Efficient Earth Surface Monitoring with TomoSAR: from PSDS to ComSAR

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Big Data challenge

- Massive InSAR dataset with time
- How to exploit such Big InSAR Data for long term monitoring ?
- In the literature, Sequential Estimator is an initiative processing scheme to tackle distributed scatterer targets.

Objective

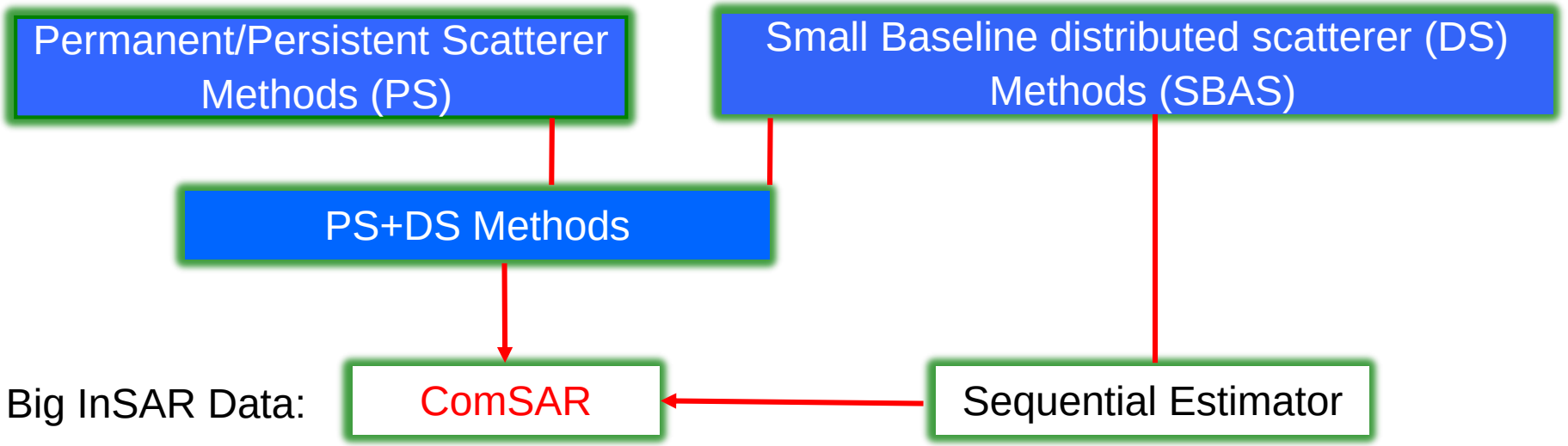
- Phase Linking technique
- Introduce a Compressed SAR (so-called ComSAR) algorithm
- TomoSAR: first open-source PSDS and ComSAR

InSAR time series approaches

- Analysis wrapped phase
- High resolution – single look
- PS limitation in rural environments

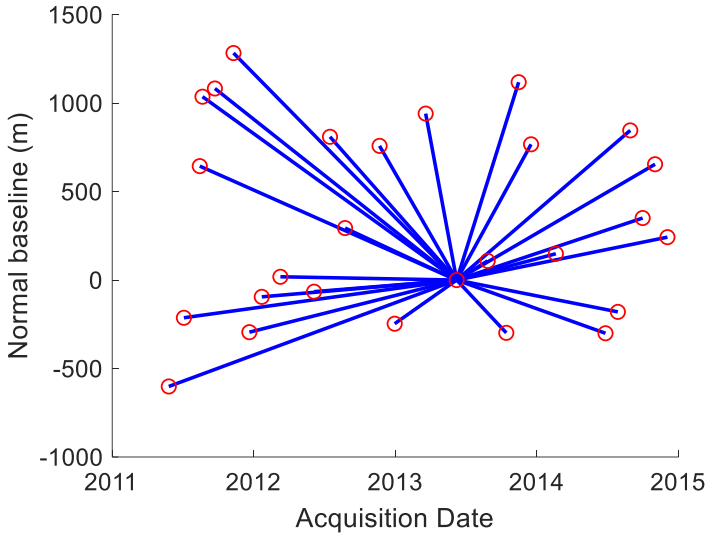
- PS+DS is best for all

- Analysis unwrapped phase
- Low/high resolution – multi/single look
- Works better in rural environments
- Phase unwrapping error
- Lower performance

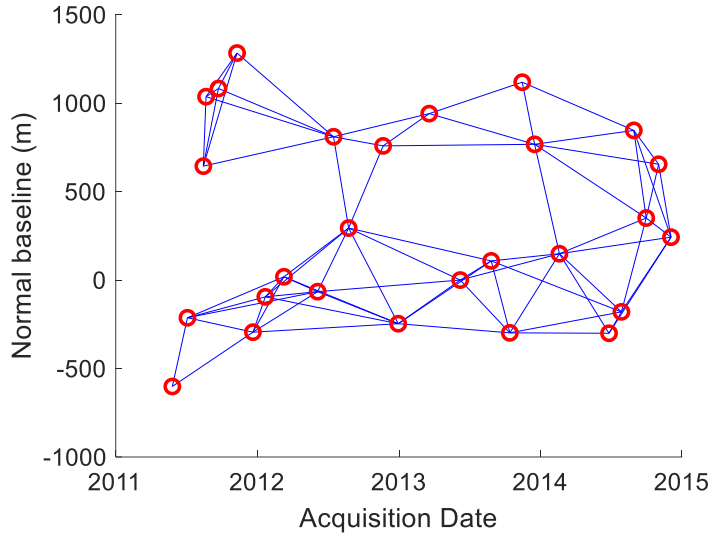


Possible interferometric sets

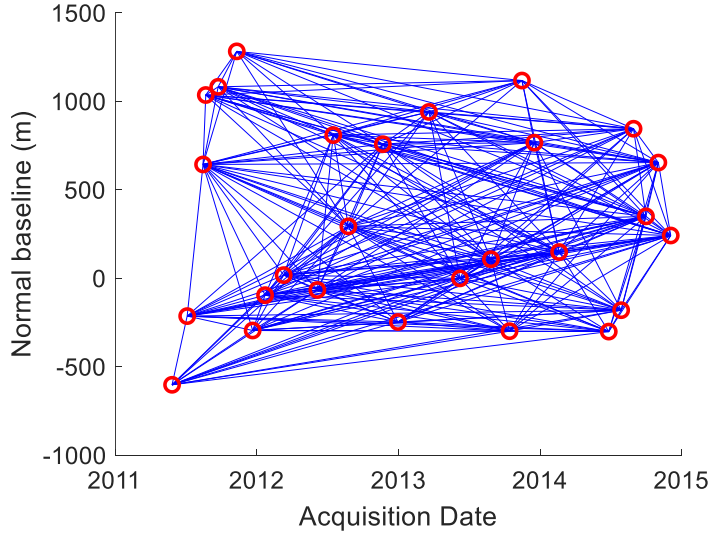
PS single master network



DS subset network

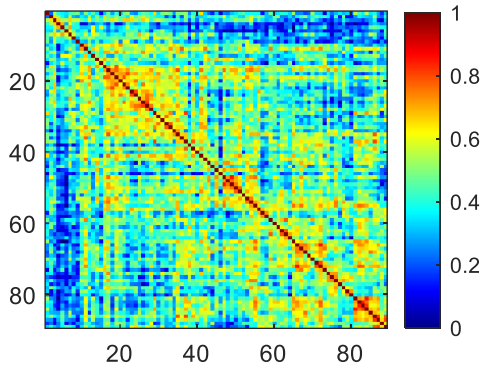


PSDS full connected network



Phase Linking

Suppose N single look complex images are available, all possible combinations equals to N(N-1)/2. As in PS, N-1 values are sufficient.



Phase Linking algorithm is a statistical method (maximum likelihood estimation - MLE) used in interferometry to combine multiple interferometric phases into a single equivalent single-reference.

$$\hat{\boldsymbol{\lambda}}_{\mathrm{MLE}} = \arg\min_{\boldsymbol{\lambda}} \left\{ \sum_{n=1}^{N} \sum_{m=n+1}^{N} \gamma'_{nm} \cos(\phi_{nm} - \vartheta_n + \vartheta_m) \right\}$$

$\boldsymbol{\lambda} = [\vartheta_1, \vartheta_2, ..., \vartheta_N]^T$ is the optimal phase that needs to be estimated from the filtered N(N-1)/2 phases.

γ'_{nm} is defined as weight factor in the optimization.

(D. Ho Tong Minh and S. Tebaldini. Interferometric Phase Linking: algorithm, application, and perspective*. IEEE Geoscience and Remote Sensing Magazine. pp. 2-18, ISSN: 2168-6831. DOI.10.1109/MGRS.2023.3300974. Aug. 2023.)*

Phase Linking

Method Reference	Name	Weight	Descriptions
Computation			
Guarnieri and Tebaldini [10]	MLE	γ'_{nm}	The element of Hadamard product $\lvert\hat{\Gamma}\rvert^{-1} \circ \hat{\Gamma}$, with the iterative solution
Ferretti et al. [11]	MLE	γ'_{nm}	Similar to Guarnieri and Tebaldini [10], with the solution by Broyden–Fletcher–Goldfarb–Shanno algorithm
Cao et al. [13]	Coherence	$\hat{\gamma}_{nm}$	The element of coherence matrix $\hat{\Gamma}$ (with equal-weighted factor $\hat{\gamma}_{nm} = 1$)
Fornaro et al. [14]	EVD	$\hat{\gamma}_{nm}\eta'_{nm}$	η'_{nm} is the element of matrix $\lvert\eta_1\rvert\lvert\eta_1\rvert^T$, where $\lvert\eta_1\rvert$ is the maximum eigenvector of coherence matrix $\hat{\Gamma}$
Ansari et al. [15]	EMI	γ'_{nm}	Similar to Guarnieri and Tebaldini [10], with the iterative solution which initializes as the minimum eigenvector of the matrix $\lvert\hat{\Gamma}\rvert^{-1} \circ \hat{\Gamma}$
Coherence matrix			
Ho Tong Minh and Ngo [16]	MLE	$\gamma_{nm}^{compression}$	The element of Hadamard product $\lvert\hat{\Gamma}_{compression}\rvert^{-1} \circ \hat{\Gamma}_{compression}$
Zwieback [17]	MLE	$\gamma_{nm}^{regularization}$	The element of Hadamard product $\lvert\hat{\Gamma}_{regularization}\rvert^{-1} \circ \hat{\Gamma}_{regularization}$

TABLE I

CHARACTERISTICS OF THE MAIN PHASE LINKING APPROACHES.

(D. Ho Tong Minh and S. Tebaldini. Interferometric Phase Linking: algorithm, application, and perspective. *IEEE Geoscience and Remote Sensing Magazine. pp. 2-18, ISSN: 2168-6831. DOI.10.1109/MGRS.2023.3300974. Aug. 2023.)*

Phase Linking

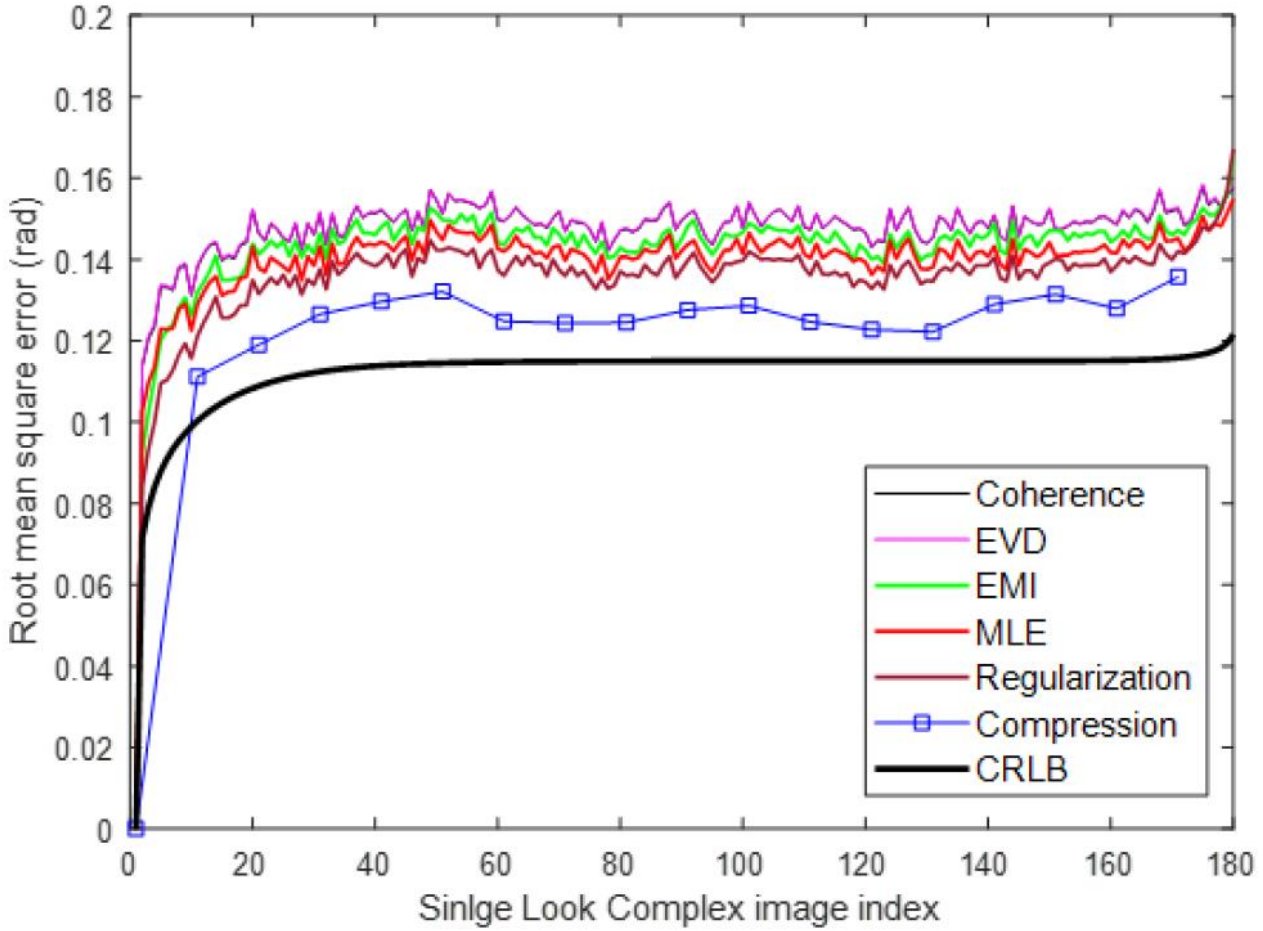


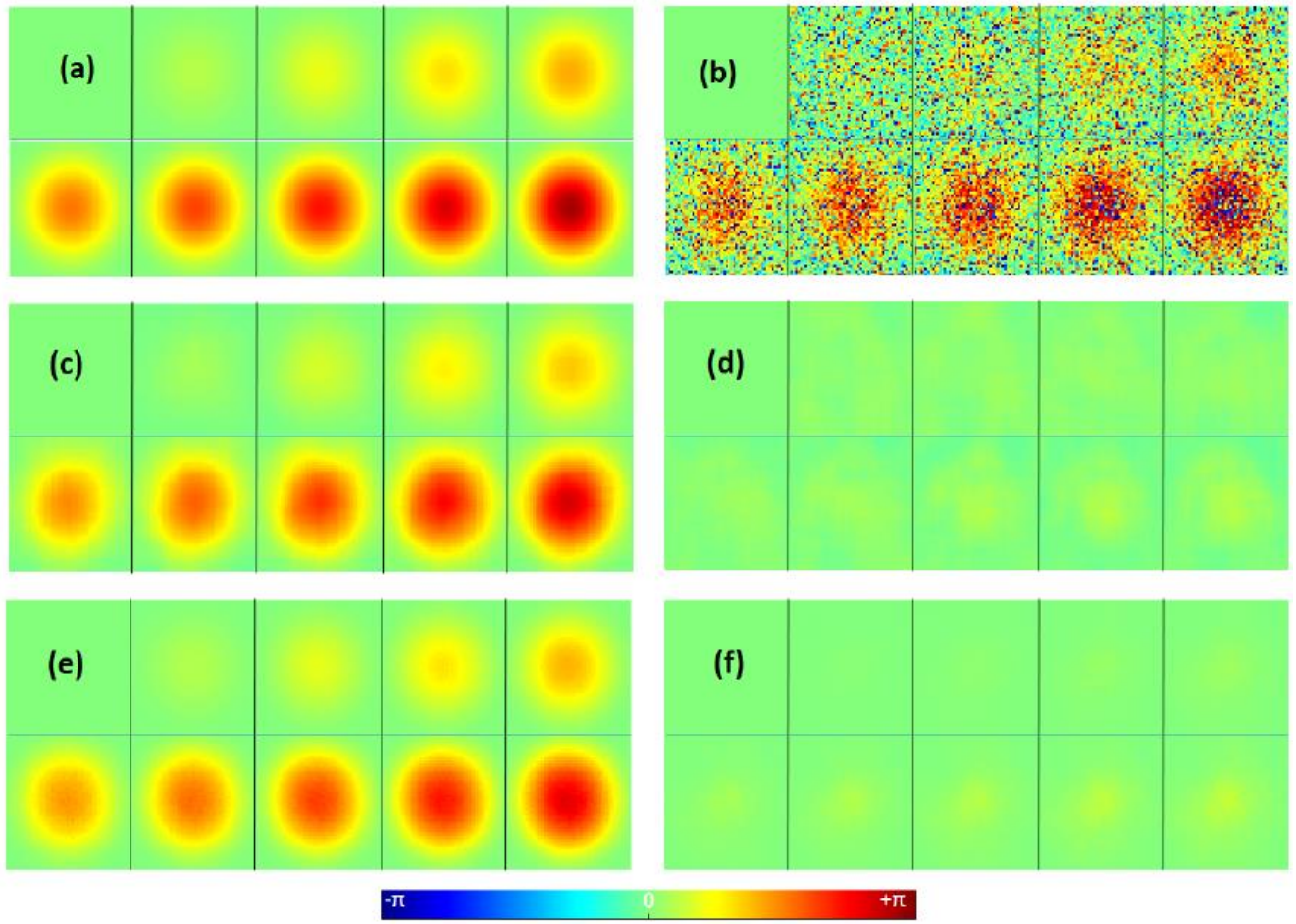
Illustration on Phase Linking performances using a Sentinel-1 temporal coherence model. The coherence is modeled as two exponential decays and a long-term coherent component. The performances are ordered to facilitate the visualization.

*(*D. Ho Tong Minh and S. Tebaldini. Interferometric Phase Linking: algorithm, application, and perspective*. IEEE Geoscience and Remote Sensing Magazine. pp. 2-18, ISSN: 2168-6831. DOI.10.1109/MGRS.2023.3300974. Aug. 2023.)*

Phase Linking

Synthetic example on Phase Linking using Deep Learning.

(a) Simulated deformed signal for interferograms using the first acquisition as the reference image.
(b) Interferograms after adding decorrelation noise.
(c) Results of the MLE method using all interferograms.
(d) Residuals of the MLE method (i.e., the difference between subfigures (a) and (c)).
(e) Results of the Deep Learning method using Unet model.
(f) Residuals of the Deep Learning method (i.e., the difference between subfigures (a) and (e)).



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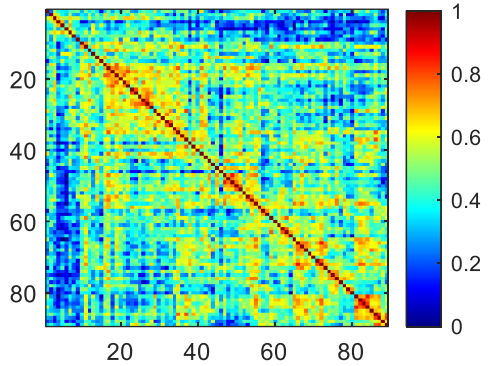
From PS to PS+DS

<u>Identification</u> of Distributed Scatterers

- At each range-azimuth (r,x) location, find the family of statistically homogeneous pixels (SHP) by applying the two-sample test.

- **InSAR coherence matrix (the main actor)**: the matrix of complex correlation among all available interferometric at each range-azimuth location.

$$W_{nm}(r,x) = \langle y_n\ (r,x,\boldsymbol{SHP_i}) \cdot y_m^*(r,x,\boldsymbol{SHP_i})\rangle$$

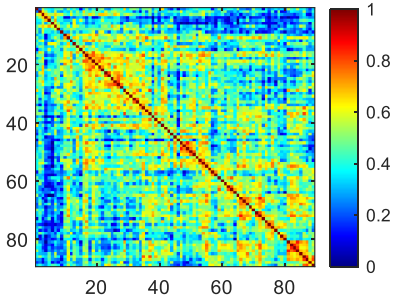


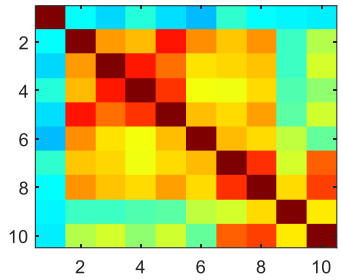
- The **Phase Linking** algorithm is employed to exploits all the N(N-1)/2 interferograms available from N images, in order to squeeze the best estimates from the N - 1 phases.

- Select the DS exhibiting a phase linking coherence value higher than 0.25 and substitute the phase values of the original SAR images with their optimized $\varphi_n(r,x)$ values.

When the selection of PSDS candidates is done, the traditional PS algorithm can be applied for the estimation of displacement time series of each measurement point.

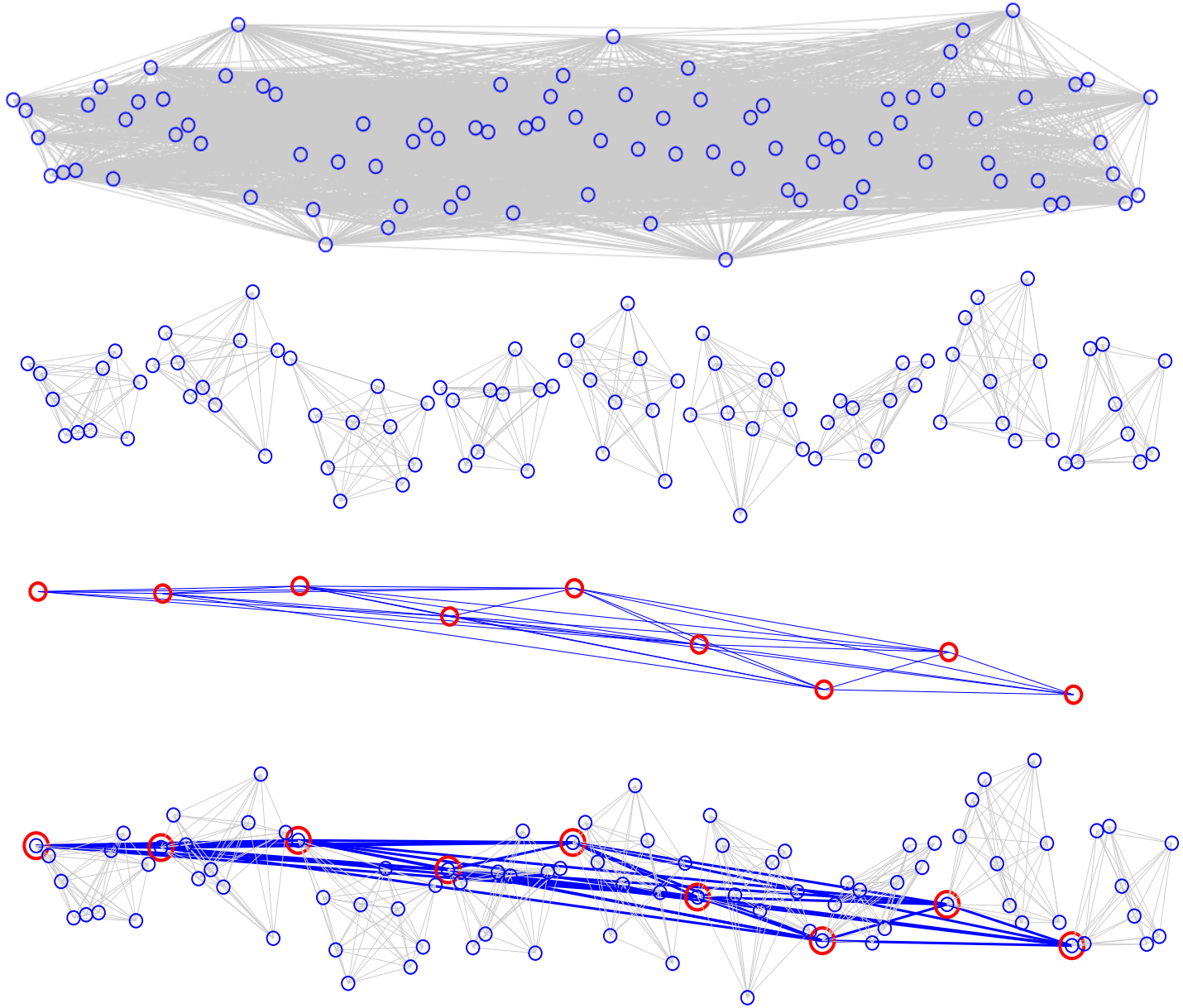
From PSDS to ComSAR



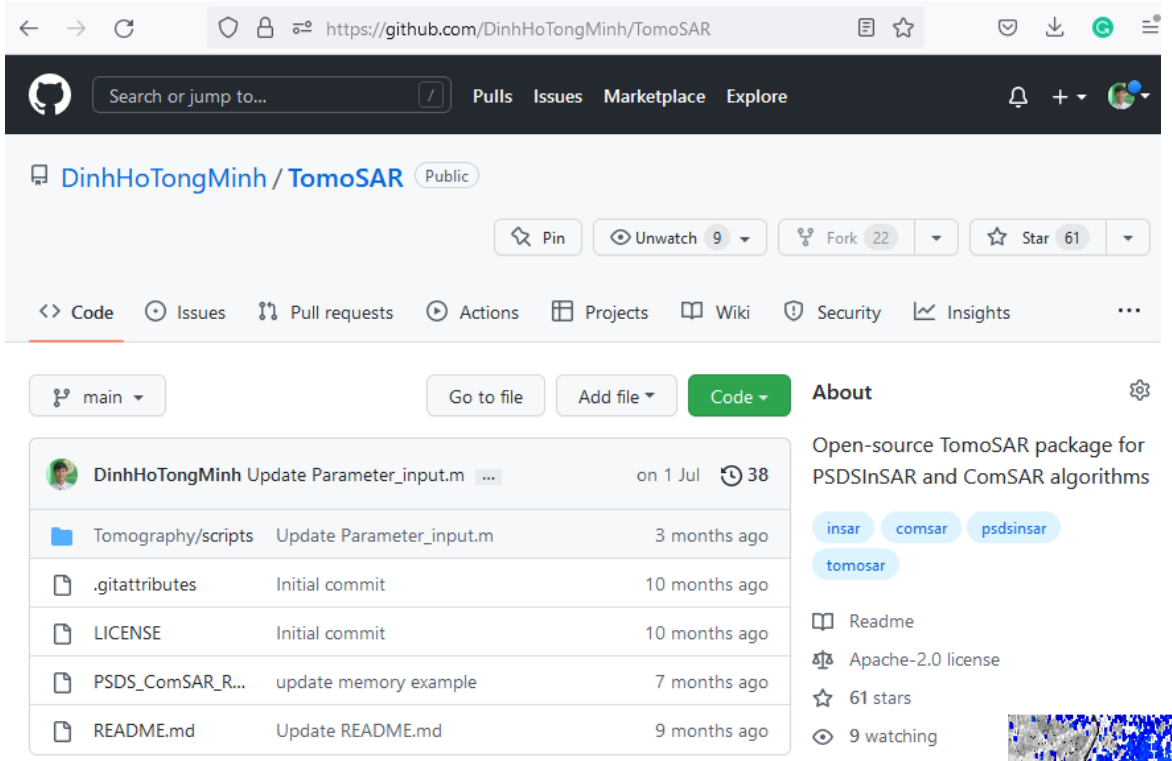


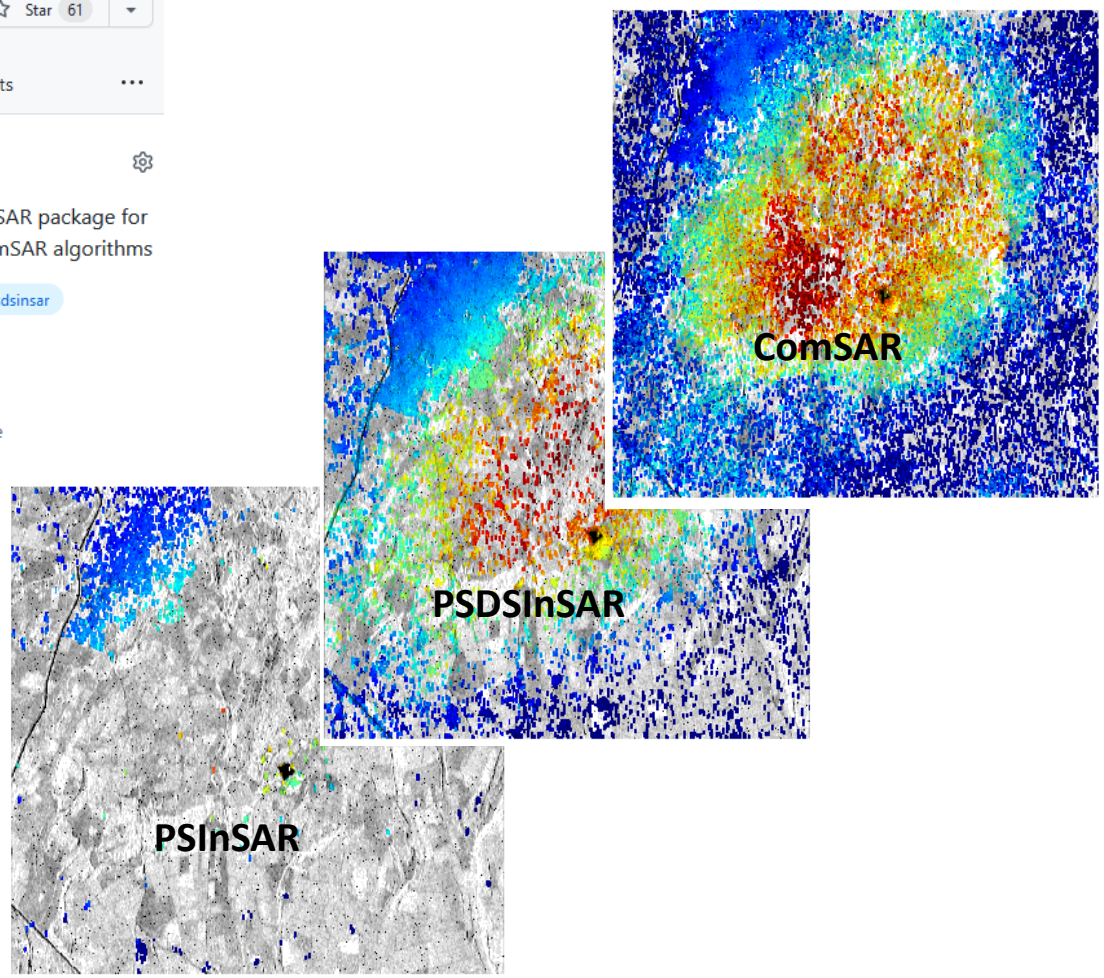
Compressed version

Full time series



TomoSAR: open-source PSDS and ComSAR





ComSAR is friendly Big Data processing.

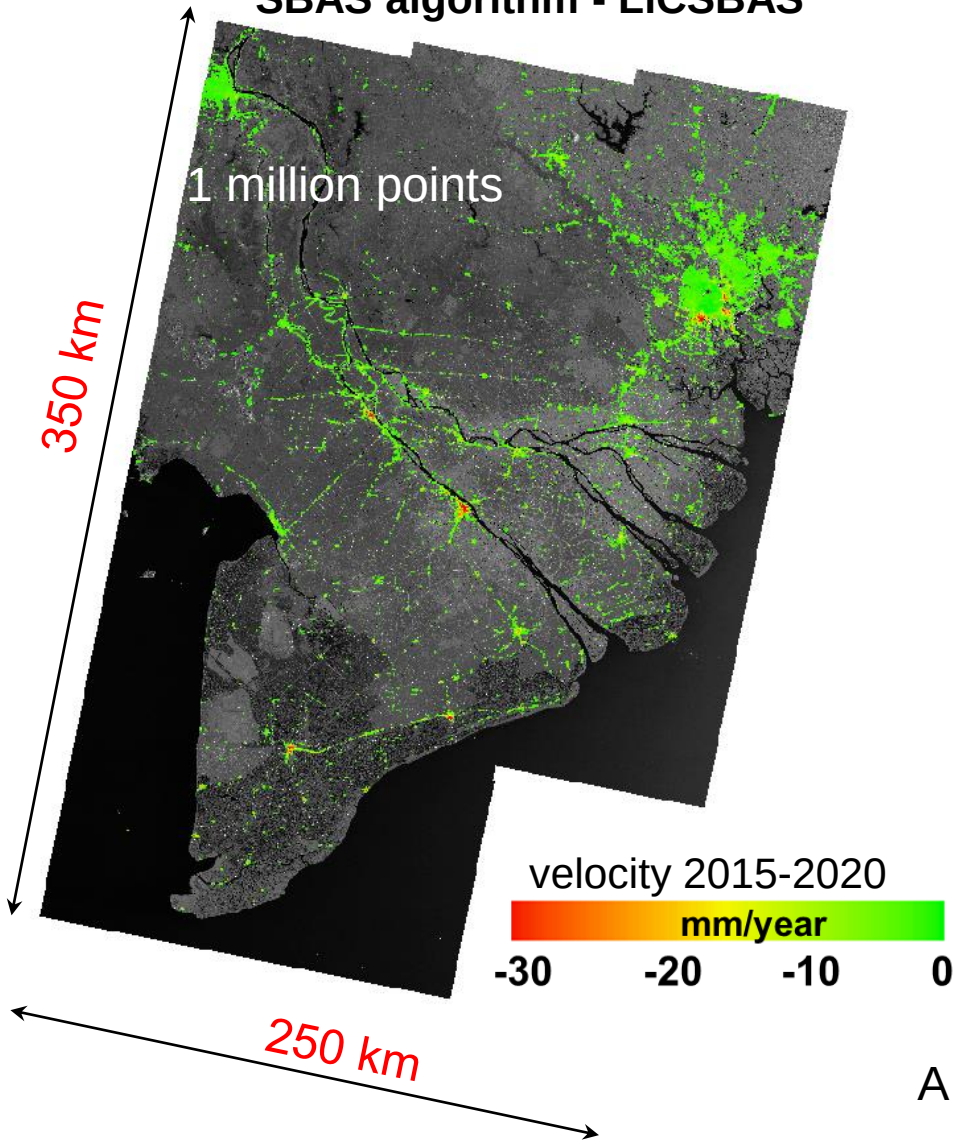
i.e:

200 images of 500x2000 size

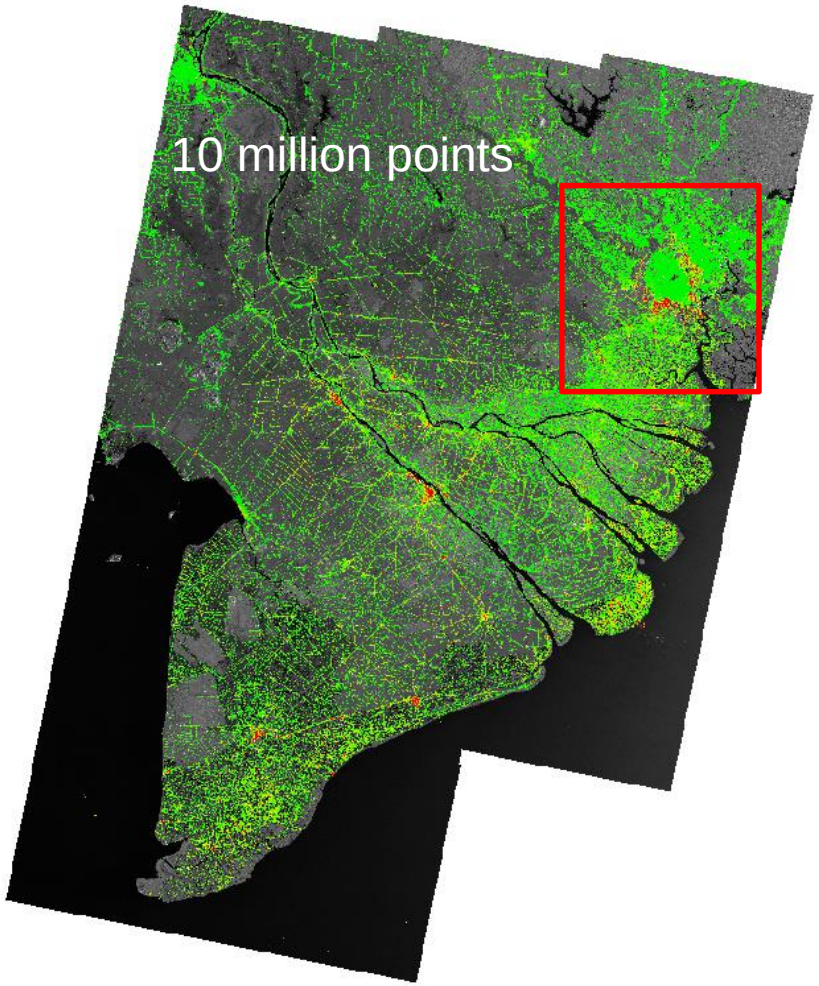
- 220 GB is for PSDS
- 45 GB for ComSAR

Delta-wide subsidence

SBAS algorithm - LiCSBAS



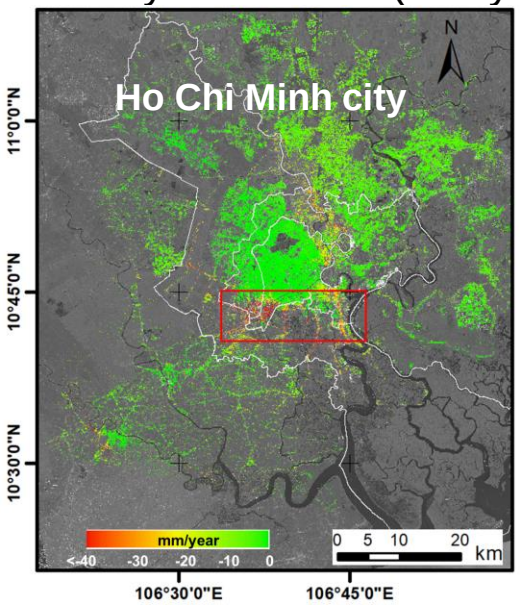
PSDS algorithm - TomoSAR

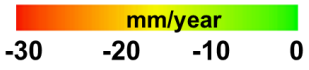


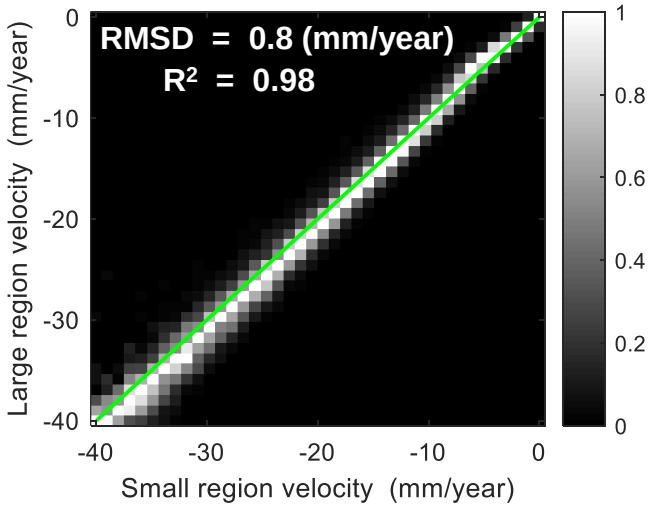
A coherent processing in one SLC coverage !

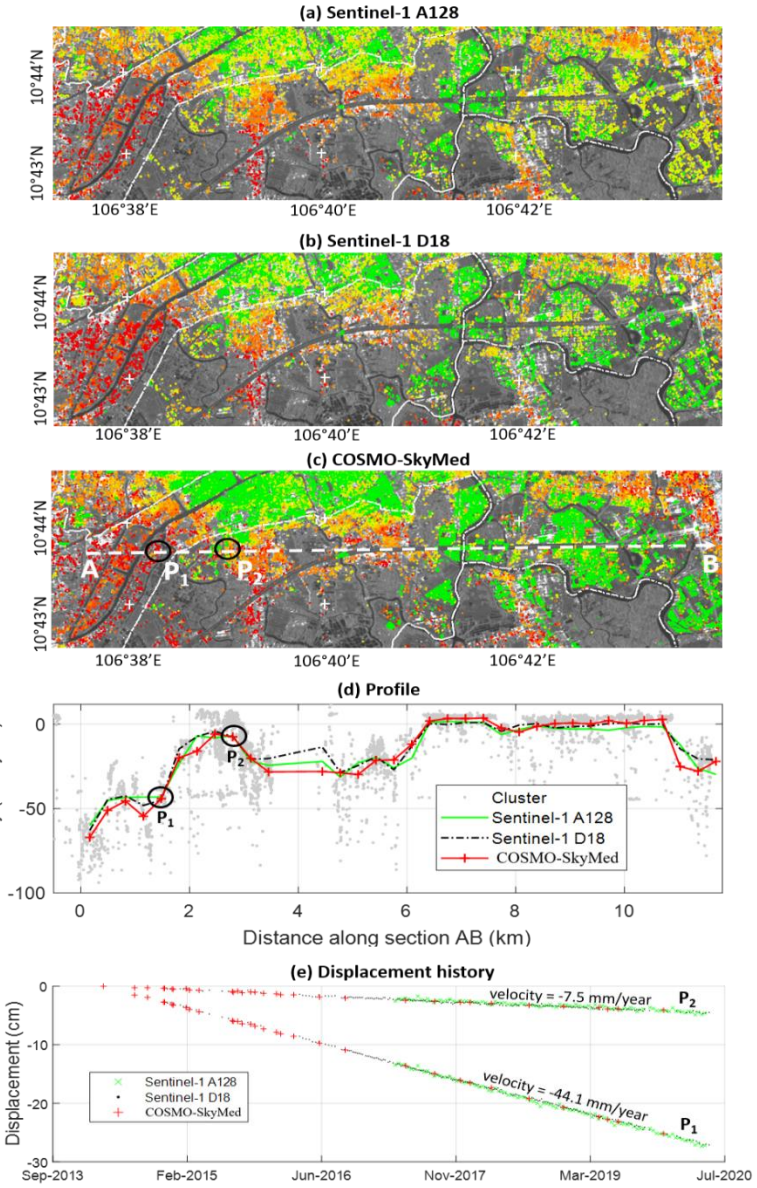
Delta-wide subsidence

Velocity 2015-2020 (mm/year)



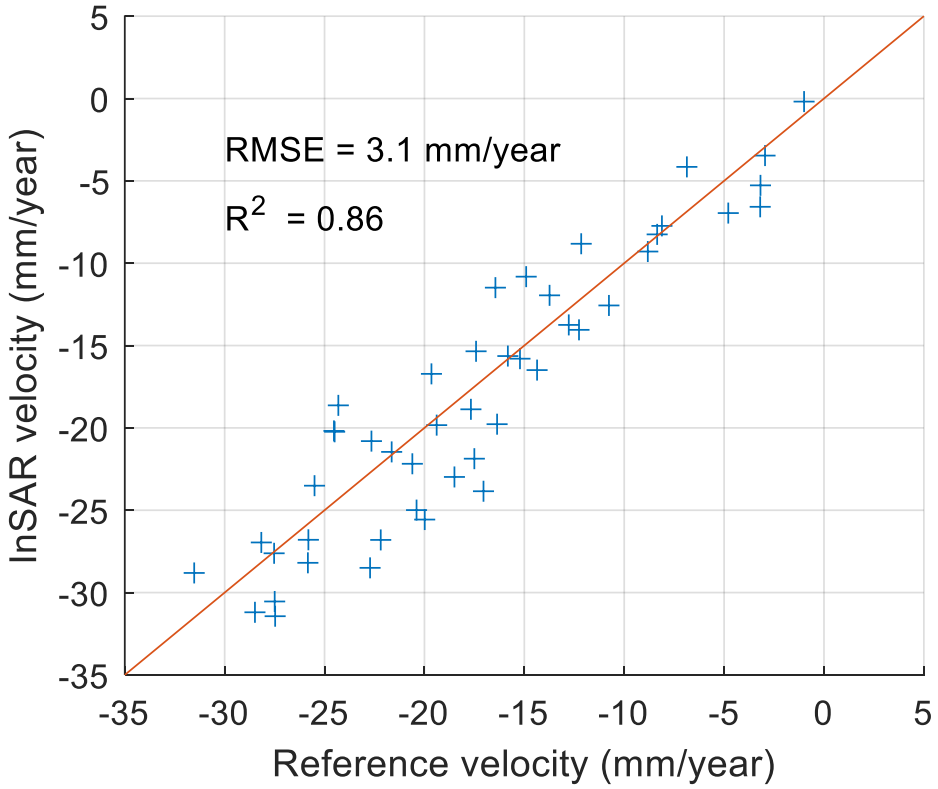


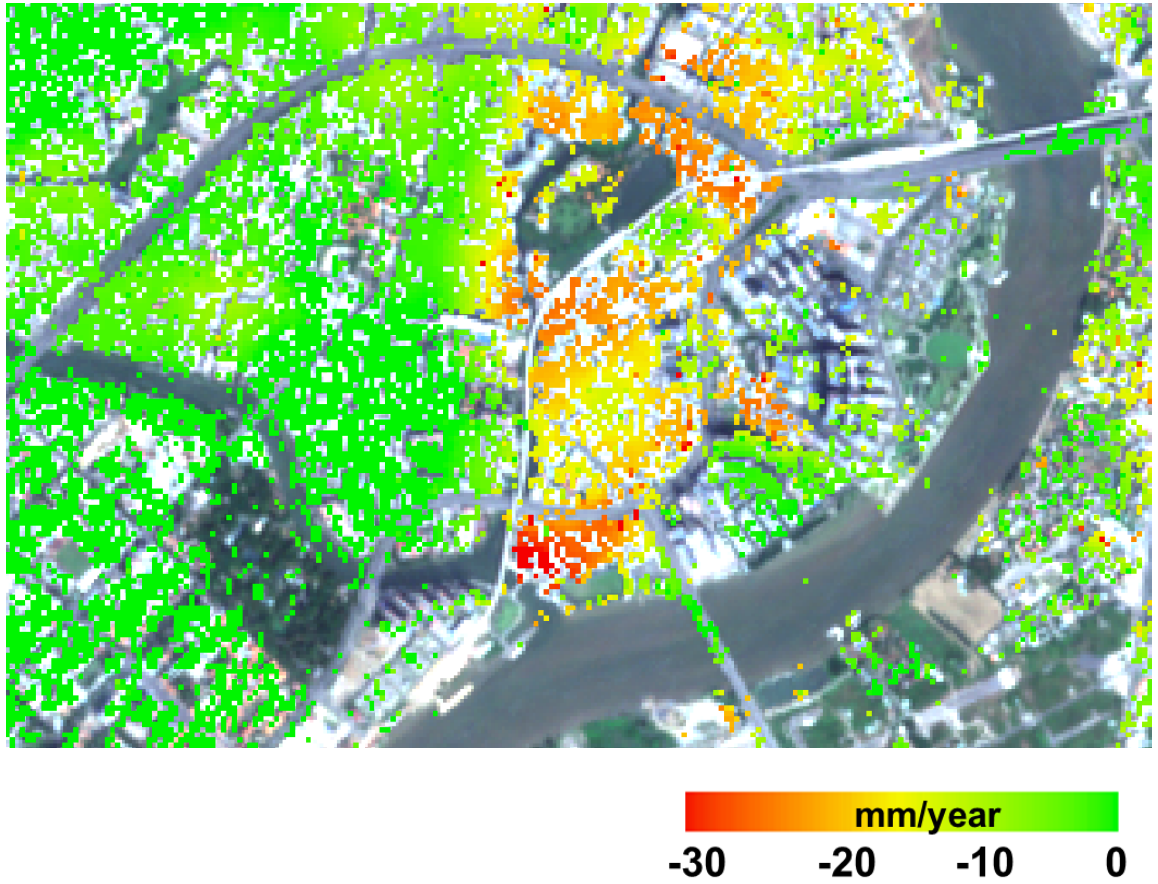




(The HCMC velocities are freely available for download from https://zenodo.org/record/5497723)

Delta-wide subsidence





Good agreement in vertical velocity between reference and InSAR velocity (2017 - 2021)

Summary

- **Phase Linking algorithm is the key to handling signal decorrelations. Deep Learning approach can be a valuable tool to improve the accuracy and efficiency of the process.**

- **TomoSAR is the first public domain tool available to jointly handle PS and DS targets (https://github.com/DinhHoTongMinh/TomoSAR).**

- **Follow us at:**

https://www.youtube.com/DinhHoTongMinh

https://www.facebook.com/groups/RadarInterferometry

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