Large-scale Long Time-series InSAR Land Subsidence Research in the Pearl River Estuary

xiaowen lu (✉ cdslxw@163.com)

The second institute of oceanography ,SOA

Hui Gao

Second Institute of Oceanography SOA

Ziyin Wu

Second Institute of Oceanography SOA

Shoujun Li

Second Institute of Oceanography SOA

Jihong Shang

Second Institute of Oceanography SOA

Dineng Zhao

Second Institute of Oceanography SOA

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1 **Title page:**

2 **Title: Large-scale Long Time-series InSAR Land Subsidence Research in the Pearl**

3 **River Estuary**

4 Author #1: **Xiaowen Luo**, No. 36, Baochubei Road, Hangzhou, China,

5 cdslxw@163.com

6 Author #2: Hui Gao, No. 579, Qianwangang Road, Qingdao, China and

7 No. 36, Baochubei Road, Hangzhou, China, 407842481@qq.com

8 Author #3: Ziyin Wu, No. 36, Baochubei Road, Hangzhou, China and No. 800,

9 Dongchuan Road, Minhang District, Shanghai, China, zywu@sio.org.cn

10 Author #4: Shoujun Li, No. 36, Baochubei Road, Hangzhou, China,

11 0911guang@163.com

12 Author #5: Jihong Shang, No. 36, Baochubei Road, Hangzhou, China,

13 shangjihong@yeah.net

14 Author #6: Dineng Zhao, No. 36, Baochubei Road, Hangzhou, China,

15 zhaodineng@sio.org.cn

16

Abstract

Due to the influence of human activity and changes in natural conditions, the Pearl River Estuary (PRE) has emerged as a large-scale area of land subsidence, which represents a serious threat to the quality of human life and sustainable socio-economic development. In response to the problems associated with the lack of man-made targets of traditional time-series Interferometric Synthetic Aperture Radar (InSAR) in estuaries and other coastal areas, a distributed scatterers (DS) InSAR method based on a spatially adaptive filter and an eigendecomposition algorithm to estimating the optimal phase of statistically homogeneous DS was applied to obtain subsidence data using 67 scenes Sentinel-1A SAR images covering the PRE. The temporal and spatial distribution characteristics of land subsidence were analyzed. The results suggest that land subsidence in the PRE was widespread and unevenly distributed with large differences between 2015 and 2018. The northwest and southeast are the main subsidence areas, with a maximum sedimentation rate greater than 25 mm/year.

Keywords

33 Pearl River Estuary, Estuarine coastal zone, Land subsidence, Distributed scatterer,

34 Time series

35

36 **Main Text**

37 **Introduction**

38 The Pearl River Delta (PRD) is located in the south-central region of the Guangdong

39 Province, China, adjacent to Hong Kong and Macao, which is characterized by dense

40 cities with developed economies. The PRD is one of the three major economic circles in

41 China and is known as the "South China Sea Pearl." Estuary deltas are vulnerable to

42 marine, terrestrial, and river interactions (Song and Liu 2013). During the past 30 years,

43 the PRE has developed rapidly but human activity, such as infrastructure construction

44 and underground mining, as well as changes in natural conditions, has influenced the

45 PRE to such an extent that the PRE has developed large-scale land subsidence, which

46 can cause a series of geological hazards, such as the destruction of infrastructure.

47 Moreover, global sea level rise (Nicholls and Cazenave 2010) has aggravated the impact

48 of saltwater upwelling and the risk of storm surge disasters, which represents a serious

threat to the quality of human life and sustainable socio-economic development (Dixon et al. 2006; Higgins et al. 2014). Therefore, accurately monitoring land subsidence throughout the PRE in a timely manner and investigating the causes of subsidence are crucial.

Interferometric Synthetic Aperture Radar is characterized by all-weather, wide coverage, such that it can rapidly gather global high-precision three-dimensional terrain and micro-deformation data (Zebker et al. 1994; Massonnet and Feigl 1998). In recent years, Time series analysis methods (e.g., Permanent Scatterer (PS) InSAR (Ferretti et al. 2001) and Small Baseline Subset (SBAS) InSAR (Berardino et al. 2002)) have been widely used to monitor land subsidence in coastal areas (Jiang and Lin 2010; Wang et al. 2012; Liu 2013; Zhang et al. 2013; Erban et al. 2014; Liu et al. 2016; Zhang et al. 2016).

However, conventional time series InSAR methods used strict selection of the monitoring point target and required a high coherence level in all of interferograms (Prati et al. 2010). But there are few artificial targets in coastal areas, atmospheric disturbance is complicated, and subsidence is widespread and unevenly, it is too

65 difficult to accurately reflect the temporal and spatial variations of the land subsidence
66 (Jiang et al. 2011; Sun et al. 2018). As a result, these methods are limited in coastal land
67 subsidence monitoring.

68 Ferretti et al. (2011) proposed the SqueeSAR method to increase the density of effective
69 monitoring points by joining PS and DS targets. But this method needs to iteratively
70 solve the nonlinear optimal phase, which seriously affects the calculation efficiency.

71 Pointing at the above problems, Han et al. (2017) proposed a method based on an
72 eigendecomposition algorithm to estimating the optimal phase of statistically
73 homogeneous DS, which greatly improved the calculation efficiency. The application in
74 Shangyu District along the Hangzhou Bay coast verified the Effectiveness. In view of
75 the current research on the land subsidence in the Pearl River Estuary, which are all
76 within a small area (Wang et al. 2012; Yang and Li 2018; Dai et al. 2019), with the free
77 publication of Sentinel-1A data, this paper uses the method proposed by Han[21] to
78 monitor large-scale land subsidence in the PRE from 2015 to 2018 with 67 scenes
79 Sentinel-1A SAR images. And the deformation time series and annual deformation rate
80 with a high spatio-temporal resolution were obtained. The leveling data were applied to

evaluate the accuracy of the InSAR monitoring results. We also analyzed the spatial and temporal distribution characteristics of the subsidence.

Methods

This paper applied the time-series InSAR method proposed by Han et al. (2017), Figure 1 shows the overall framework of the DSInSAR. The basic data processing steps are as follows, first, the SLC images are registered to the master image, the nonparametric tests is used to select the candidate points of stable DS and the phase of the DS candidate point target is used to perform spatial adaptive filtering and construction of the covariance matrix. Then, the optimal phase is estimated by the eigendecomposition method and substitutes the phase value of the original SAR images. Finally, the selected DS according to the goodness of fit test is processed together with the PS using the conventional PSInSAR algorithm for estimating the displacement time series for each measurement point, including terrain error correction, atmospheric error correction, base line refinement and phase unwrapping. The key steps of estimating the optimal phase based on the eigendecomposition method in the process of DS point selection are below.

Fornaro et al. (2015) proposed the method to estimate the optimal phase of eigendecomposition algorithm first. The optimal phase is estimated by extracting the phase of the eigenvector related to the largest eigenvalue from the covariance matrix or coherence matrix. The eigendecomposition of the coherence matrix selected by the KS test algorithm and subjected to spatial adaptive filtering is obtained as follows:

$$T = \sum_{i=1}^N \lambda_i T_i = \sum_{i=1}^N \lambda_i U_i U_i^H \quad (1)$$

where λ_i is the eigenvalue and sorted in descending order, and U_i is the eigenvector.

Assuming that U_1 is the maximum feature component, it can be expressed as a maximum constraint problem, and the phase of the feature vector corresponding to the maximum feature value is taken as the optimal phase of the DS candidate point (Cao et al. 2016).

$$U_1 = \arg \max_u \{U_1^H T U_1\} \quad (2)$$

with the constraint condition:

$$U_1^H U_1 = 1 \quad (3)$$

Verview of the study area and study data

Study area

113 The PRD is located in the estuary of the Pearl River, which has formed from deposits
114 that derive from the Xijiang River, Beijiang River, and Dongjiang River. The
115 geographical coordinates are 112°30'–114°15'E and 21°17'–23°30'N. The PRD is in the
116 subtropical monsoon climate zone, experiencing a warm and humid climate with
117 abundant rainfall. Soft soil covers the most region and has a large deposition thickness.
118 In recent years, the influence of human activity and changes in the natural conditions
119 have caused large-scale land subsidence in the PRD, which has seriously endangered
120 the sustainable socio-economic development in the region. In this study, we selected the
121 areas with serious land subsidence in the PRE as the study areas, which covers
122 approximately 3,000 km², shows in Figure 2.

123 **Data sources**

124 We used 67 scenes Sentinel-1A SAR images, spanning from June 2015 to March 2018,
125 which were obtained with an interferometric wide data imaging mode, scanning width
126 of 250 km, and ground resolution of 5 m × 20 m. The Shuttle Radar Topography
127 Mission (SRTM) 30 m Digital Elevation Model (DEM) data provided by NASA was
128 applied to remove terrain phase and DEM errors.

129 **Results and analysis**

130 The temporal/perpendicular baseline plots of SAR data sets is as in Figure 3. Based on
131 the data processing, we obtained the linear annual mean deformation rate (shown in
132 Figure 4) and cumulative subsidence distribution (shown in Figure 5) of land
133 subsidence in the PRE from June 2015 to March 2018. The negative values represent
134 subsidence (green to red) and the positive values represent uplift (light blue to blue).
135 Based on Figure 4 and Figure 5, we can observe that the ground surface of the PRE has
136 a tendency as a whole to settle, where subsidence is unevenly distributed, such that
137 certain areas have clear subsidence phenomena, with a small uplift area extent.
138 Subsidence along the west bank of the PRE is more widely distributed and bigger than
139 those along the east bank. The northwest (Guangzhou, Foshan) and southeast (Southern
140 Dongguan) of the PRD are the master subsidence areas. The northwest and southeast
141 regions of the PRD are the main subsidence areas. The average subsidence rate in the
142 northwest mainly ranges from 5–15 mm/yr, the maximum subsidence rate in the local
143 area is up to 25 mm/yr, and the maximum subsidence is up to 45 mm in three years. The
144 overall subsidence rate at Changan Town to the south of Dongguan City is 8–15 mm/yr,

where the maximum subsidence rate can reach 20 mm/yr. The stable monitoring area is mainly concentrated in the vicinity of Humen Town to the west of Dongguan City. We observed no clear sinking phenomenon in this area.

Conclusions

In this study, we applied the DS-InSAR time-series method based on the KS test and eigendecomposition to process and analyze the 67 scenes Sentinel-1A SAR images covering the PRD. The spatial-temporal distribution of land subsidence in the large area of the PRD is obtained. We conclude that these methods effectively enhanced the spatial density of the high-quality InSAR monitoring targets in the estuary area, which, in turn, improved the accuracy of the InSAR time series deformation inversion. We verified that the method is feasible for land subsidence monitoring in the estuary area. The results suggest that the research area generally shows a land subsidence trend, while the northwest and southeast are the main subsidence areas, with a maximum subsidence rate greater than 25 mm/year.

Declarations

161 **Ethics approval and consent to participate**

162 Not applicable.

163 **Consent for publication**

164 Not applicable.

165 **List of abbreviations**

166 PRE: Pearl River Estuary

167 InSAR: Interferometric Synthetic Aperture Radar

168 DS: distributed scatterers

169 PRD: Pearl River Delta

170 PS: Permanent Scatterer

171 SBAS: Small Baseline Subset

172 SRTM: Shuttle Radar Topography Mission

173 DEM: Digital Elevation Model

174 **Availability of data and materials**

175 Sentinel-1A SAR products are available from

176 <https://scihub.copernicus.eu/>. SRTM 30 m DEM products can be

177 downloaded from <http://gdex.cr.usgs.gov/gdex/>.

178 **Competing interests**

179 The authors declare no conflicts of interest.

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186 **Authors' contributions**

187 X. L., Z. W., S. L., J. S. and D. Z. conceived and designed the
188 experiments. H. G. and X. L. processed insar data. H. G. and X. L. wrote
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198 **Authors' information**

199 **Xiaowen Luo** received the Ph.D. degree in geodesy and geomatics from
200 the Institute of Geodesy and Geophysics, Chinese Academy of Sciences,
201 Hubei, China, in 2007. He is currently an Associate Professor with the
202 Second Institute of Oceanography, Ministry of Natural Resources, China.
203 His primary research interests include seabed survey and information
204 systems.

205 **Hui Gao** received the B.E. degree in surveying and mapping from
206 Shandong Agricultural University, Tai'an, China, in 2017. He is
207 currently a Master with Marine Charting, Shandong University of
208 Science and Technology, Qingdao, China. His current research interests

209 include seabed survey and information systems.

210 **Ziyin Wu** received the Ph.D. degree in marine geology from Zhejiang

211 University, Zhejiang, China, in 2008. He is currently a Professor with the

212 Second Institute of Oceanography, Ministry of Natural Resources and

213 School of Oceanography, Shanghai Jiao Tong University, China. His

214 primary research interests include seabed survey and information

215 systems.

216 **Shoujun Li** received the Ph.D. degree in geodetection and information

217 technology from China University of Geosciences, Wuhan, China, in

218 2015. He is currently a Professor with the Second Institute of

219 Oceanography, Ministry of Natural Resources, China. His research

220 interests include submarine topography and tectonic geomorphology.

221 **Jihong Shang** received the Ph.D. degree in marine geology from the

222 Institute of Oceanology, Chinese Academy of Sciences, China, in 2008.

223 He is currently an Associate Research with the Second Institute of

224 Oceanography, Ministry of Natural Resources, China. His research

225 interests include submarine topographic survey and morphotectonics
226 study.
227 **Dineng Zhao** received the Ph.D. degree in marine geology from
228 Zhejiang University, Zhejiang, China, in 2017. He is currently a
229 Research Assistant with the Second Institute of Oceanography of Natural
230 Resources Ministry, China. His research interests include submarine
231 topographic survey.

232 **Endnotes**

233 The manuscript has no endnotes.

234

235 **References**

- 236 Berardino P, Fornaro G, Lanari R, Sansosti E (2002) A new algorithm for surface
237 deformation monitoring based on small baseline differential SAR interferograms. IEEE
238 Transactions on Geoscience and Remote Sensing 40(11): 2375-2383
239 Cao N, Lee H, Jung HC (2016) A phase-decomposition-based PSInSAR processing
240 method. IEEE Transactions on Geoscience and Remote Sensing 54(2): 1074-1090

241 Dai YW, Wu XW, Min XY, Wang H, Zhu HL, Peng LC (2019) Ground deformation
242 monitoring of major cities in the Pearl River Delta region using time series InSAR
243 technique. *Journal of Guangdong University of Technology* 36(4): 92-98

244 Dixon TH, Amelung F, Ferretti A, Novali F, Rocca F, Dokka R, Sella G, Kim S,
245 Wdowinski S, Whitman D (2006) Space geodesy: Subsidence and flooding in New
246 Orleans. *Nature* 441(7093): 587-588

247 Erban LE, Gorelick SM, Zebker HA (2014). Groundwater extraction, land subsidence,
248 and sea-level rise in the Mekong Delta, Vietnam. *Environmental Research Letters* 9(8)

249 Ferretti A, Prati C, Rocca F (2001) Permanent scatterers in SAR interferometry. *IEEE*
250 *Transactions on Geoscience and Remote Sensing* 39(1): 8-20

251 Ferretti A, Fumagalli A, Novali F, Prati C, Rocca F, Rucci A (2011) A new algorithm
252 for processing interferometric data-stacks: SqueeSAR. *IEEE Transactions on*
253 *Geoscience and Remote Sensing* 49(9): 3460-3470

254 Fornaro G, Verde S, Reale D, Pauciuillo A (2015) CAESAR: An approach based on
255 covariance matrix decomposition to improve multibaseline–multitemporal
256 interferometric SAR processing. *IEEE Transactions on Geoscience and Remote Sensing*

257 53(4): 2050-2065

258 Han P, Yang XX, Bai L, Sun QS (2017) The monitoring and analysis of the coastal

259 lowland subsidence in the southern Hangzhou Bay with an advanced time-series InSAR

260 method. *Acta Oceanologica Sinica* 36(7): 110-118

261 Higgins S, Overeem I, Steckler MS, Syvitski JP, Seeber L, Akhter SH (2014) InSAR

262 measurements of compaction and subsidence in the Ganges-Brahmaputra Delta,

263 Bangladesh. *Journal of Geophysical Research* 119(8):1768-1781

264 Jiang LM, Lin H (2010) Integrated analysis of SAR interferometric and geological data

265 for investigating long-term reclamation settlement of Chek Lap Kok Airport, Hong

266 Kong. *Engineering Geology* 110(110): 77-92

267 Jiang LM, Lin H, Ma JW, Kong B, Wang Y (2011) Potential of small-baseline SAR

268 interferometry for monitoring land subsidence related to underground coal fires: Wuda

269 (Northern China) case study. *Remote Sensing of Environment* 115(2): 257-268

270 Liu Y (2013) Spationtemporal evolution of land subsidence and mechanism discussion

271 in the Yellow River Delta, China. The University of Chinese Academy of Sciences

272 Liu YL, Huang HJ, Liu YX, Bi HB, Zhang Y, Luo YX (2016) Monitoring of land

273 subsidence and impacts of human activities in the Yellow River Delta using the small
274 baseline subset method. *Marine Geology & Quaternary Geology* (5): 173-180

275 Massonnet D, Feigl KL (1998) Radar interferometry and its application to changes in
276 the Earth's surface. *Reviews of Geophysics* 36(4): 441-500

277 Nicholls R J, Cazenave A (2010) Sea-Level rise and its impact on coastal zones.
278 *Science* 328(5985): 1517-1520

279 Prati C, Ferretti A, Perissin D (2010). Recent advances on surface ground deformation
280 measurement by means of repeated space-borne SAR observations. *Journal of*
281 *Geodynamics* 49(3): 161-170

282 Song HL, Liu XT (2014) Effect of reclamation activities on wetlands in Estuarine Delta
283 in China. *Wetland Science* 11(2): 297-304

284 Sun QS, Jiang LM, Jiang M, Lin H, Ma PF, Wang HS (2018) Monitoring Coastal
285 Reclamation Subsidence in Hong Kong with Distributed Scatterer Interferometry.
286 *Remote Sensing* 10(11)

287 Wang H, Wright TJ, Yu YP, Lin H, Jiang LL, Li CH, Qiu GX (2012) InSAR reveals
288 coastal subsidence in the Pearl River Delta, China. *Geophysical Journal International*

289 191(3): 1119-1128

290 Yang YB, Li H (2018) Application of SBAS technology to the surface deformation

291 based on Sentinel-1A radar image. Engineering of Surveying and Mapping 27(8): 42-48

292 Zebker HA, Rosen PA, Goldstein RM, Gabriel AK, Werner C (1994) On the derivation

293 of coseismic displacement fields using differential radar interferometry: The Landers

294 earthquake. Journal of Geophysical Research 19617-19634.

295 Zhang JZ, Huang HJ, Liu YX, Liu Y (2013) Monitoring and analysis of ground

296 subsidence in the modern yellow river delta area based on psinsar technique. Scientia

297 Geographica Sinica 33(7): 831-836

298 Zhang JZ, Huang HJ, Bi HB, Wang Q (2016) Monitoring ground subsidence in the

299 modern Yellow River Delta based on SBAS time-series analysis. Geomatics and

300 Information Science of Wuhan University 41(002): 242-248

Figures

Figure 1

Overall framework of the DSInSAR

Figure 2

Study Areas with serious land subsidence in the PRE

Figure 3

Temporal/perpendicular baseline plots of SAR data sets

Figure 4

Linear annual mean deformation rate

Figure 5

Cumulative subsidence distribution

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