Parallel Processing of Sentinel-1 InSAR Time-series Data for Large Scale Deformation Detection in North China Plain

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ABSTRACT

Boosted by the launch of Sentinel-1 radar satellites from the European Space Agency (ESA), we now have the opportunity to investigate the large-scale tectonic deformation and anthropogenically caused crustal deformation. Here we use the 4-year times-series data in the entire North China Plain (NCP), to detect the surface subsidence related deformation. By using the Sentinel-1 Synthetic Aperture Radar (SAR) data in the Interferometic Wide Swath mode(IW), we obtain one track of 5/6 frame InSAR data over the NCP region, about 1000 km long and 250 km wide. To accelerate processing, we parallelize the modules of StaMPS software, and utilize the Chinese high-performance computation (HPC) facility, named Sunway TaihuLight. The Line-of-Sight (LOS) InSAR data are inverted for the subsidence/uplift distribution of the entire NCP region, and the deformation of the whole NCP are presented for the first time. However, the correlation between subsidence distribution and the fault zones of NCP is worth for further research.

INTRODUCTION

The NCP is a vital agricultural region of China and is highly-populated, so the groundwater utilization is quite heavy in this region for irrigation by human beings. This leads to an overdraw of groundwater and fast subsidence over the whole area.

Over the last 50 years, with the rapid growth of urban population, groundwater has been overexploited, which leads to fast and severe subsidence problem. After groundwater losing supply balance, there would be irreversible inelastic permanent deformation. And a series of geological disasters and ecological environment problem would occur and be intensified. In recent years, some groundwater recharge experiments have been taken and some protection policy are implemented, the rate of surface subsidence is slow down, but no reversal occuring.

OBJECTIVE

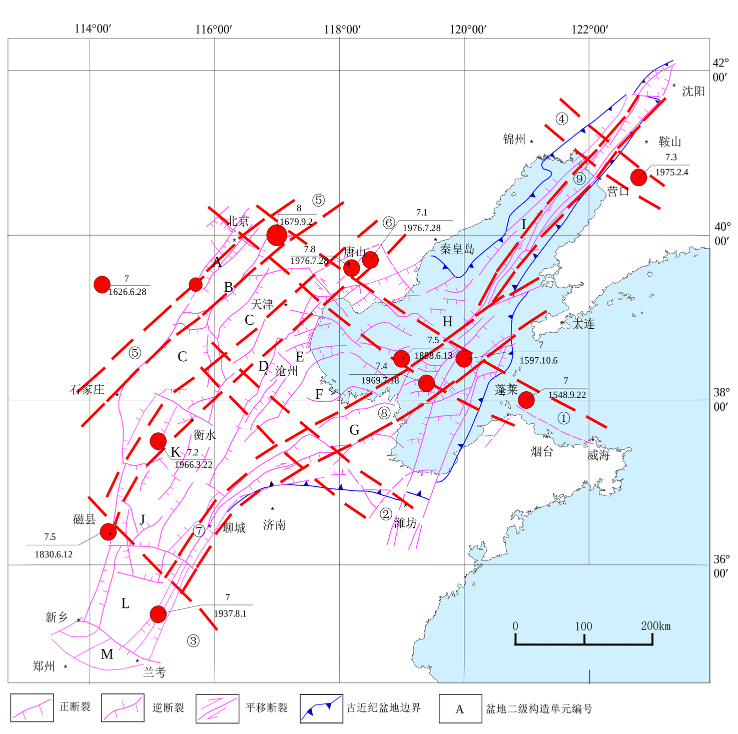


Figure 1. Tectonic map of NCP, according to the research by Xu Jie and Ji Fengju in 2015. The pink lines are inactive fault zones, and the red lines are Cenozoic active fault zones. Red points are Ms ≥ 7.0 earthquakes from A.D. 1000 to the present in the NCP. Three systems of active faults, such as eastwest-, northeast- and northwest-trending faults have been revealed. They are all under the effect of nearly east- west-orientated compressive stress. The northeast-trending faults have undergone right-lateral shear, while the northwest-trending faults have left-lateral strike-slip component of motion.

METHOD

The Sentinel-1A radar satellite of ESA acquires C-band SAR images using the IW mode with 12-day revisiting cycles, and will be able to revisit same ground target and form interferometric images with 6-day intervals with the Sentiel-1B satellite together. We utilize 72 SAR data in track A142, from Aug 23, 2015 to Nov 11, 2018. Then we choose the Dec 10, 2017 as master image for keeping high spatiotemporal coherence. As over 50 millions PS points identified in NCP, no single workstation could hold on the data volume. Therefore we use mesh algorithm for parallel processing of the data, and also use HPC to deal with it.

We use GAMMA software to generate interferograms in parallel, and StaMPS based on MATLAB to make PS points selection and processing. We mesh the research area into 908 patches (Figure 2), with each patches containing no more than 500 thousand PS points. Then we use parallel processing of StaMPS on HPC (Figure 3).

We use parallelized kriging interpolation method to estimate spatially correlated atmosphere noise on unwrapped phase. By setting suitable spatially correlated distance threshold, we can estimate the covariance matrix(Σ_{aps}^{sar}) among all of the PS points for atmosphere noise filtering.

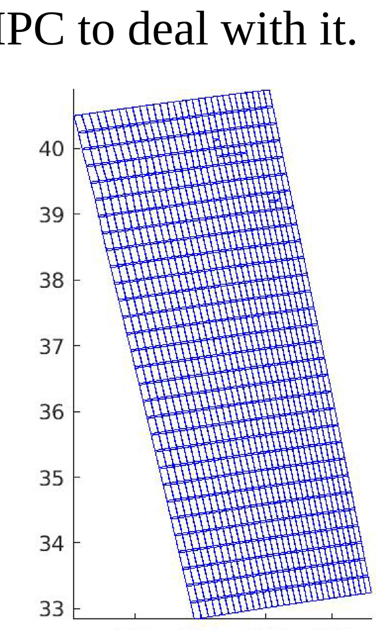


Figure 2. Mesh result, totally 908 patches.

$$\phi_{aps}^{x,y} = c \cdot L_{x,y}^{\alpha} + k \cdot H_{x,y}$$

$$\eta_{aps}^{x,y} = \frac{1}{2} \cdot \left[\left(\phi_{aps}^{x,ref}\right)^2 + \left(\phi_{aps}^{y,ref}\right)^2 - \left(\phi_{aps}^{x,y}\right)^2\right]$$

$$\Sigma_{aps}^{sar} = \begin{bmatrix} \eta_{aps}^{1,1} & \cdots & \eta_{aps}^{1,p} \\ \vdots & \eta_{aps}^{x,y} & \vdots \\ \eta_{aps}^{p,1} & \cdots & \eta_{aps}^{p,p} \end{bmatrix}$$

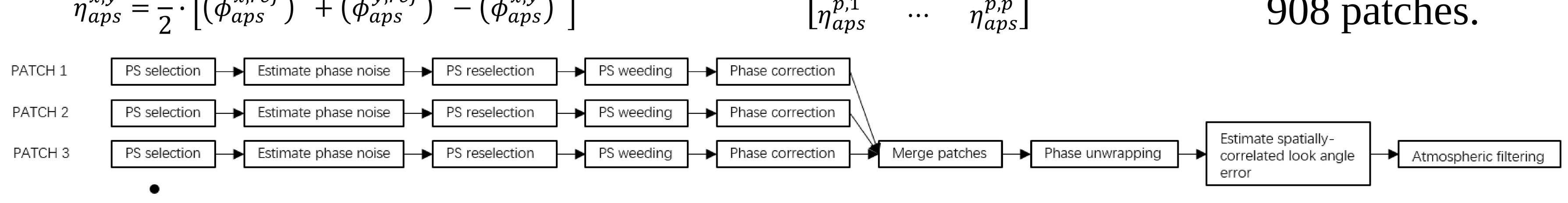
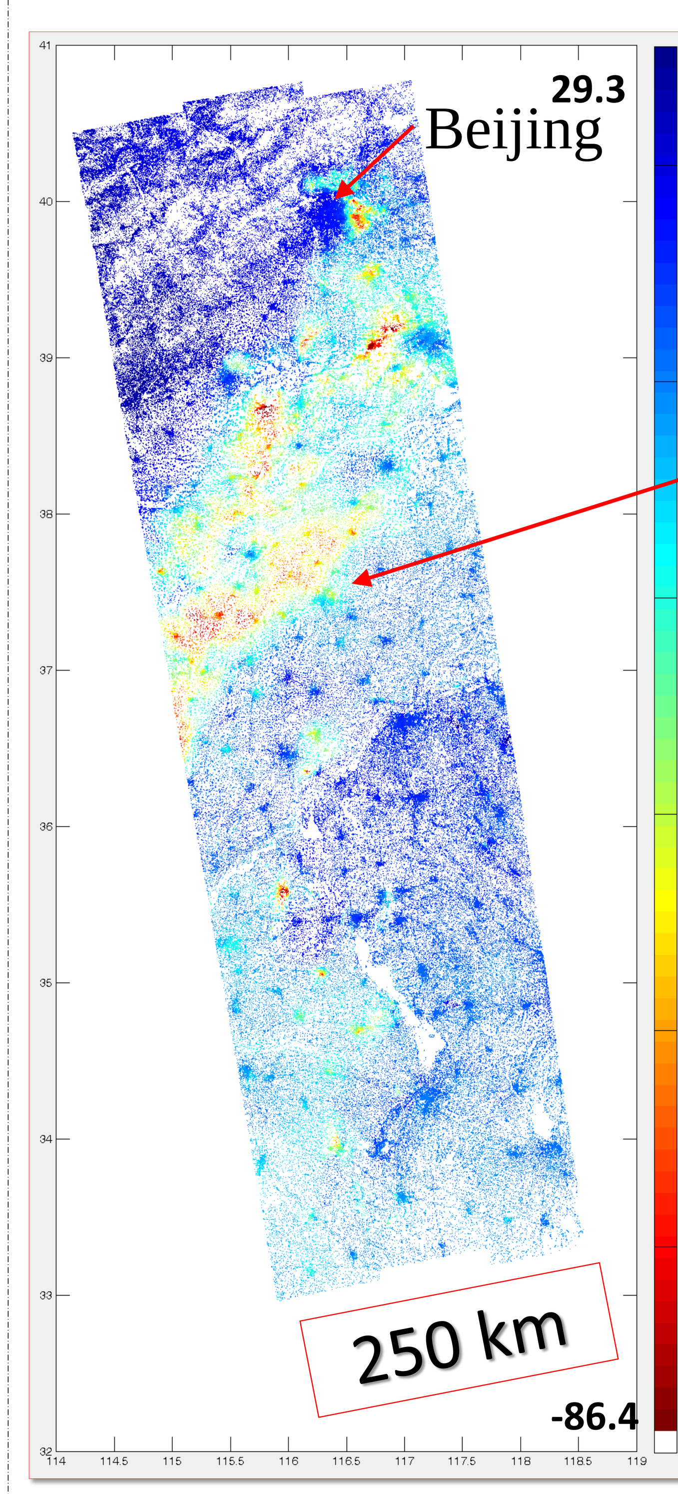
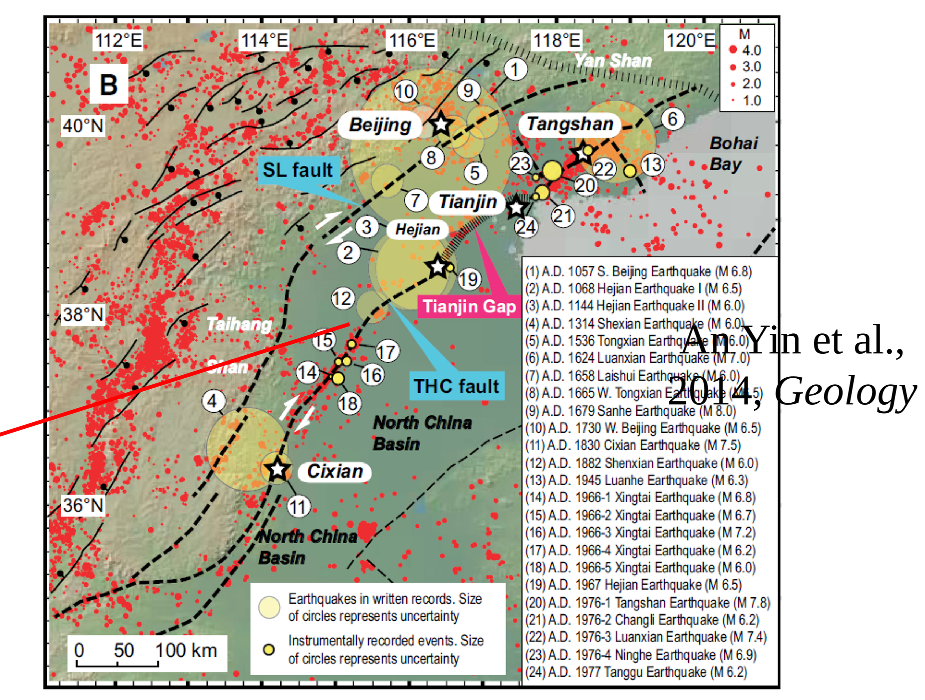


Figure 3. The processing flow chart for StaMPS. Before merge step, the process between different patches are independent, so we use different calculate nodes on HPC to process it parallel. After merge step, we need to process all the patches together, so we use the large memory node on HPC, the so called "the fat node".

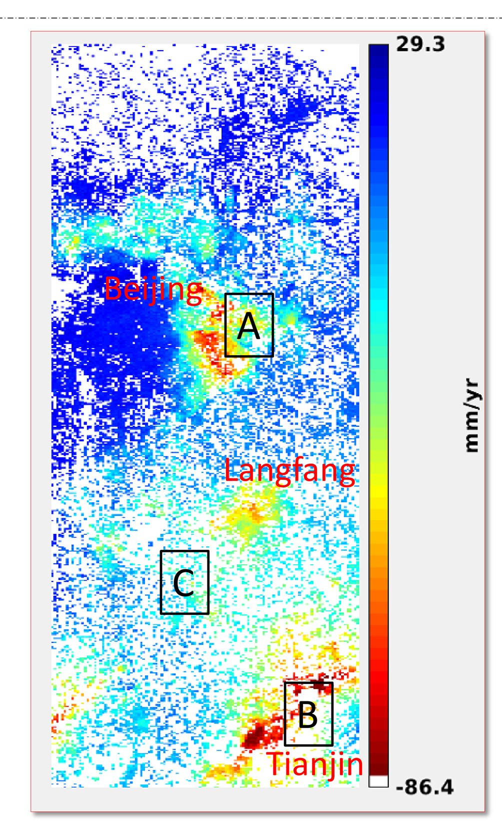
RESULT

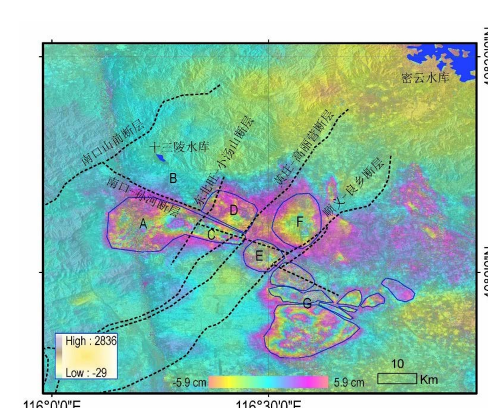




An Yin et al., 2014, *Geology*

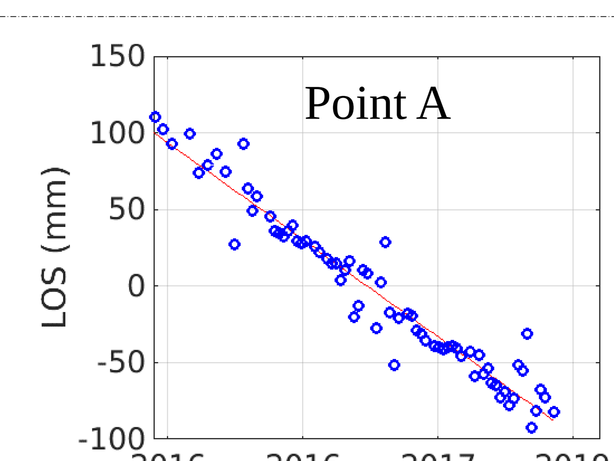
Figure 4. The left figure is the distribution of average LOS deformation rate in units of mm/year. Subsidence is the most important source of deformation. The fastest subsidence rate is about 80 mm/year. The right figure is the distribution of several active faults in NCP. We can easily find out that the southern boundary of subsidence area is highly correlation with THC fault, the Tangshan-Hejian-Cixian fault. Also, the northern boundary of subsidence area is highly correlation with TMP fault, the Taihang Mountains Piedmont fault, a late Quaternary active fault zone.

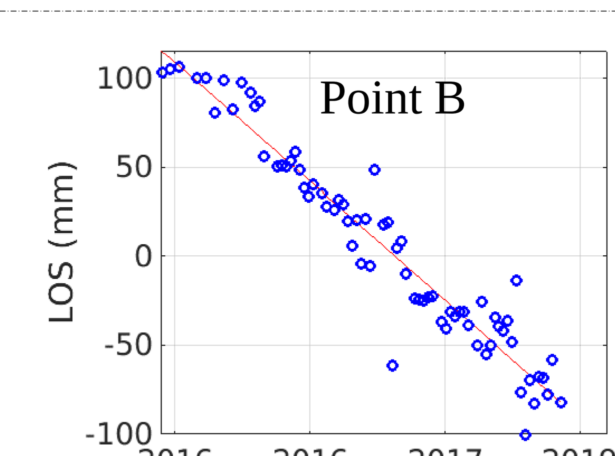




Liang Fang et al., 2013, *Earthquake*

Figure 5. The left figure is the detail around Beijing. We can see high correlation between subsidence area with highly-populated cities. The upper figure is the result of subsidence distribution using ALOS-1 data by Liang Fang et al. Both results show the highly correlation between the subsidence distribution and the fault zones.





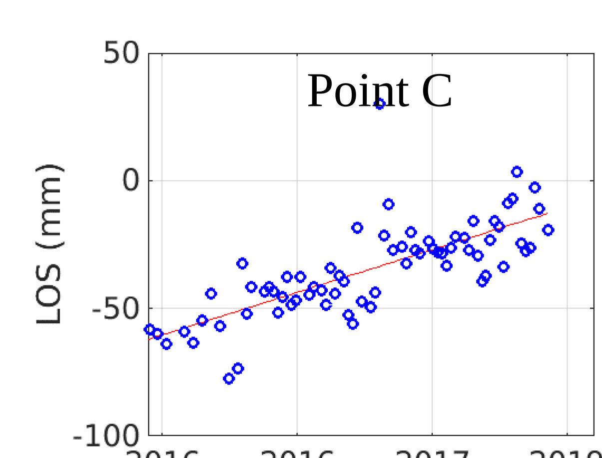


Figure 6. Several typical sampling point's time series of all the 72 unwarp interferograms. The locations of three points are shown in Figure 5. Point A is in the subsidence region near Beijing City. Point B is in the subsidence region near Tianjin City. Point C is in the non-subsidence region between two points.

CONCLUSION

Using parallel processing method and HPC, the Sunway TaihuLight, we get large-scale deformation distribution and time-series evolution of NCP in last four years. For the most important source of deformation is surface subsidence, we can see severe subsidence in NCP region, especially around highly-populated cities. Also, we could find highly correlation between the subsidence boundary and the fault zones, regardless of active or inactive they are. The mechanism is under further investigation. The work is support by Dragon 4 project for seismic detection (ID 32431).