathbf{h} \cong \frac{\mathbf{d}}{\cos\vartheta}$$

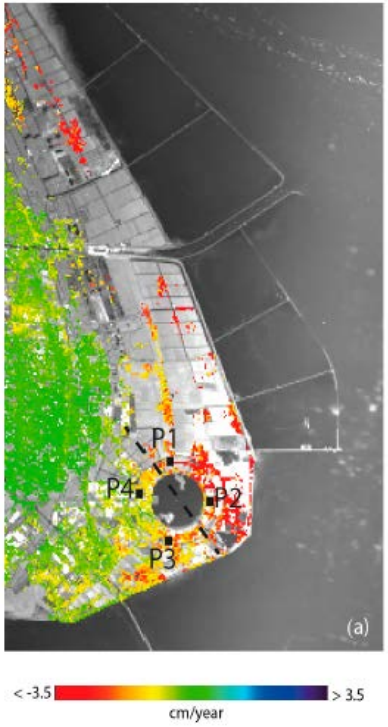
- The combined time-series are then searched for:

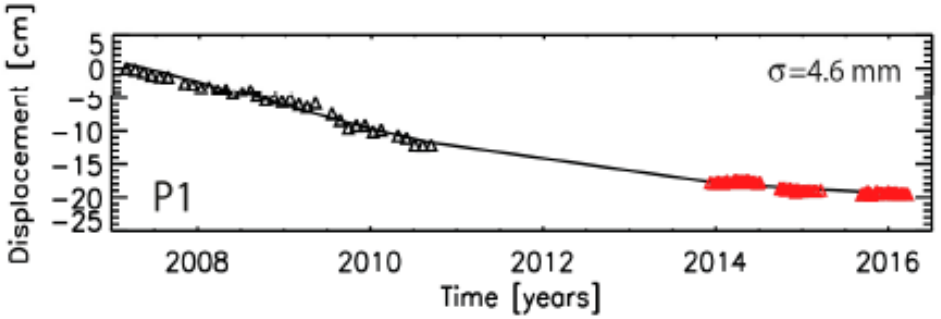
$$\mathbf{H}\left(\hat{h}\right) = \left[h_{1,1}, h_{1,2}, \ldots, h_{1,Q_1}, h_{2,1} + \hat{h}, h_{2,2} + \hat{h}, \ldots, h_{2,Q_2} + \hat{h}\right]$$

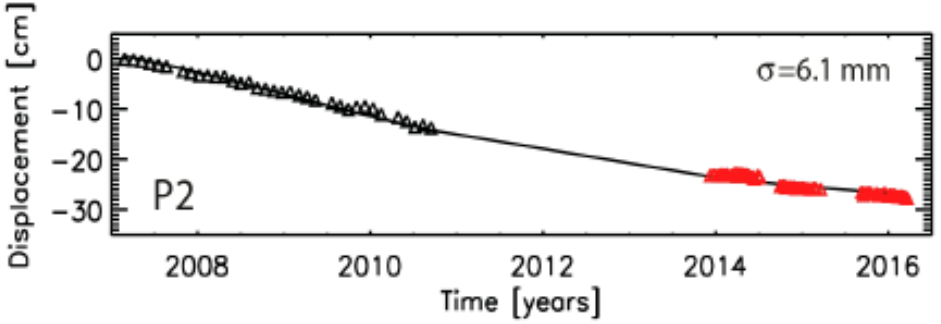
- The unknow bias $\hat{h}$ is found by solving the following non-linear problem

$$S, k, \lambda, \delta, \hat{h} = \arg\min\left[\left|\left|m - H\right|\right|_2\right]$$

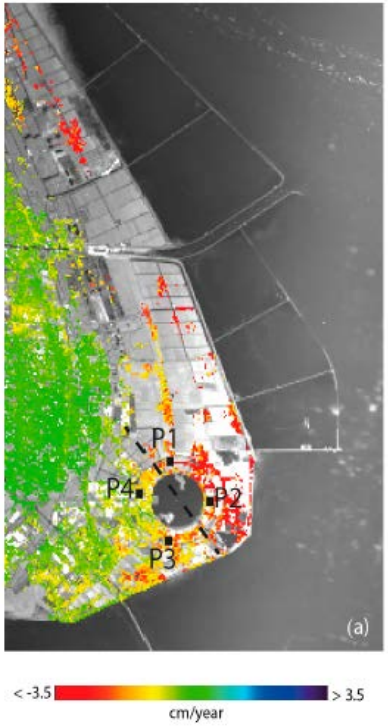
On Combining COSMO-SkyMed and ENVISAT data

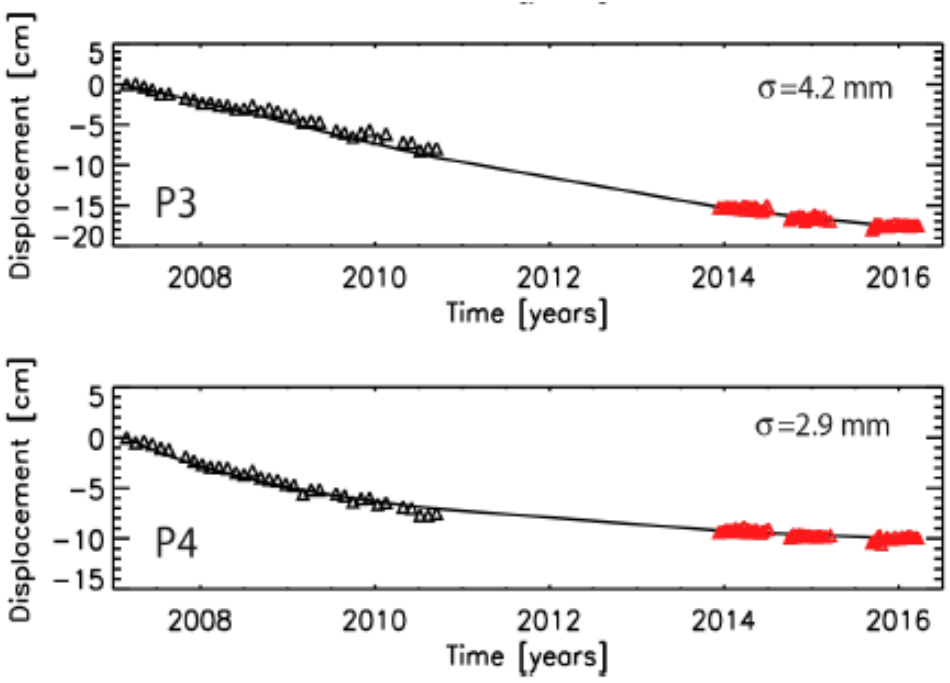






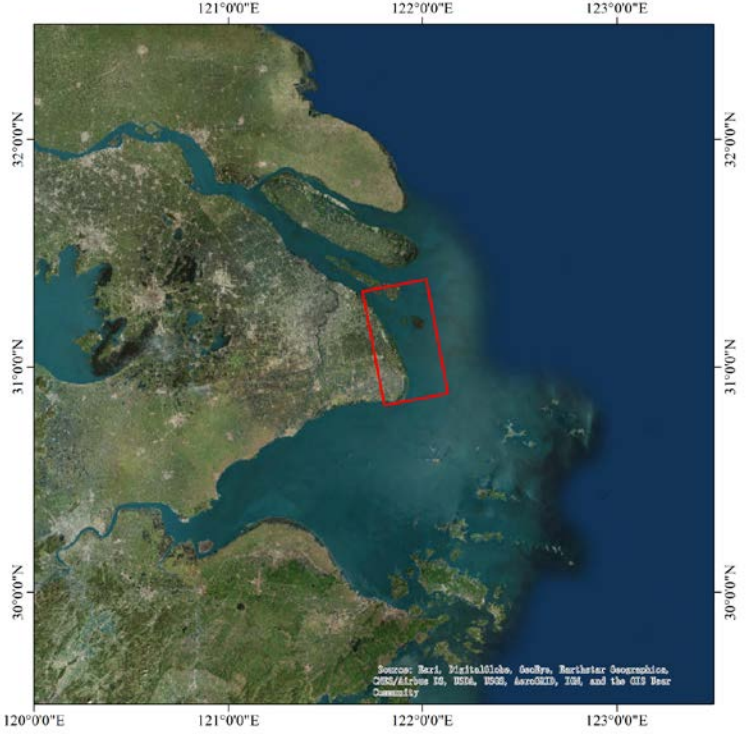
On Combining COSMO-SkyMed and ENVISAT data





InSAR Results on 2009-2010 TerraSAR-X data

- Frequency: 9.65GHz
- Product type: SLC
- Incidence angle: 20° - 45°
- Sensor mode: Stripmap(SM)
- Polarisation: HH
- Orbit direction: **Ascending**



- **Differential Interferogram generation**

  Parameters setting

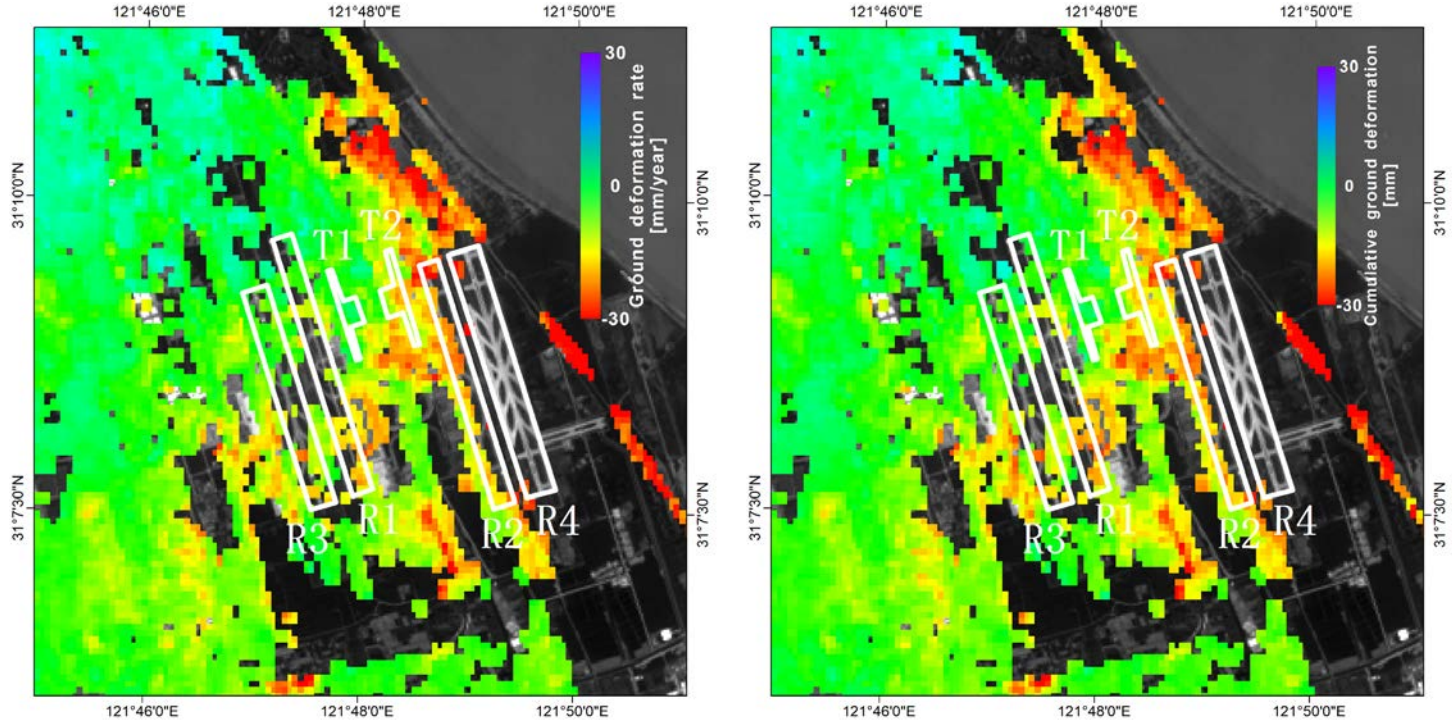
  - External DEM file: ASTER V2 (pixel size is 30m)
  - Multi-look operation: 10 looks in range direction and 10 looks in azimuth direction
  - Filter method: Goldstein
  - Unwrapping method: Delaunay MCF

- **Coherent points identification**

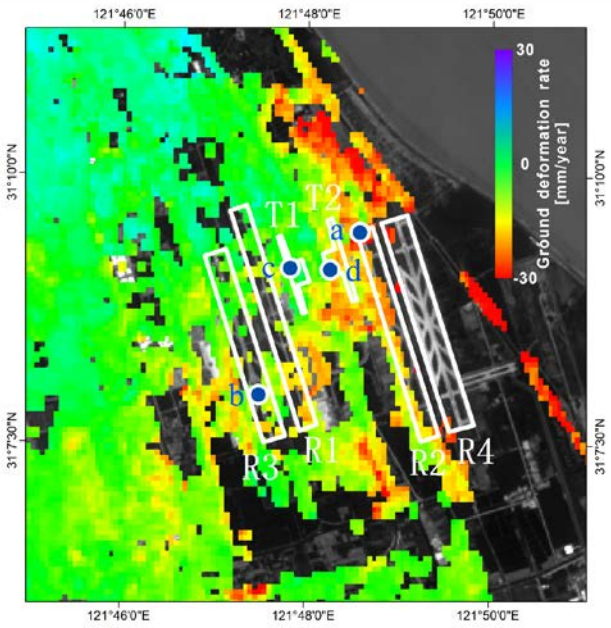
  Parameters setting

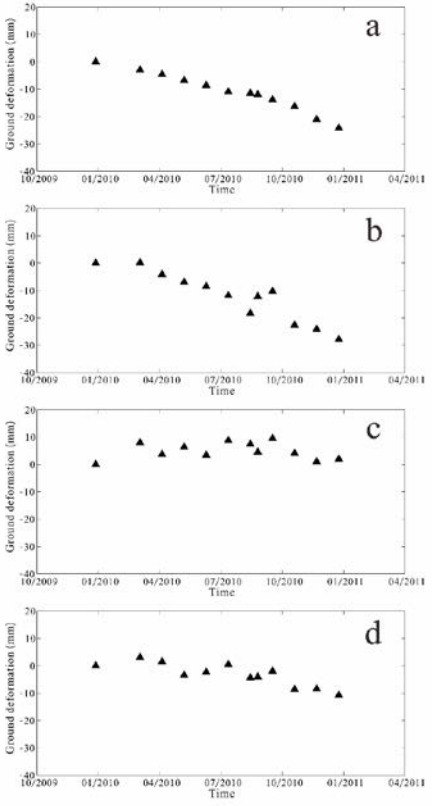
  - Temporal coherence: 0.5
  - Spatial coherence: 0.2

Ground settlement of Pudong International Airport



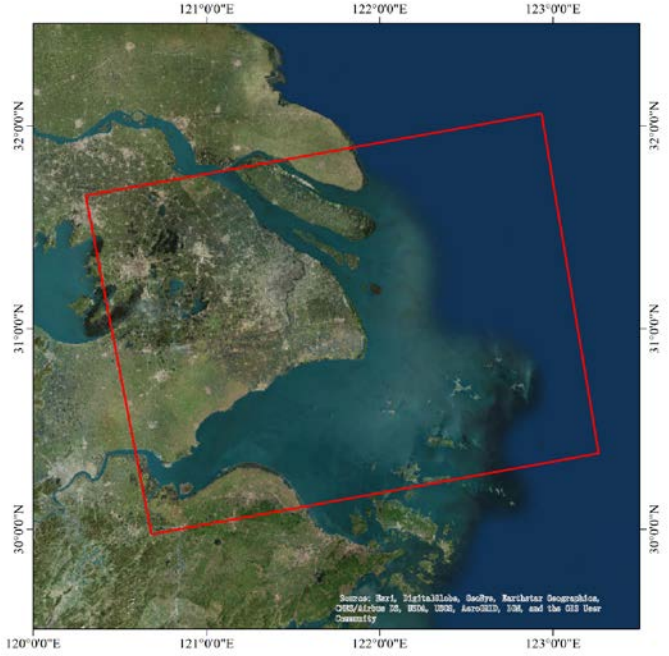
Ground settlement time series of four selected points acquired by SAR dataset collected from 2009 to 2010.





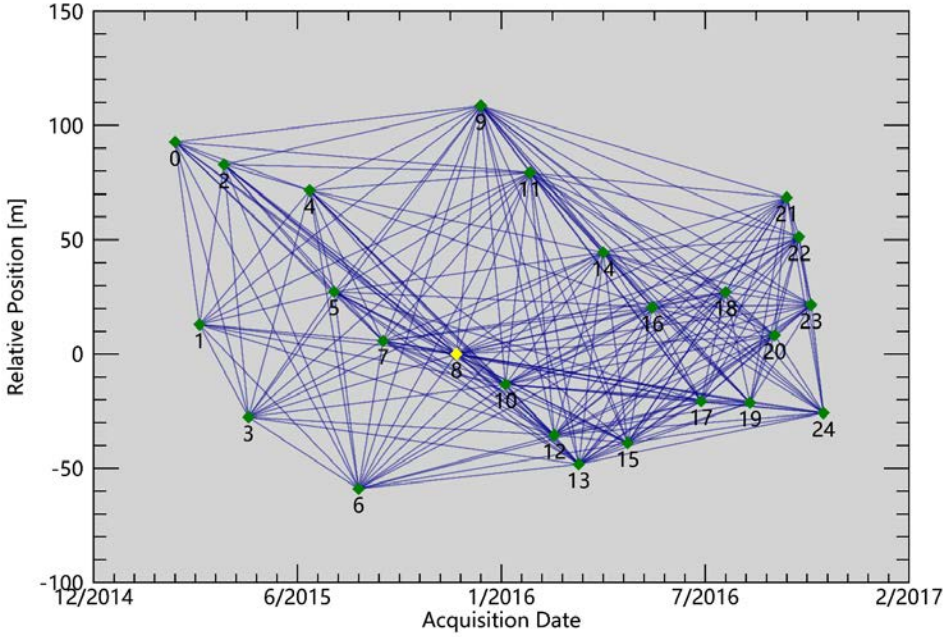
Insights on present state of deformation of Shanghai: Sentinel-1 Data Processing.

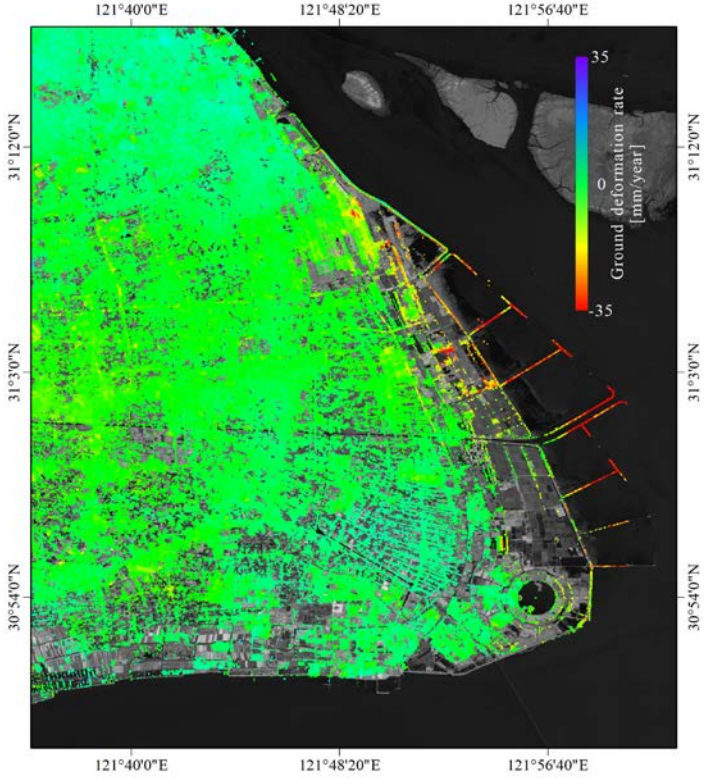
- Satellite Platform: Sentinel-1A(S1A)
- Frequency: 5.405GHz
- Product type: SLC
- Incidence angle: 20° - 45°
- Sensor mode: Interferometric Wide Swath Mode (IW)
- Polarisation: VV
- Orbit direction: Ascending



Processed Using SARScape at ECNU

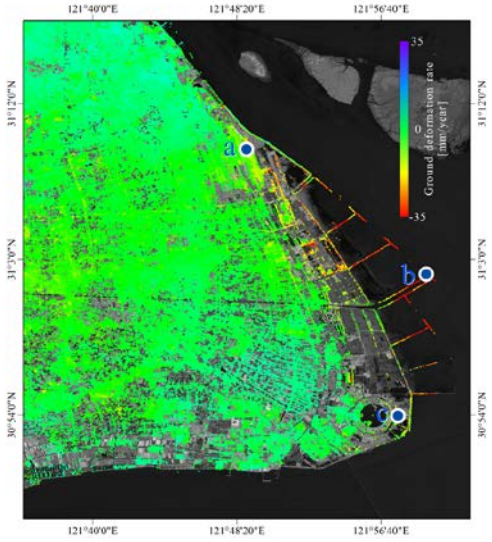
Sentinel-1 Data on Shanghai

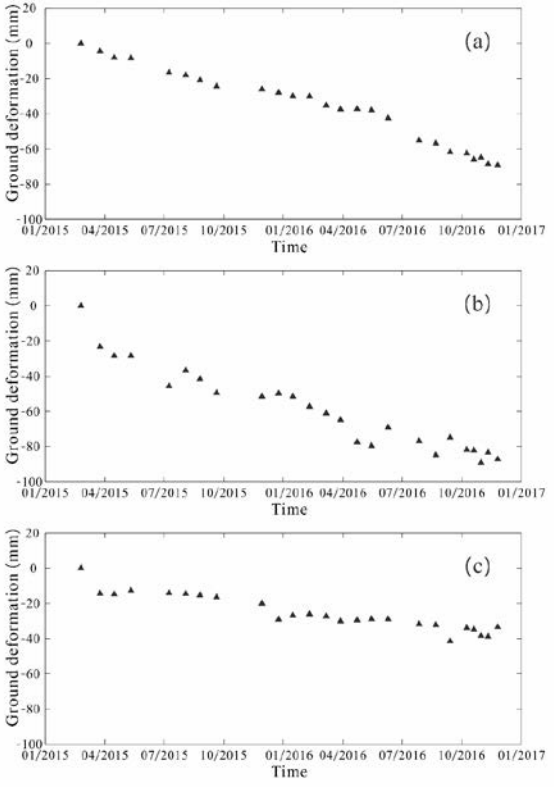




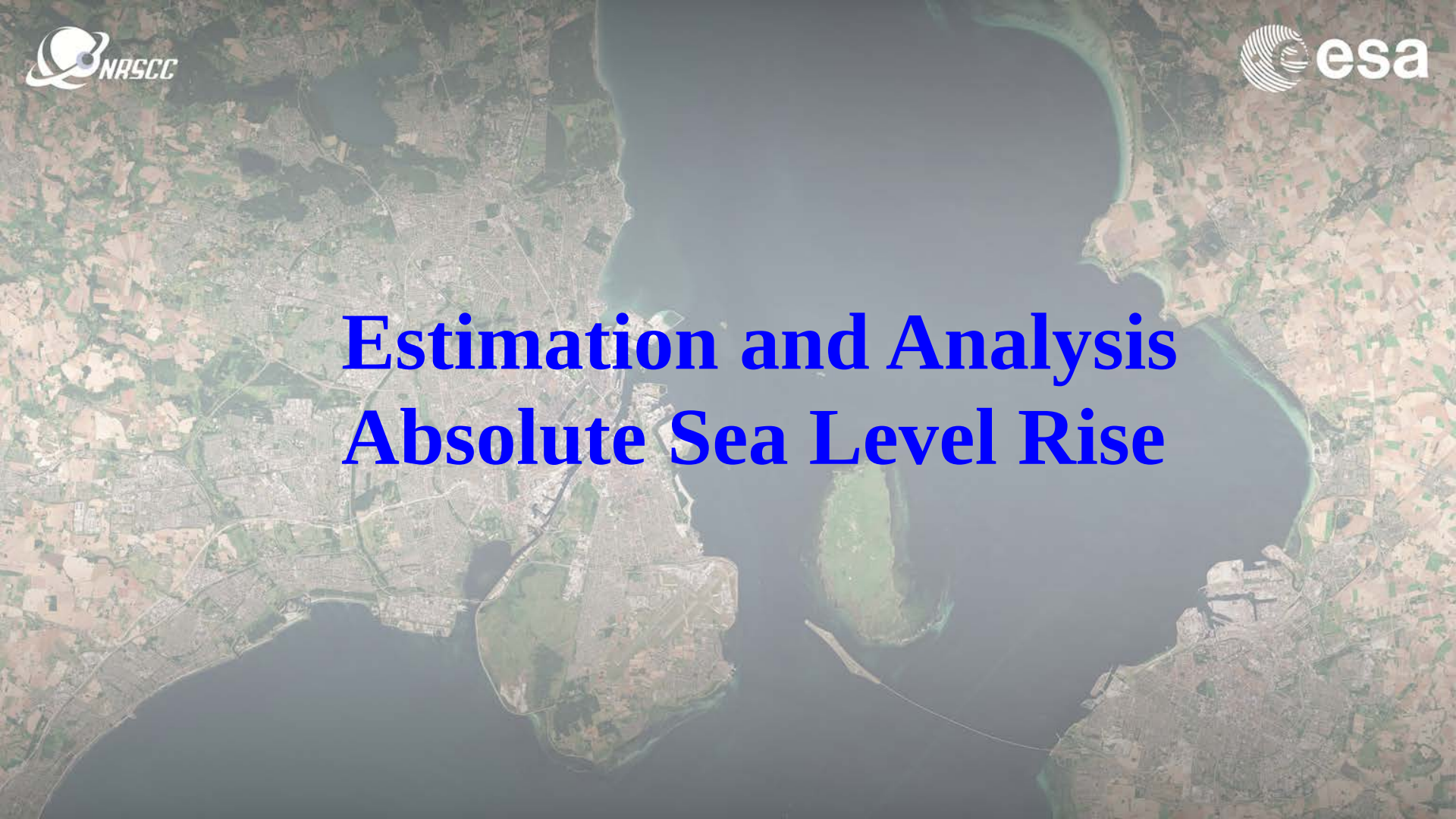
InSAR Sentinel-1 Preliminary Results

Ground deformation time series of four selected points acquired by S1A dataset collected from 2014 to 2016.



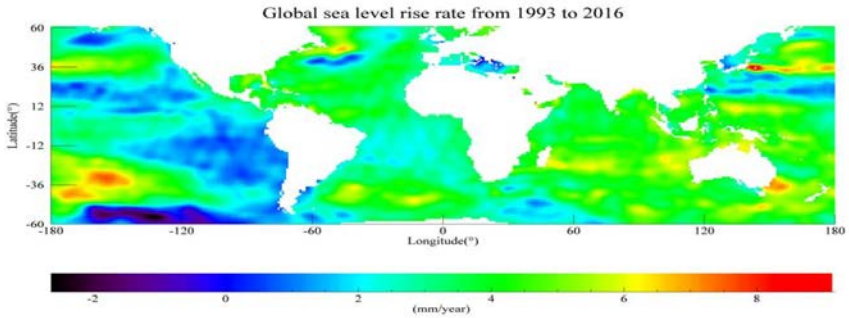


Time-Series are preliminar



Estimation and Analysis Absolute Sea Level Rise

Sea Level Rise



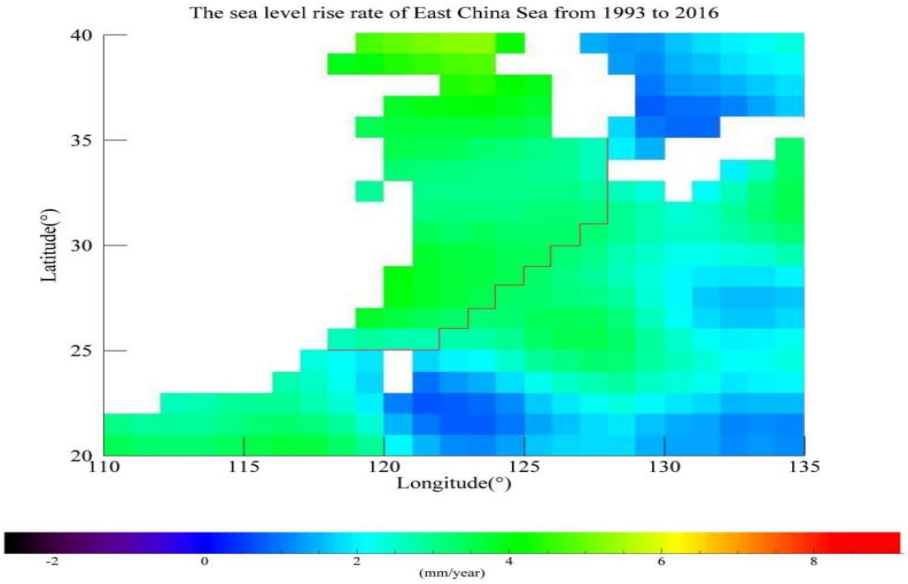
Altimeter Data

Near-global (65° S to 65° N), on a 1° × 1° grid
Monthly averages, currently from January 1993 to August 2016
With the inverse barometer correction,the seasonal signal removed and the glacial isostatic adjustment(GIA)correction

The sea level altimeter data of combined TOPEX/Poseidon, Jason-1 and Jason-2/OSTM acquired from Commonwealth Scientific and Industrial Research Organization(CSIRO).

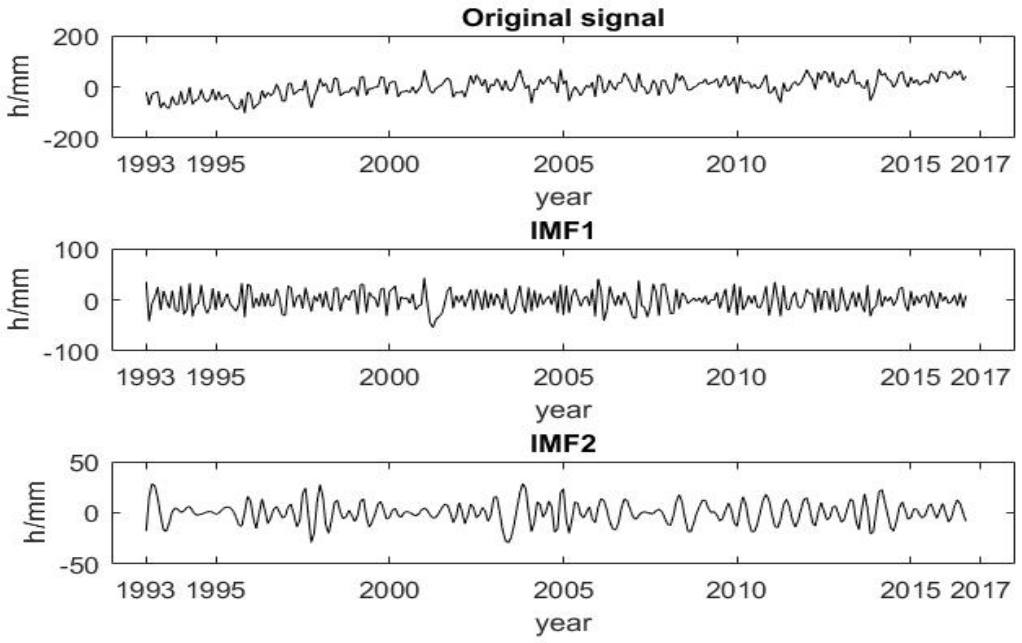
We used the data to estimate and map the global sea level rise rate with linear regression analysis.

Sea Level Rise



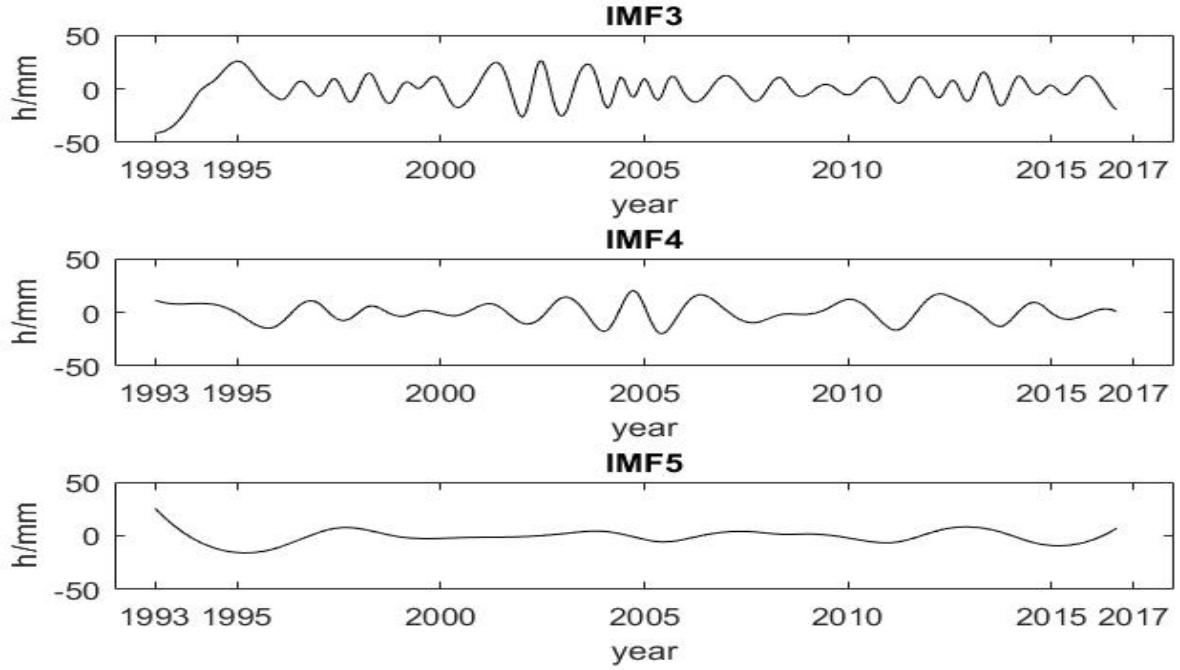
- We averaged the sea surface height of the East China Sea and obtained the mean sea level of East China Sea.
- We use EEMD decomposition for trend analysis.

Sea Level Rise



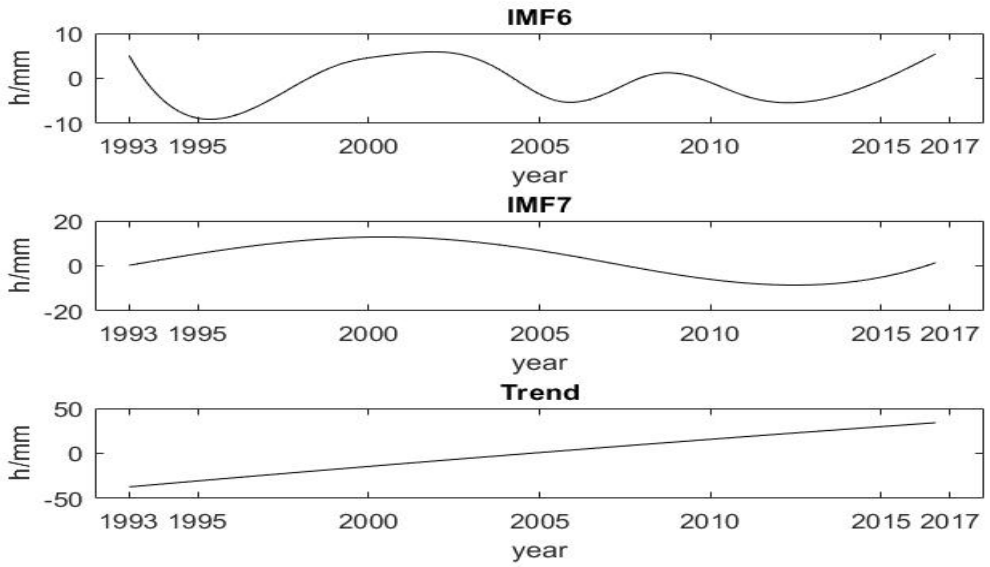
- The monthly average mean sea level datasets of the East China Sea from 1993 to 2016 are decomposed by EEMD.
- 8 Intrinsic Mode Functions (IMFs) are obtained, 7 of them are cycle terms, and one of them is long term.

Sea Level Rise

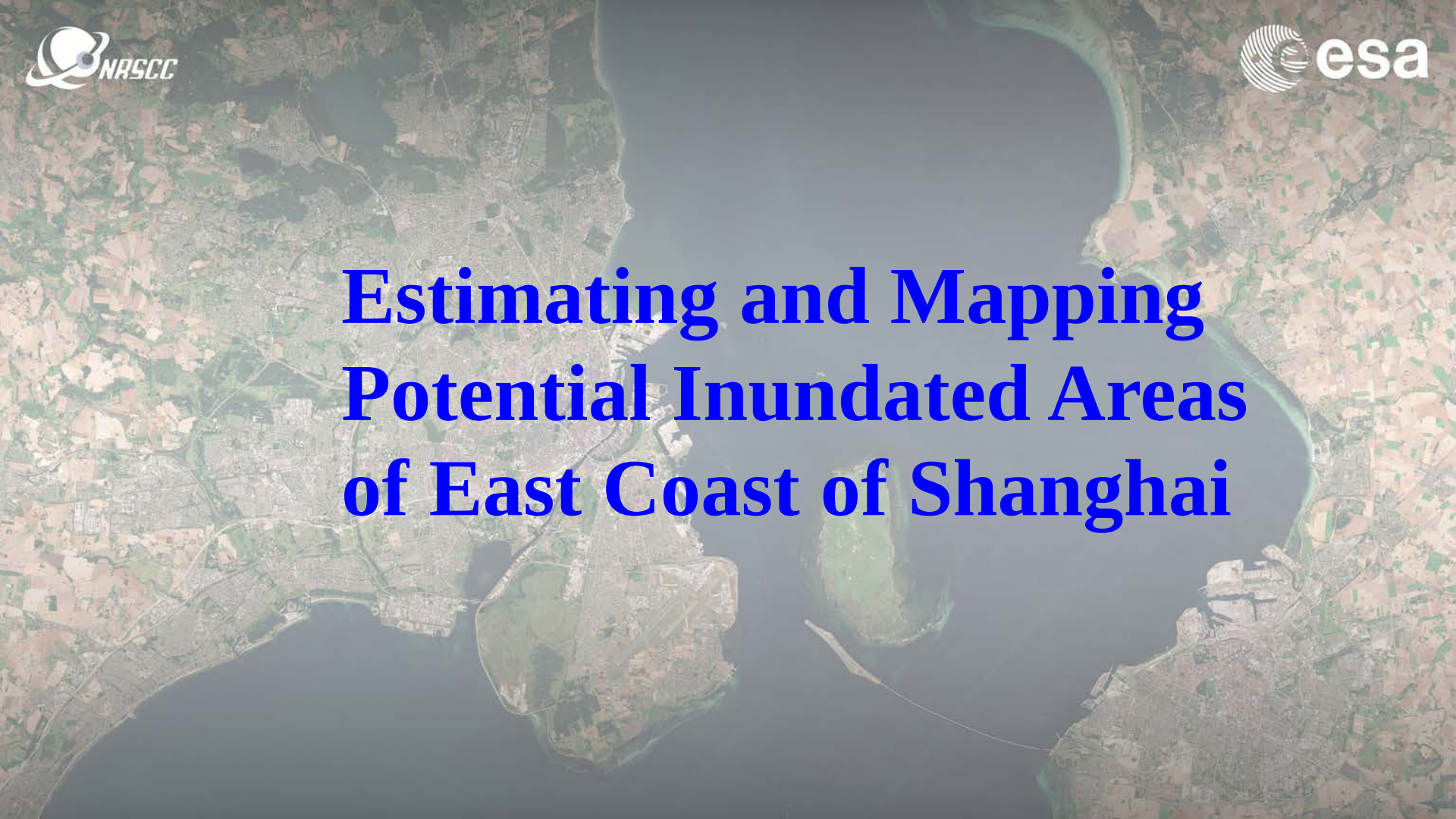


IMF1 to IMF7 are all a cycle item. They represent 3 months, 6 months, 13 months, 25 months, 62 months, 101 months, and 230 months respectively.

Trend analysis of sea level rise with EEMD



- The trend term (IFM8) shows the average sea level rise rate in the East China Sea.
- It was 3.1584 mm/yr from 1993 to 2016.
- This result is consistent with the sea level rise rate given by the China Sea Level Communique in 2016. That is 3.2 mm/yr from 1980 to 2016.



Estimating and Mapping Potential Inundated Areas of East Coast of Shanghai

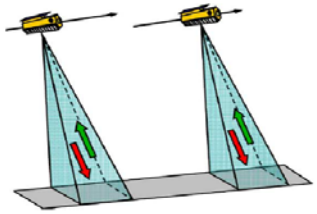
Potential inundated areas of east coast of Shanghai

- With the hypothesis that there was no seawall or the seawall was broken by flood.

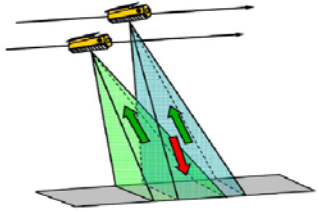
- We predict the relative sea level rise in 2020, 2025 and 2030 considering ground subsidence, the current terrain with high resolution, tides, and absolute sea level rise.

A false composite image (652) of Landsat 8 acquired on Feb. 7 2016, Lingang New City in Shanghai.

DEM Generation Using Bistatic TerraSAR-X data



$\Delta t \geq 11$ days



$\Delta t = 0$ days

Repeat-pass missions (monostatic)

$$\phi = \phi_{topo} + \phi_{def} + \phi_{atm} + \phi_{orbit} + \phi_{scat} + \phi_{noise}$$

Decorrelation hinders DEM generation

TanDEM-X (bistatic)

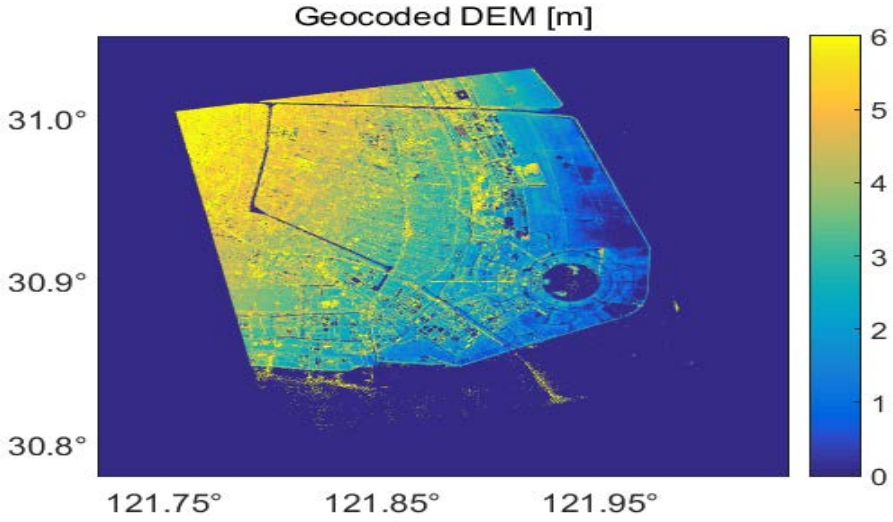
$$\phi = \phi_{topo} + \phi_{def} + \phi_{atm} + \phi_{orbit} + \phi_{scat} + \phi_{noise}$$

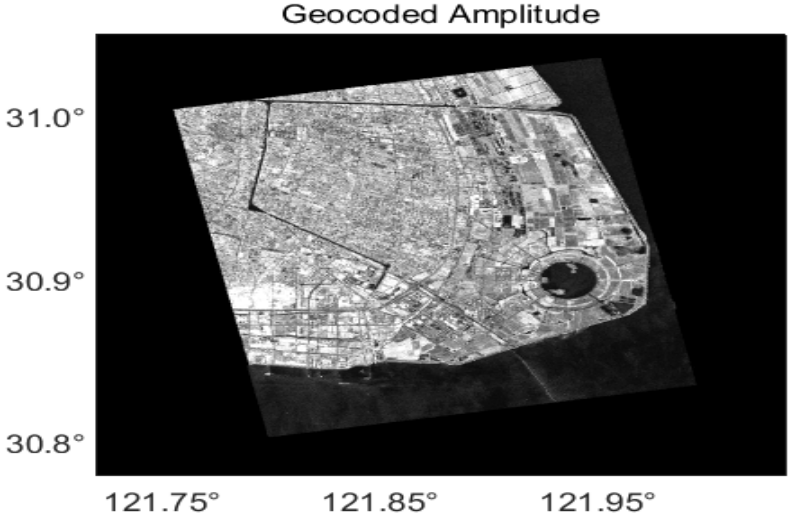
Not an issue for bistatic data

TanDEM-X enables to generate high-resolution DEMs

ϕ: interferometric phase
ϕ_{topo}: topographic phase
ϕ_{def}: deformation
ϕ_{atm}: atmospheric effects
ϕ_{scat}: backscattering properties
ϕ_{noise} : noise

TanDEM-X DEM of Shanghai





TanDEM-X data pair acquired on 04 November 2012

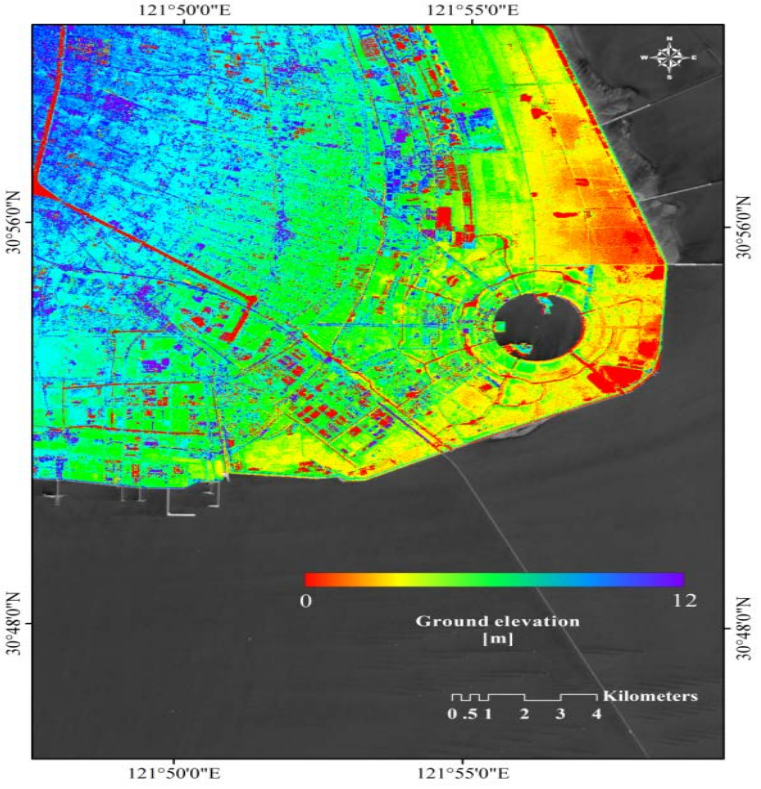
DEM with a resolution of 6 m was generated using an adapted version of DORIS for bistatic data processing

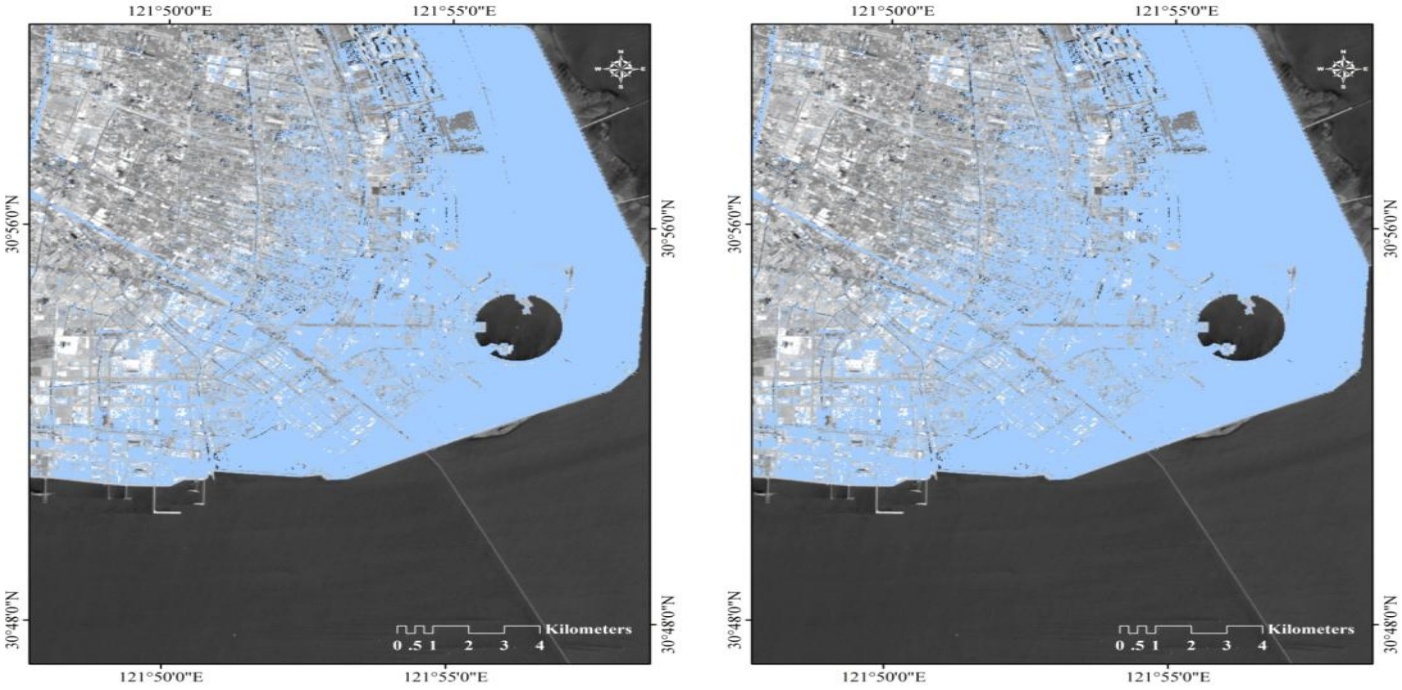
DEM Generation Using Bistatic TerraSAR-X data

- InSAR technique was used to generate high resolution DEM of Lingang New City of Shanghai with TerraSAR-X SAR images in 2012.

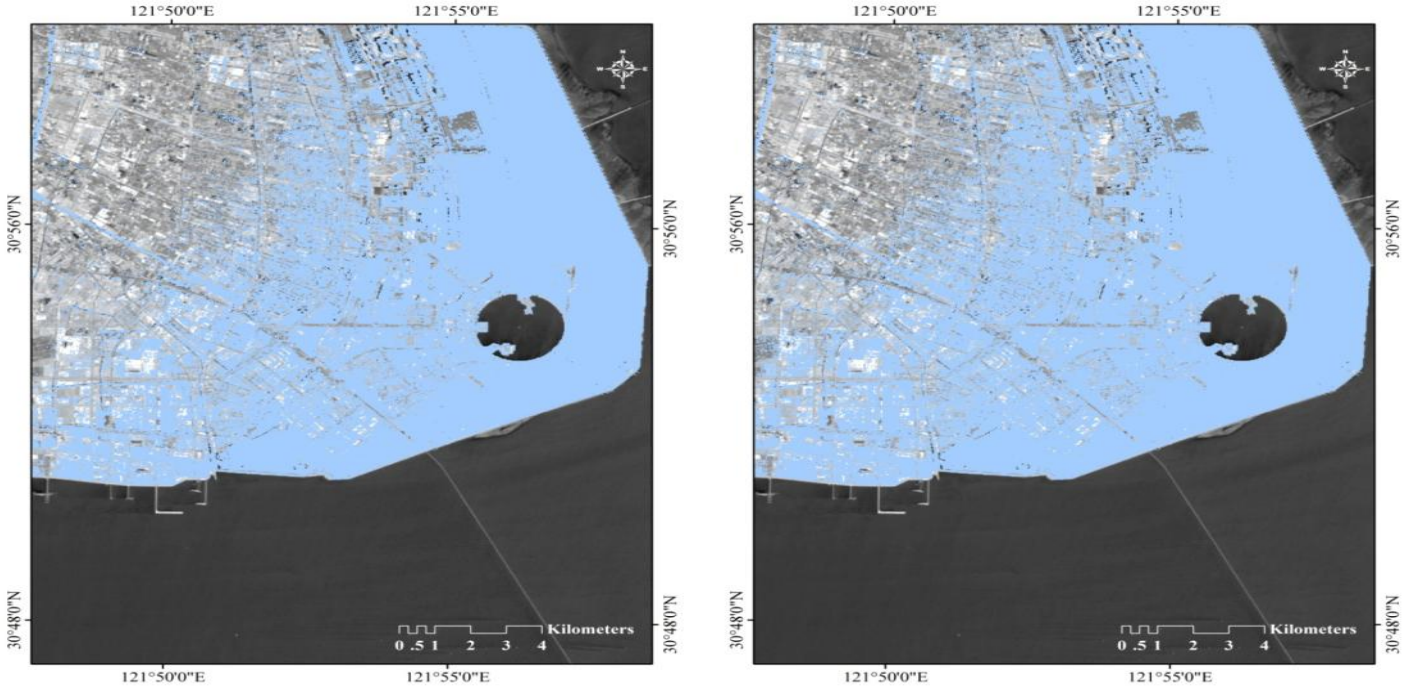
- In order to reduce the influence of incoherent noise, 2 * 2 multi-look processing was carried out.

- The newest DEM of the Lingang New City with 6 m * 6 m resolution has been obtained.

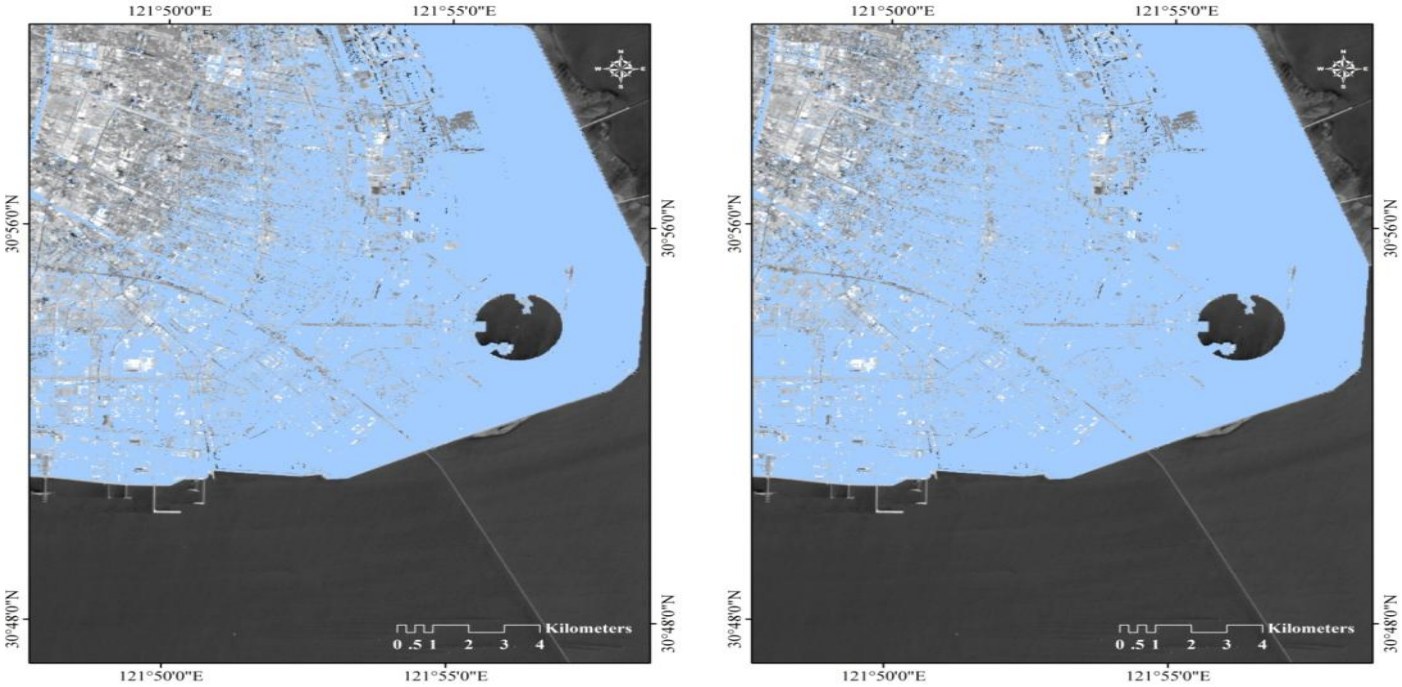




The left figure shows potentially flooded areas at high tide of 5-year tide.
The right figure shows potentially flooded areas at high tide of 10-year tide.



The left figure shows potentially flooded areas at high tide of 20-year tide.
The right figure shows potentially flooded areas at high tide of 50-year tide.



The left figure shows potentially flooded areas at high tide of 100-year tide.
The right figure shows potentially flooded areas at high tide of 1000-year tide.

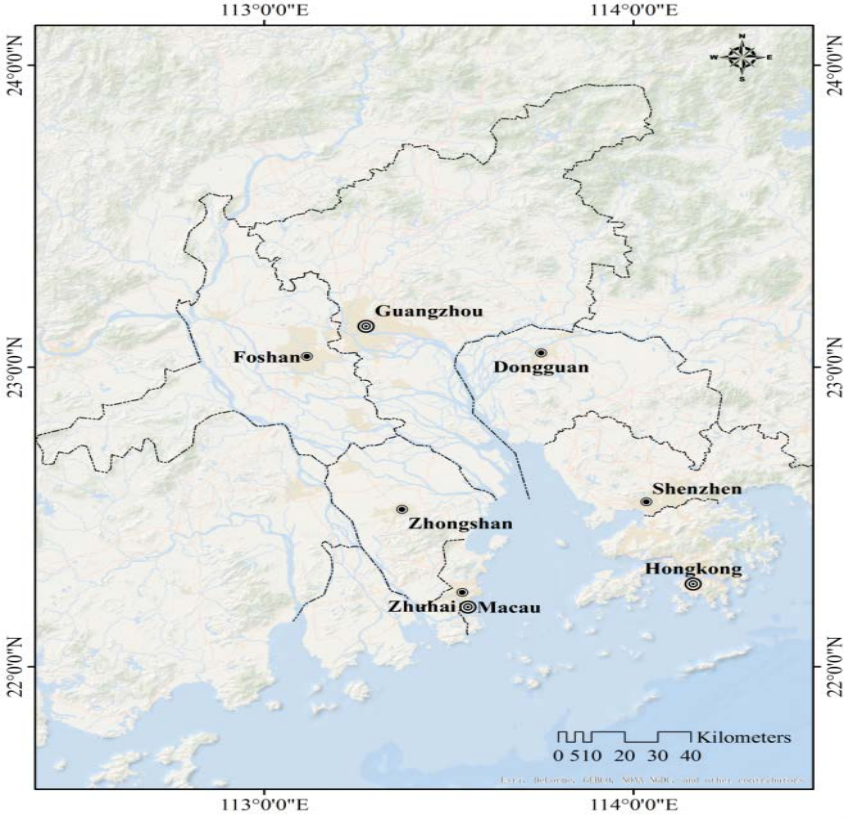
Difference tide	Flooded area (km^2)		
	2020	2025	2030
5 years tide	137.09	137.63	138.11
10 years tide	147.02	147.55	148.10
20 years tide	154.02	154.63	155.25
50 years tide	167.02	167.80	168.50
100 years tide	177.33	178.03	178.76
1000 years tide	203.64	204.16	204.67

- Once the coastal artificial seawalls of Lingang New City was broken by big flood, over one half of study area could be flooded.

- It indicates that delta region are highly sensitive to increasing risks from ground subsidence caused by human activities and naturally deposits consolidation, local sea level rise, and climate extreme events.

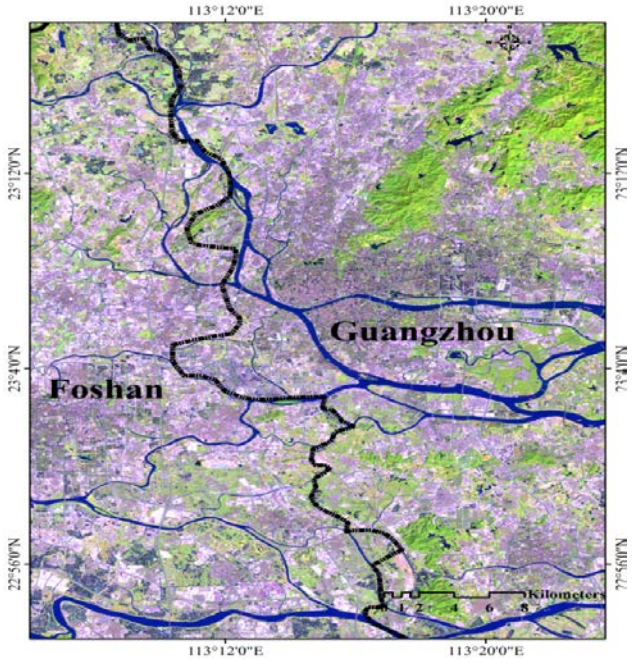
- 2016-2017 Ground Displacement of Honk Hong Area
- Detection ground deformation time evolution of Pearl River Delta
- Detection continuous ground deformation time evolution of Yangtze River Delta

On the Pearl River Delta Region



- The Pearl River Delta (PRD) is the low-lying area surrounding the Pearl River estuary.
- It is one of the most densely urbanized regions in the world.
- Megacities located in PRD are Guangzhou, Shenzhen, and Hong Kong.

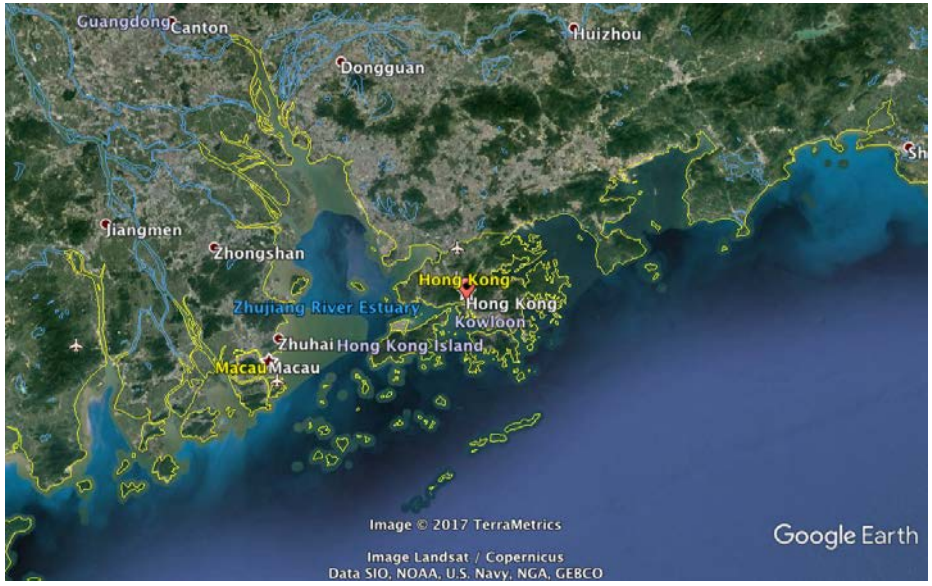
On the Pearl River Delta Region

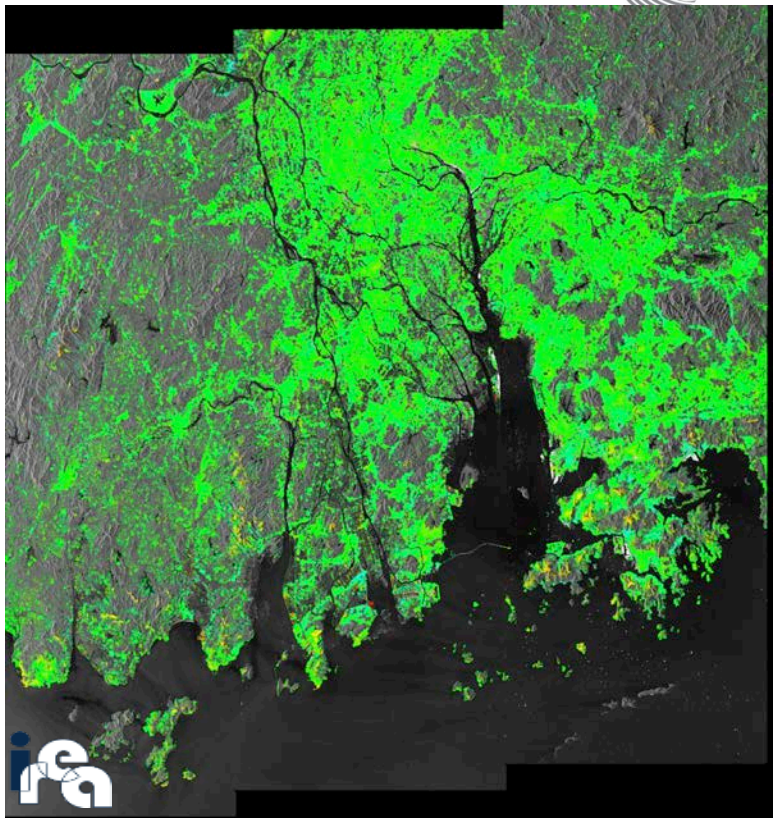


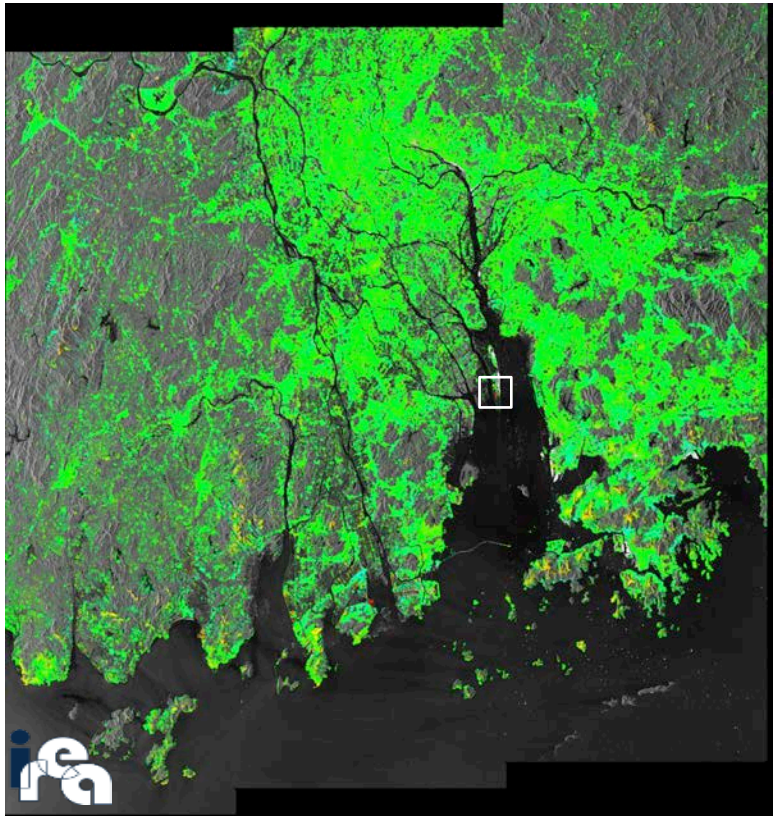
A false composite image (652) of Landsat 8 acquired on February 7 2016, showing two cities, Guan Zhou and Foshan.

- **Guangzhou** located on the PRD is the most populous city in southern China.
- **Foshan** lies at the west side of PRD. It is a prefecture-level city with dense population in the central Guangdong Province in southern China.

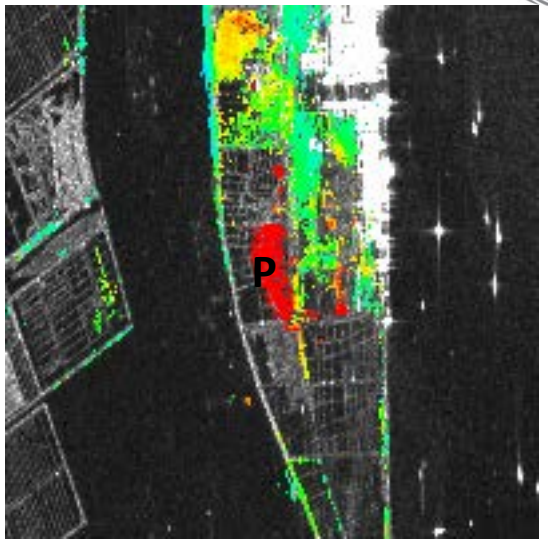
Oct. 2016-March 2017 SBAS Mean Deformation Velocity Map of the Honk Hong Area

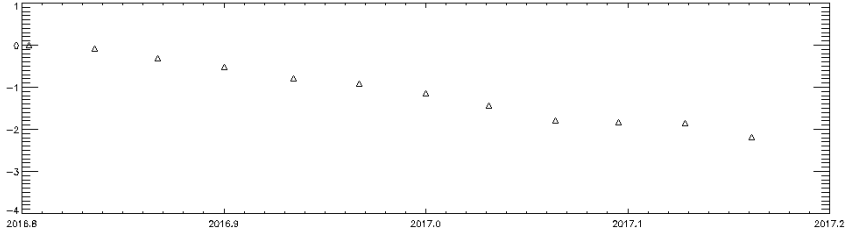


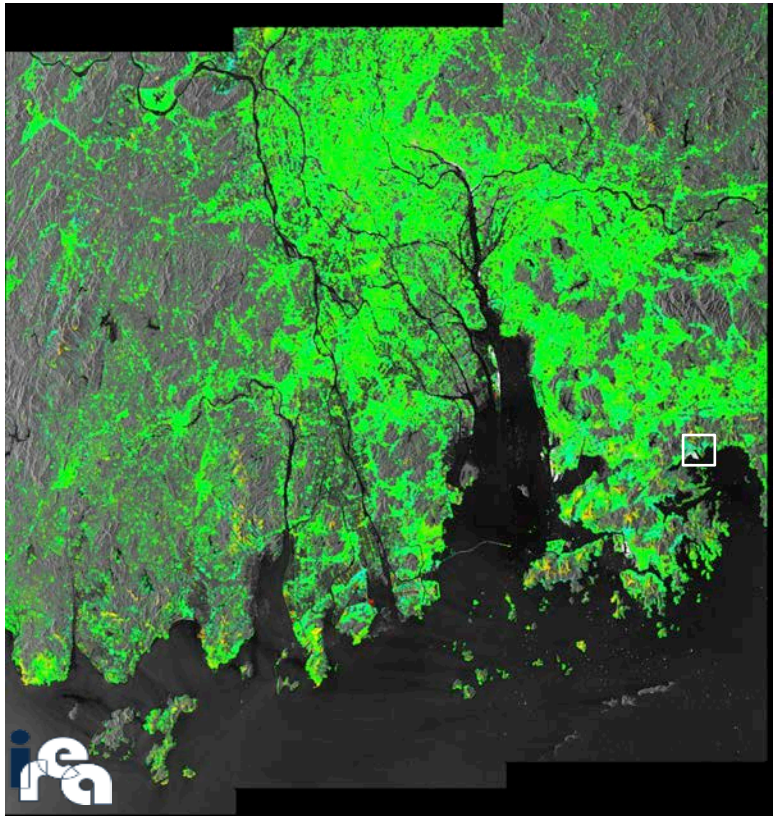


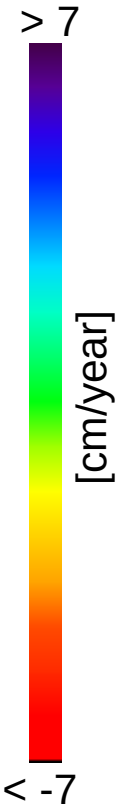


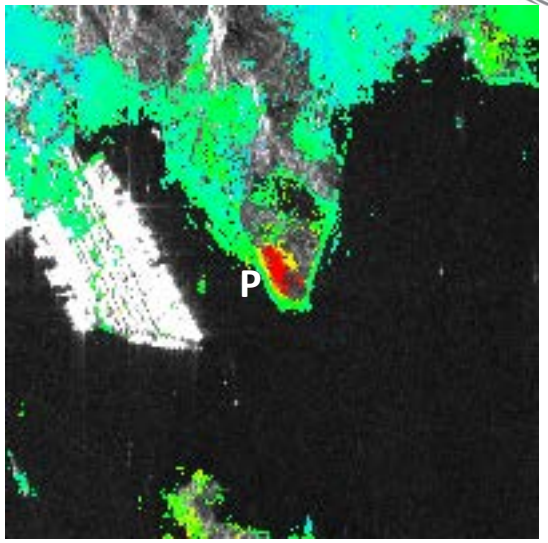

> 7
[cm/year]
< -7

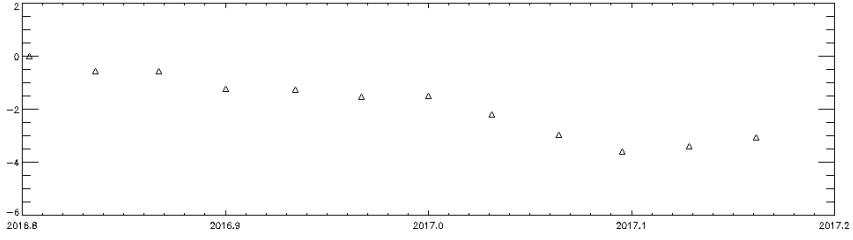

P

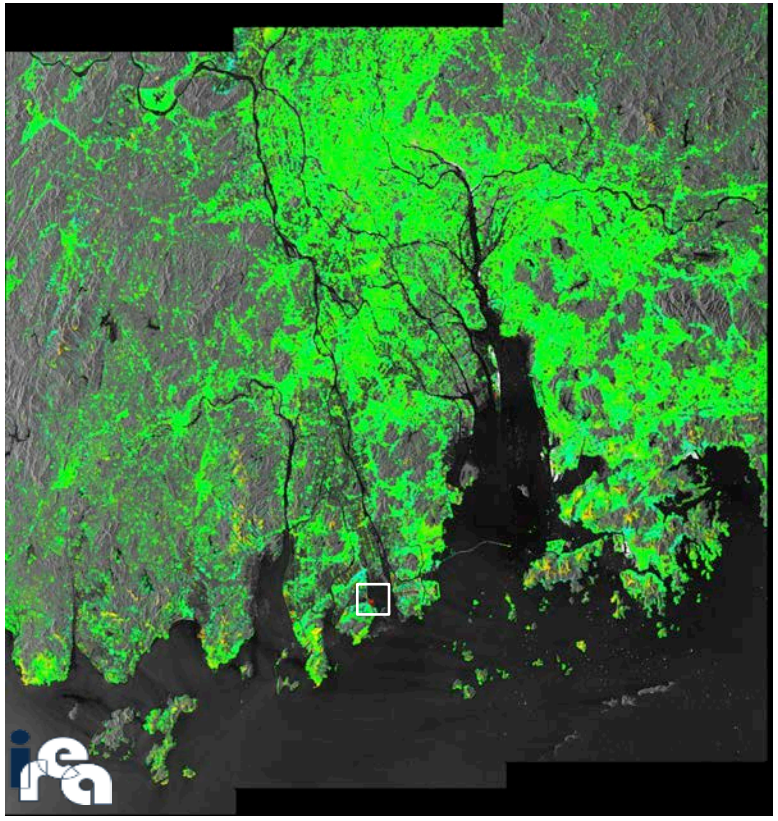

1
0
−1
−2
−3
−4
2016.8
2016.9
2017.0
2017.1
2017.2



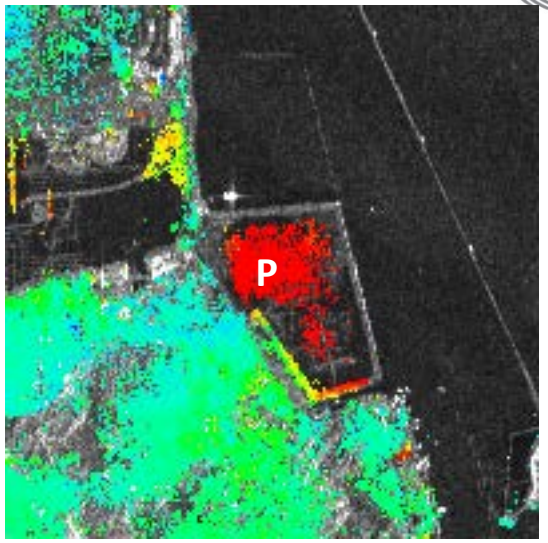

> 7
[cm/year]
< -7


P


2
0
-2
-4
-6
2016.8
2016.9
2017.0
2017.1
2017.2




> 7
[cm/year]
< -7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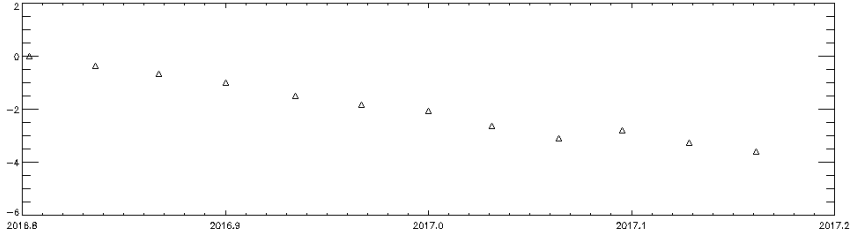
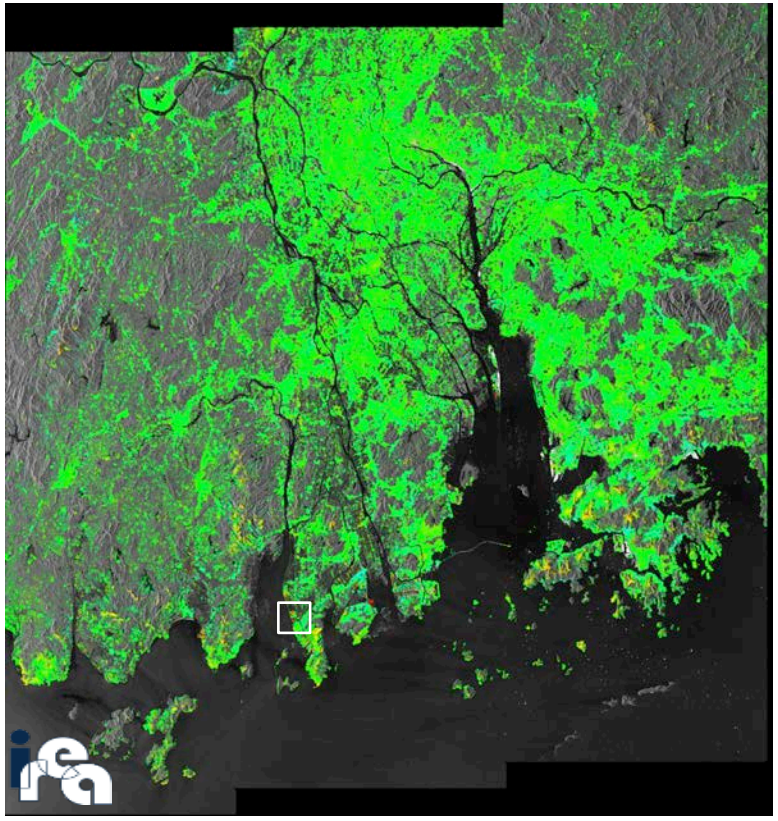
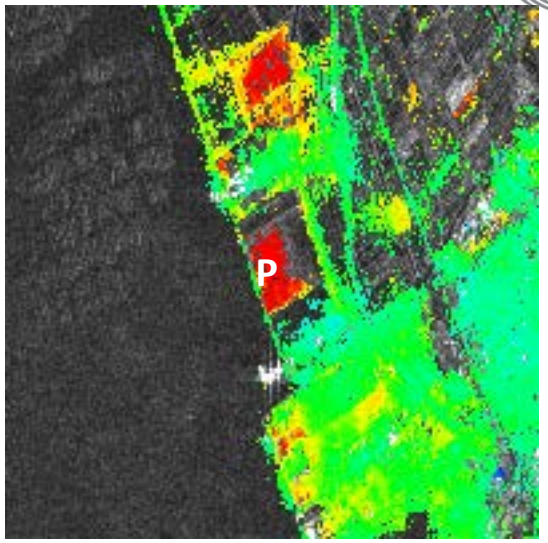

2
0
-2
-4
-6
2016.8
2016.9
2017.0
2017.1
2017.2




> 7
[cm/year]
< -7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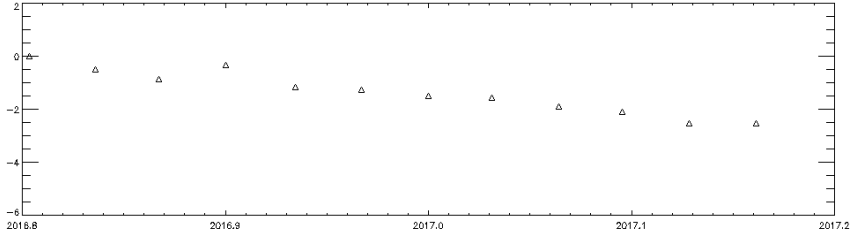
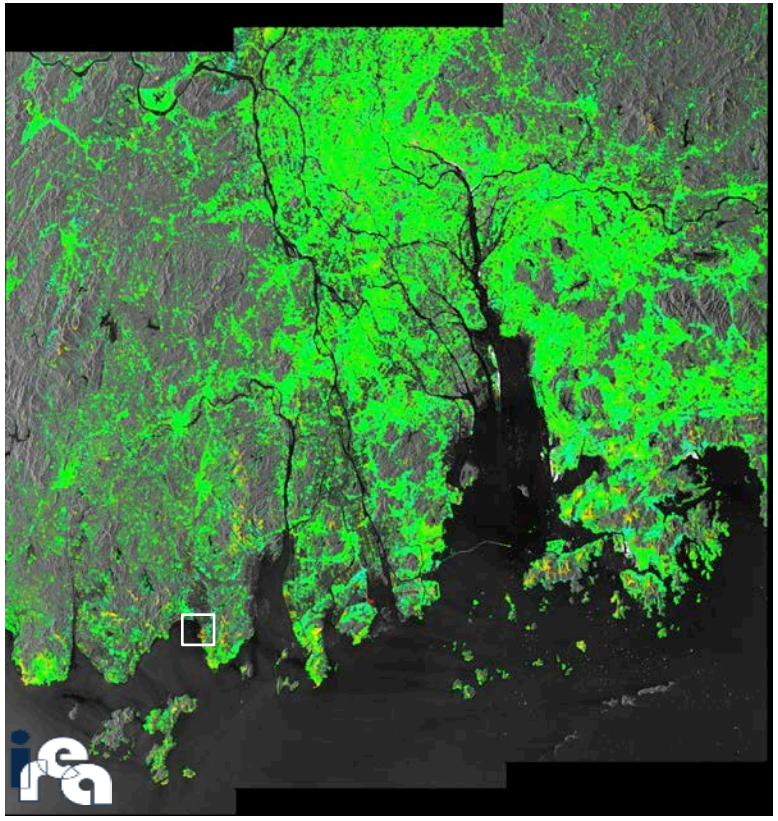
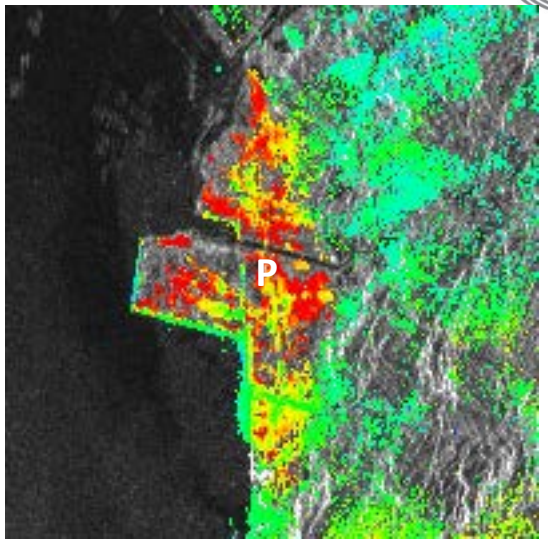

2
0
-2
-4
-6
2016.8
2016.9
2017.0
2017.1
2017.2




> 7
[cm/year]
< -7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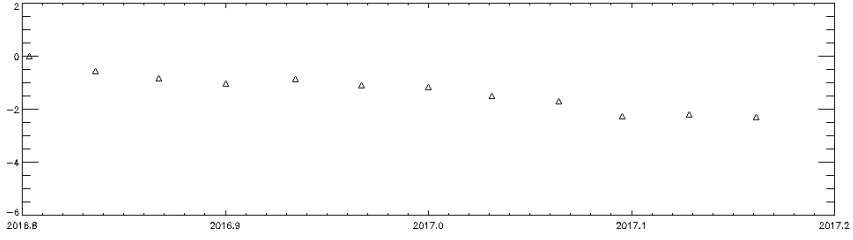
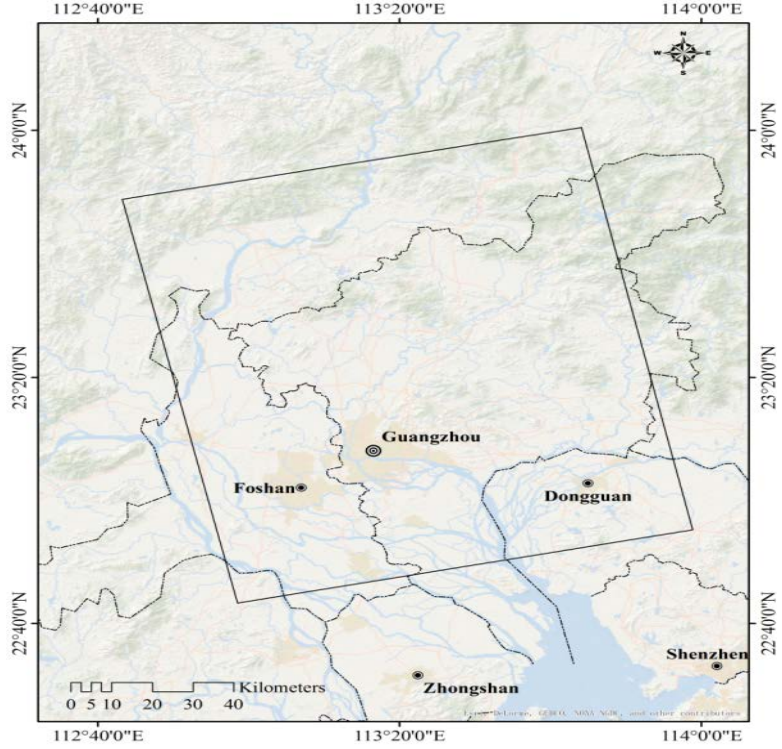
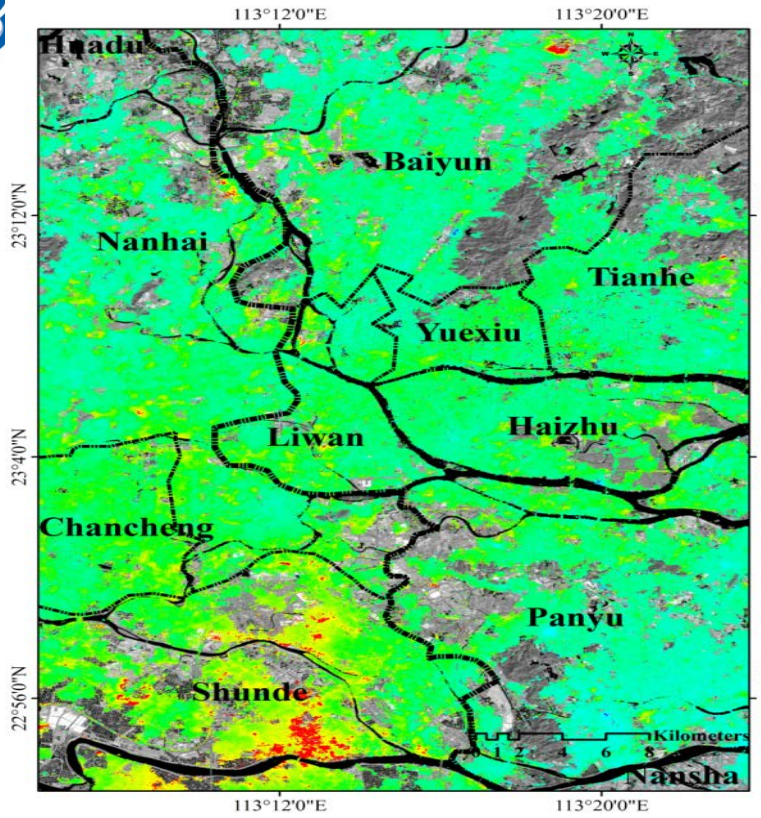

2
0
-2
-4
-6
2016.8
2016.9
2017.0
2017.1
2017.2



Spatial coverage map of the ENVISAT images

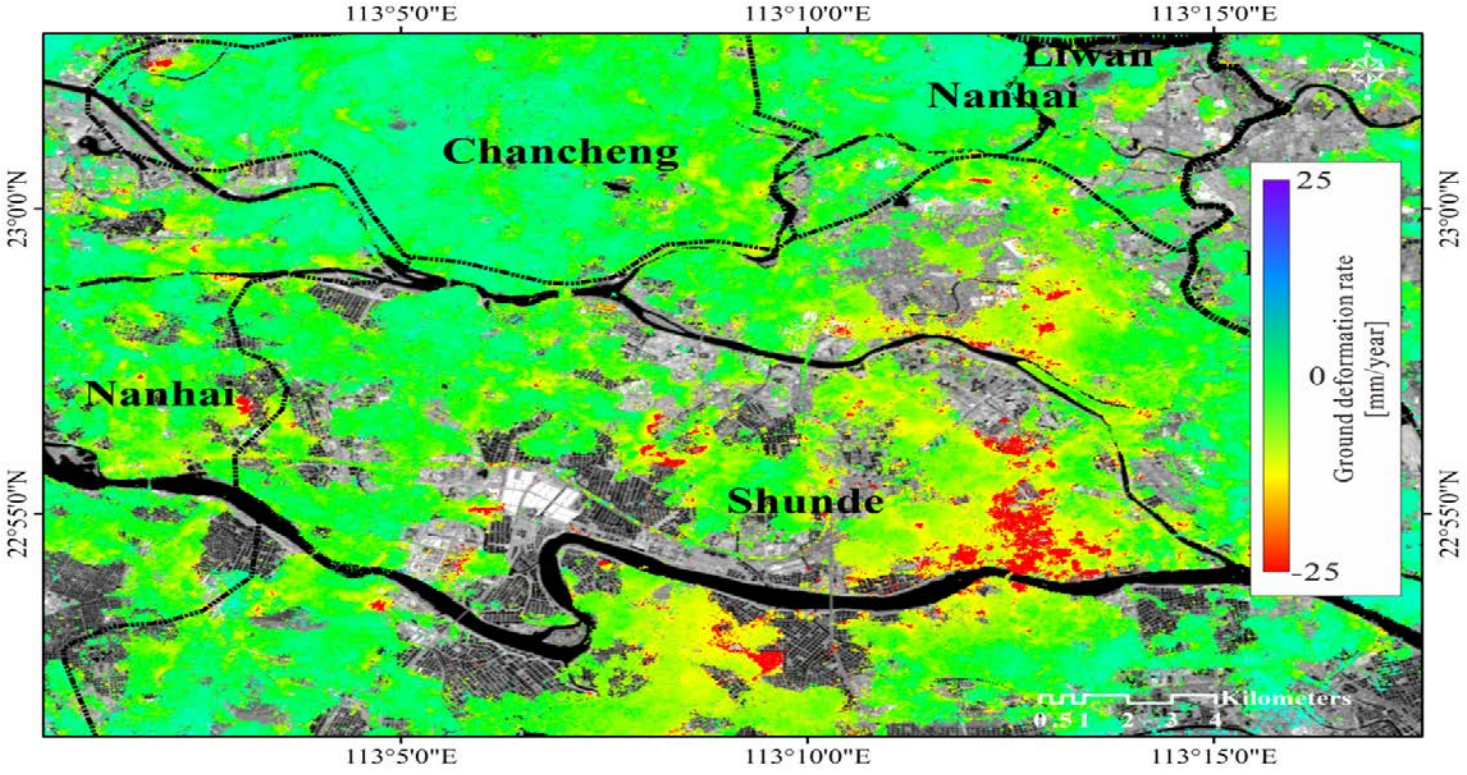
ENVISAT ASAR
Ascending passes
VV polarization
Track：297
Frame：459
Swath：I2

The ENVISAT ASAR SLC images covers the urban area of Guangzhou and Foshan.

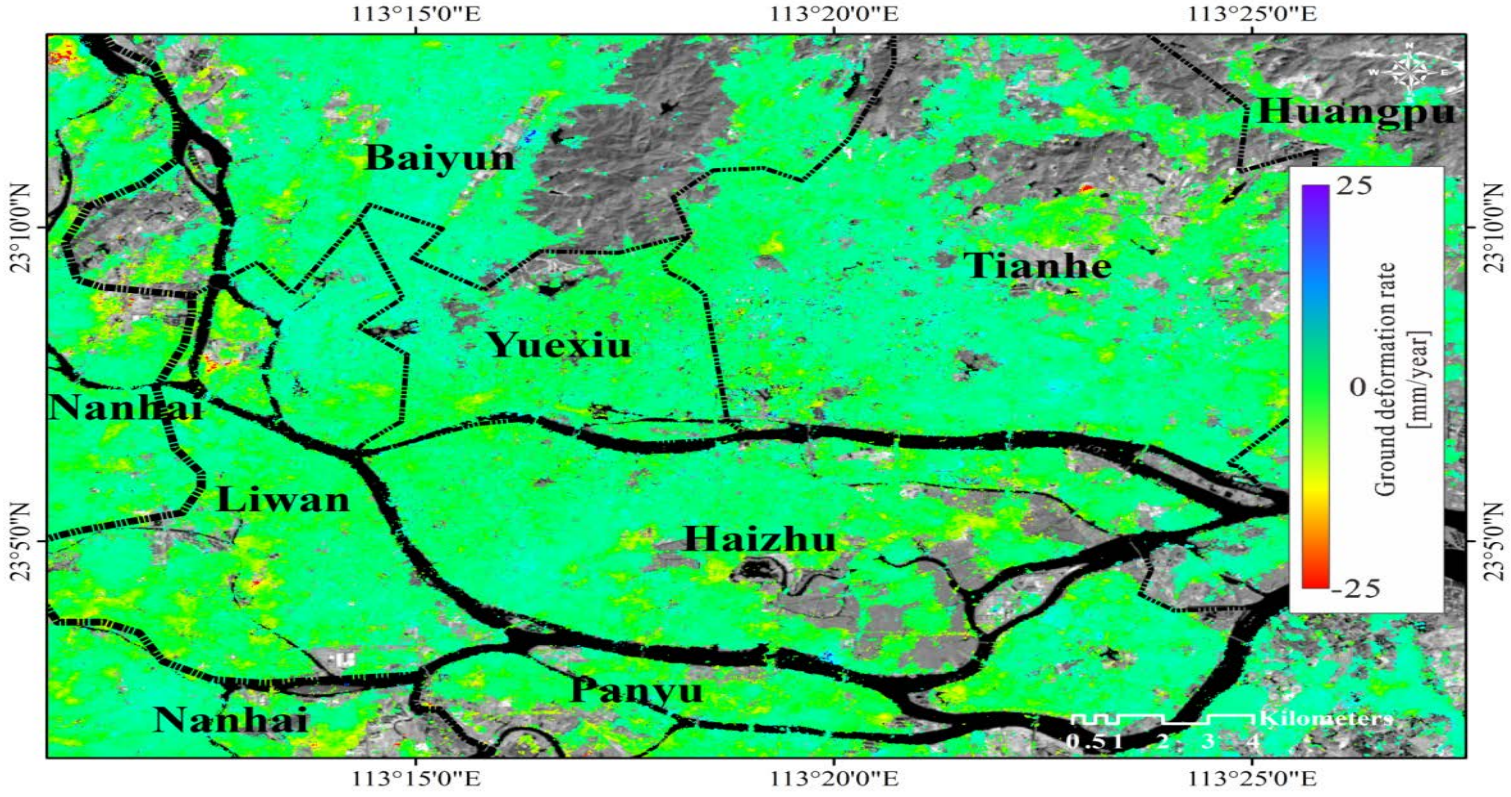


Velocity map of Guangzhou and Foshan

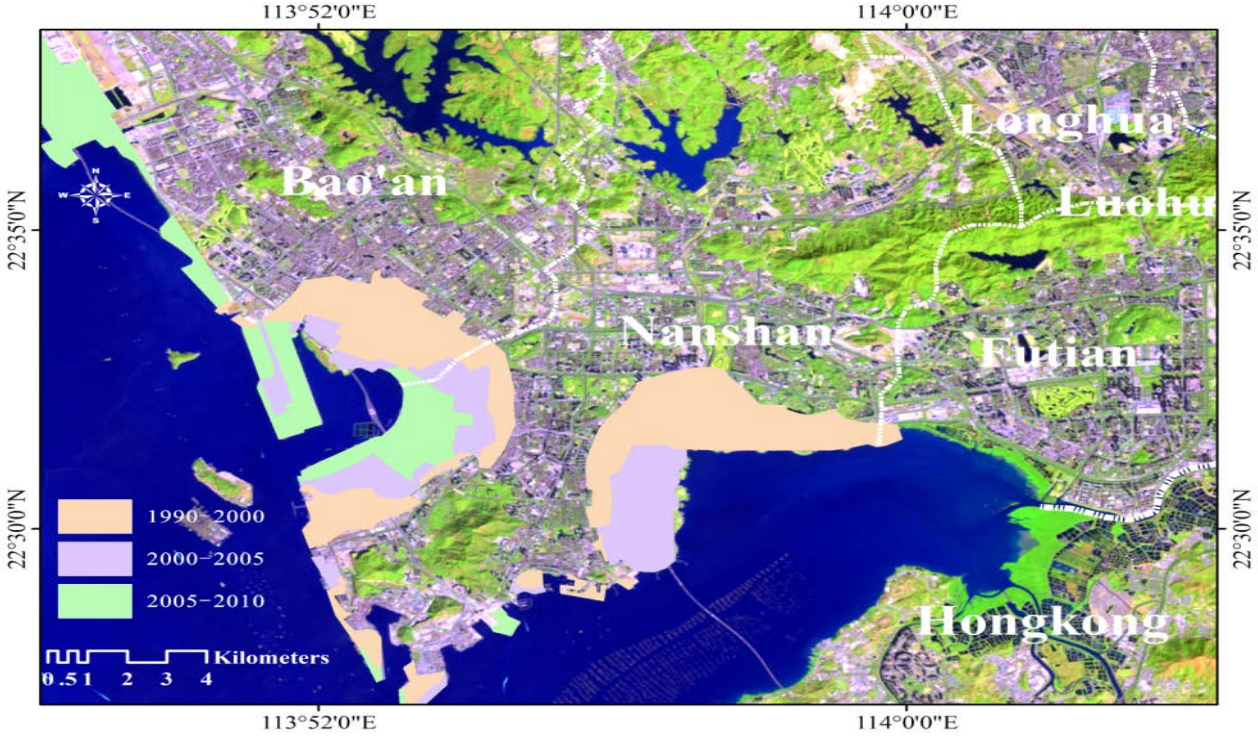
- The available 17 Envisat images were independently processed through the SBAS DInSAR processing chains.
- SBAS-DInSAR result shows a maximum (subsidence) deformation rate of about 2.5 cm/year in Liwan, Yuexiu, Haizhu, and Tianhe district of Guangzhou, and Shunde district of Foshan.



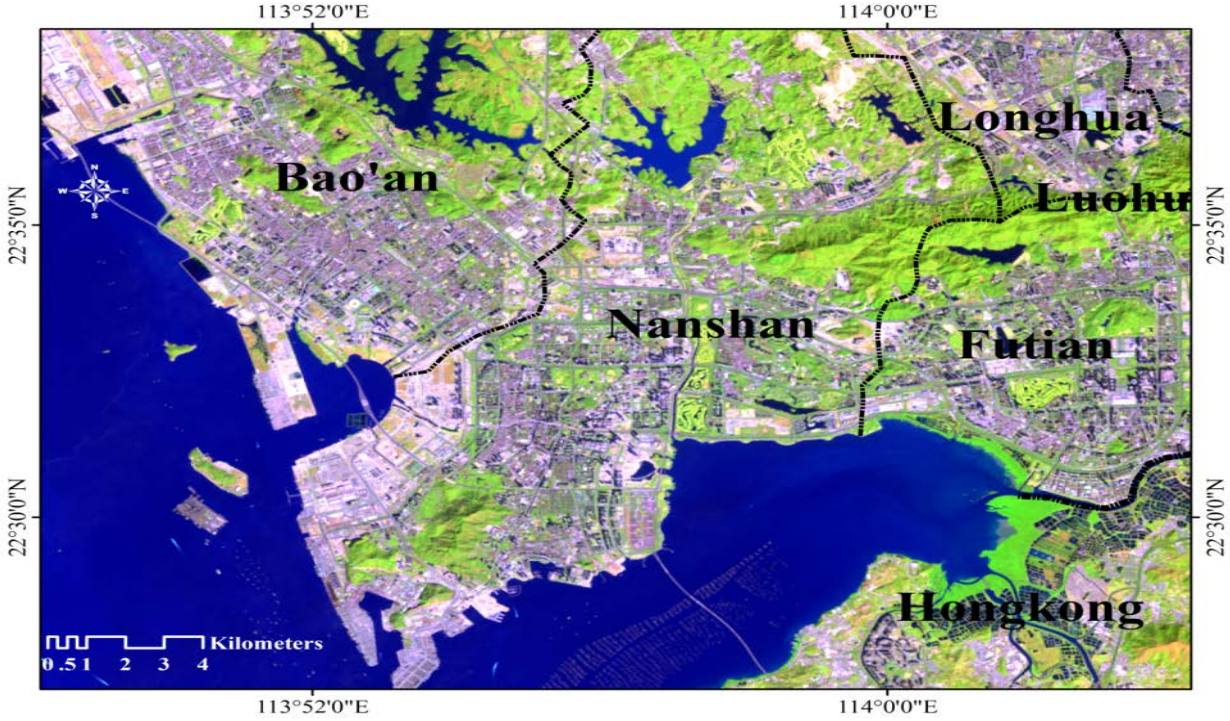
SBAS vertical mean deformation velocity map of Shunde District of Foshan.


113°15'0"E
113°20'0"E
113°25'0"E
23°10'0"N
23°5'0"N
Baiyun
Huangpu
Tianhe
Yuexiu
Nanhai
Liwan
Haizhu
Panyu
Nanhai
25
0
-25
Ground deformation rate
[mm/year]
Kilometers
0 0.5 1 2 3 4

Reclamation areas of Shenzhen



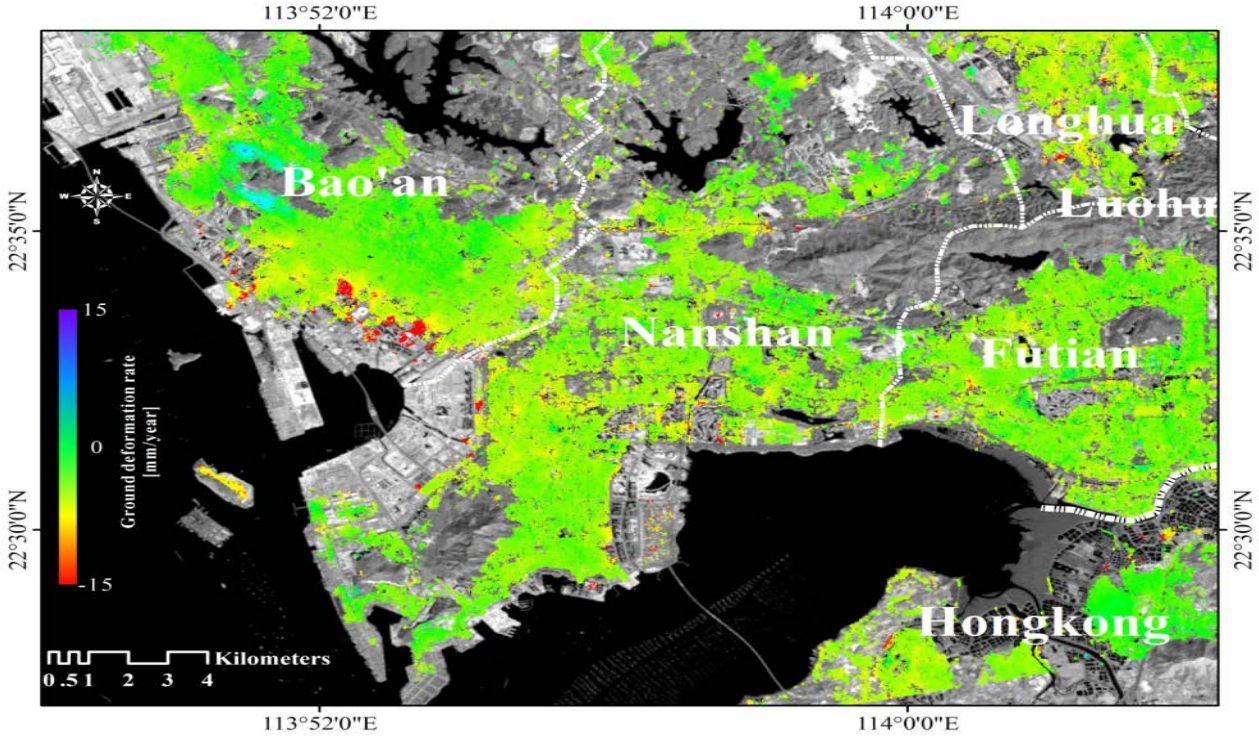
- Shenzhen has a large area of reclamation.
- These areas include Baoan Airport.
- These reclamation areas are facing the sea and with rapid ground subsidence.
- It is vulnerable to the ground subsidence and sea level rise.



- Shenzhen is located at the east side of PRD and north of Hong Kong.
- It is major city of China, and also the five largest city of China.

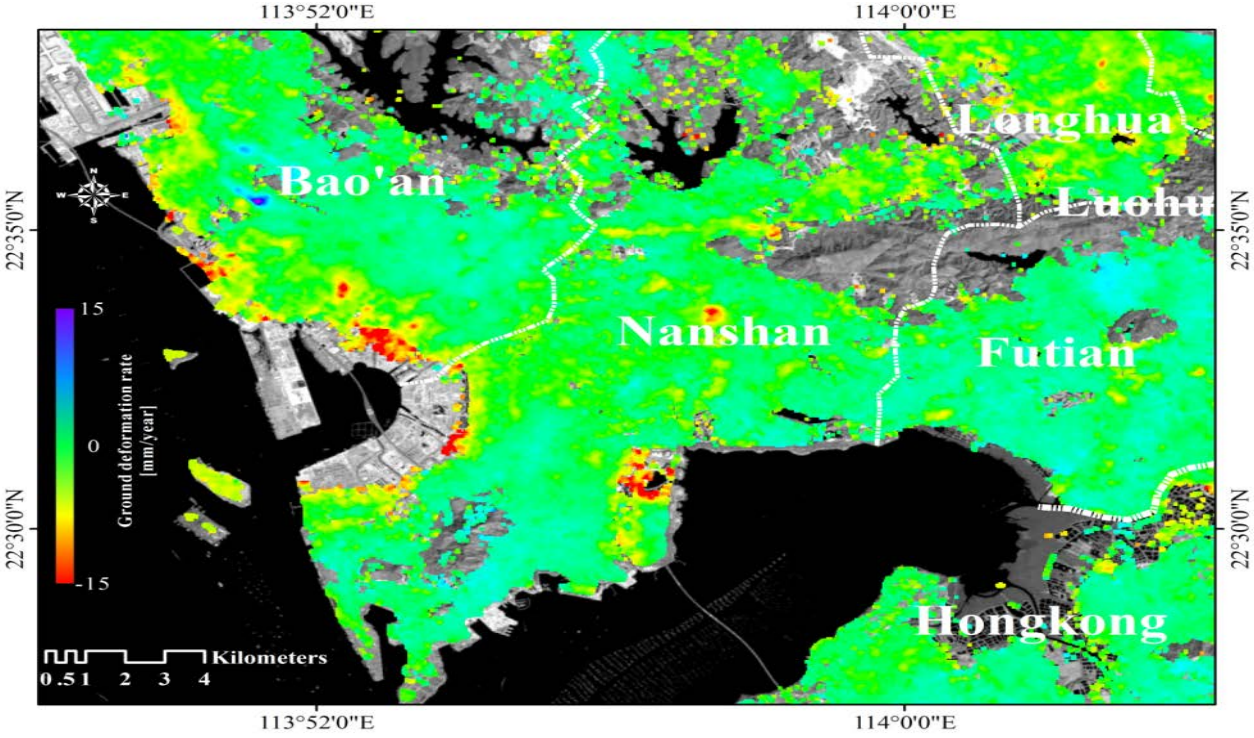
- The black rectangle is the area of the ascending ASAR image.
- The red rectangle is the area of the descending ASAR image.

ENVISAT ASAR	ENVISAT ASAR
Ascending passes	Descending passes
VV polarization	VV polarization
Track：25	Track：175
Frame：441	Frame：3159
Swath：I2	Swath：I2



ASCENDING

- Coastal reclamation area is the subsidence area with maximum subsidence values.
- The maximum subsidence rate is 15 mm/year.



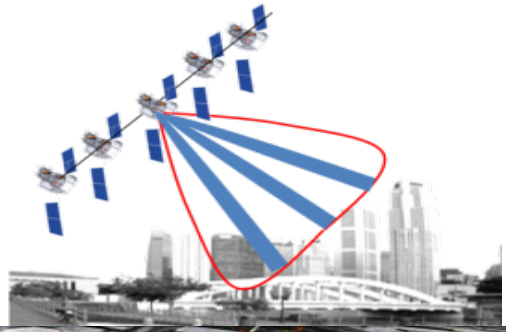
DESCENDING

- Coastal reclamation area is the subsidence area with maximum subsidence values.
- In the common region of ascending and descending passes, the distribution of ground subsidence areas and with great subsidence values are consistent.
- **Hypothesis: East-West displacement low is mostly confirmed.**

- **Further Investigation to be Done Over Next Years**

SAR Tomography/Multi-D SAR Imaging

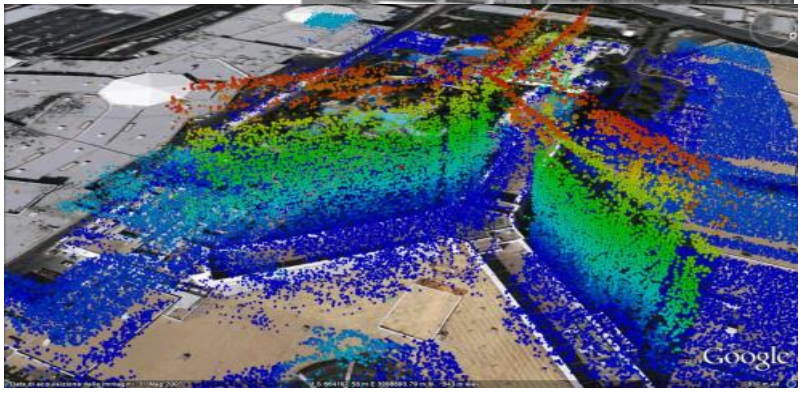
Synthetic Aperture Radar (SAR) Tomography is used to achieve a **fine-beam radar scanning** from satellite able to accurately reconstruct point clouds of buildings and structures and to track their slow movements over time, up to those associated with expansion of thermal origin .



IREA Awards on SAR Tomography:

- ⇨ *IEEE Geoscience and Remote Sensing Letters Award 2011*
- ⇨ *Student Competition prize alla Conferenza IEEE-GRSS/ISPRS JURSE 2011, Muenchen, Germany*

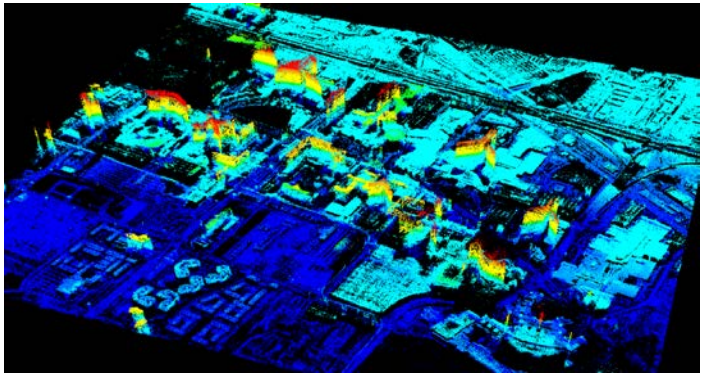
Patent: GFornaro, F. Serafino, F. Soldovieri, «Metodo di elaborazione di dati rilevati mediante radar ad apertura sintetica (Synthetic Aperture Radar - SAR) e relativo sistema di telerilevamento», RM2007A000399, 19 Lug. 2007



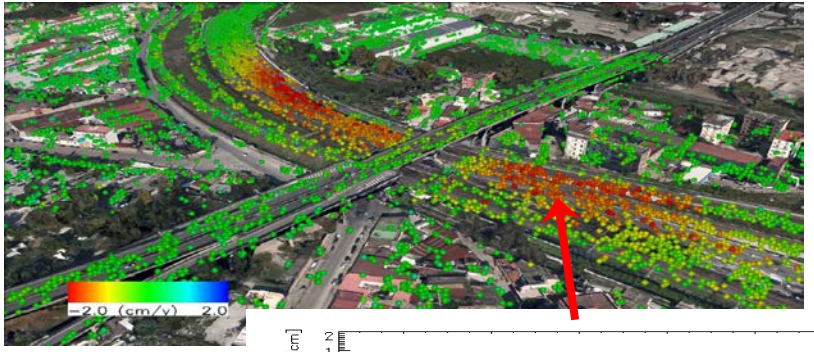
3D Reconstruction of the Mirage Hotel (Las Vegas)
Sensor: TerraSAR-X, Spatial resolution: 1m

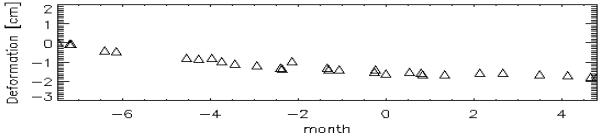
SAR Tomography/Multi-D SAR Imaging for the reconstruction and monitoring of infrastructures and buildings

3D RECONSTRUCTION



DEFORMATION MONITORING





THERMAL DILATION MONITORING