Responds to the reviewer's comments

Dear Editors and Reviewers:

On behalf of my co-authors, we thank you very much for giving us an opportunity to revise our manuscript, we appreciate editor and reviewers very much for their positive and constructive comments and suggestions on our manuscript entitled "**Methodological Considerations in Cover-Collapse Sinkhole Analyses: A Case Study of Southeastern China's Guangzhou City**". (ID: nhess-2020-53). We have studied reviewer's comments carefully and have made revision which marked in red in the paper. We have tried our best to revise our manuscript according to the comments. Attached please find responds to the reviewer's comments, which we would like to submit for your kind consideration.

1. Response to comment:

As authors make reference to cover-collapse sinkholes, at the description of factors to be evaluated in the abstract and evaluation of changes from cover are also needed to be included in the characterization.

Response: This is explained at the beginning of paragraph 1.

Mantle karst is characterized by solution processes in underground conditions that propagate progressively towards the surface(Pueyo Anchuela et al., 2015). As near-surface indicators of active karst features in ~~soil-covered~~ mantle karst regions, cover-collapse sinkholes are the result of the downward water-borne transportation of soil or other related material into underlying voids in either limestone bedrock or other soil profiles (Tharp, 1999, 2002). Cover-collapse sinkholes are primarily described using the dominant processes behind their development and/or the material involved (Gutiérrez et al., 2007b; Beck, 2012; Gutiérrez et al., 2014). Cover refers to unconsolidated allogenic deposits or residual soil material, Collapse is the brittle deformation of soil or rock material either by the development of well-defined failure planes or brecciation(Gutiérrez et al., 2014) ~~Cover-collapse sinkholes are characterized by roughly circular outlines, internal drainage, and distinct breaks in the land surface.~~

2. Response to comment:

authors make reference to "stratification of soil", I should use soil and rock structure.

Response: It has been corrected.

3. Response to comment:

Authors says that "groundwater dynamic monitoring data proved that the sinkhole in the study area was closely related to the change of groundwater level" that does not have sense as written, how sinkholes are related to water level?

Response: This is explained in paragraph 4.4.

4.4 Changes in groundwater levels

In accordance with the information obtained from the local residents and staff, the daily water output of a waterworks located 800 m east of the study area was approximately 1,200 to 6,000 m^3. The change of water output was related to the water consumption of the residents. the water levels of the local wells had dropped by about 7 m in early 2015 when a large scale karst collapse had occurred in the study area.

Groundwater monitoring data from ZK4 and ZK5 boreholes indicated that before August 2018, the groundwater level elevation fluctuated greatly, ranging from 17 to 28m above sea level in Fig. 9. The water table of ZK4 near the waterworks was lower than that of ZK5 for most of the time. During this period, two new cover-collapse sinkholes had formed. After August 2018, the waterworks stopped pumping underground, and the groundwater gradually rose and remained stable, with little fluctuation in the water level and slow response to rainfall. The water table elevation of ZK4 is about 30m, about 3m higher than that of ZK5. Since August of 2018, the groundwater levels have recovered, and no further karst collapses have occurred in the study area.

4. Response to comment:

Map from fig. 2 is difficult to evaluate if it's not included with geographic data, moreover it's a lithological map (or expected lithological map) but not a geological one (there is not information about the kind of contacts and the legend is not correctly ordered). The red lines referenced in the map are not described.

Response: Figure 2 has been modified and redrawn.

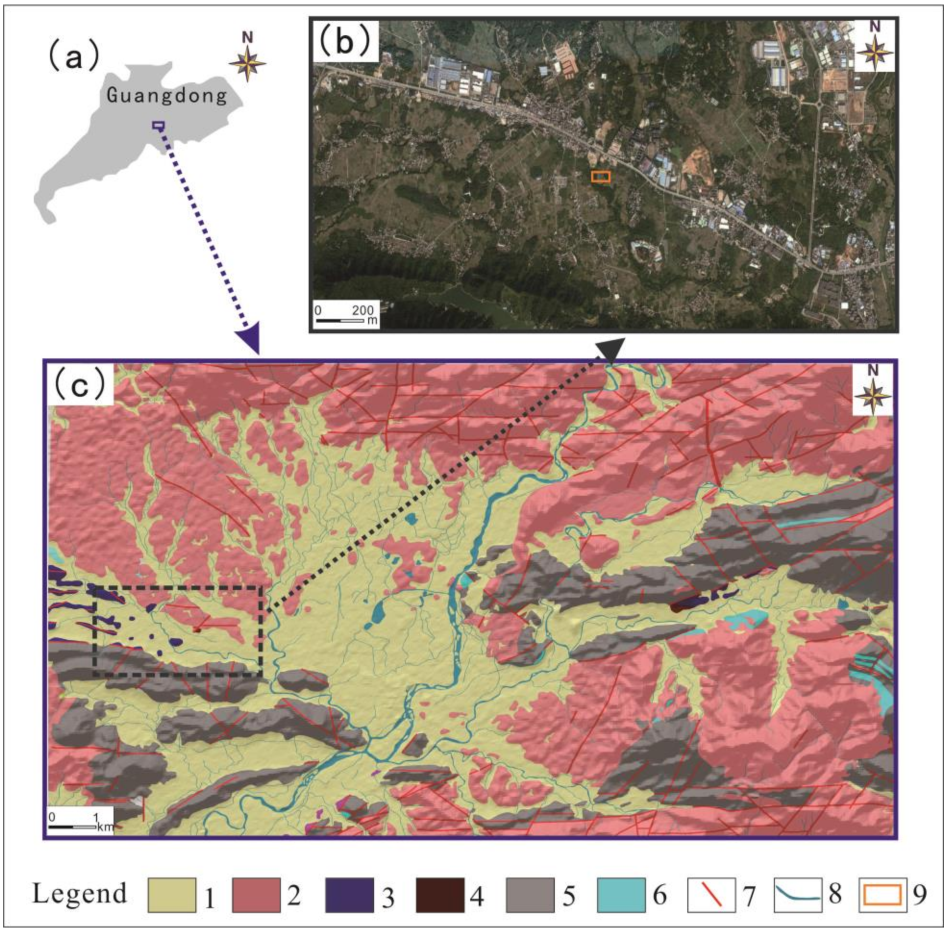


Figure 2. Geological and geomorphological setting of the study area: (a) Location of the study area in Guangdong Province of southeastern China; (b) ©Google Earth image showing the study sites. The study sites as mapped by the authors are shown; (c) Synthetic exposed stratigraphic map; 1.Quaternary sediment; 2. Jurassic Volcanic Strata; 3. Carboniferous Sandstone Strata; 4. Carboniferous Limestone Strata; 5. Devonian sandstone Strata; 6. Devonian Limestone Strata; 7.Fault; 8.River; 9. The study area

5.Response to comment:

At 3.1.3 a reference within "aerial photographs" is given, but there is not a reference to historical or previous photographs from the area that can give information about the distribution of sinkholes in the area with a more historical perspective.

Response: That has been modified by in paragraph 3.1.2.

3.1.2 Aerial photogrammetry and historical satellite remote sensing images

In aerial photogrammetry, unmanned aerial vehicle (UAV) platforms can be used to capture digital surface and terrain models for large scale mapping, with an accuracy down to the cm-level from various waypoints in investigated regions *(Chiabrando et al., 2011; Lee et al., 2016; Yeh et al., 2016)*. In the present study, detailed and accurate geomorphological data including surface elevation of the study area were provided by senseFly mapping drones using Postflight Terra 3D software in Fig. 3 and Fig. 6a. Also, historical images available from Google Earth were used to obtain information on the recent morphological changes of the analyzed sinkholes in the study area. The detailed interpretations of photographs taken on different dates (2014/10/28; 2015/12/05) shown in Fig. 5a and 5c. ~~assisted in this study's analysis of the spatio-temporal distribution patterns of the sinkholes.~~

6.Response to comment:

An inventory of sinkhole/dolines/subsident areas seem that has not been completely done before the more detailed carried out analysis.

Response: This is done in paragraph 4.1.

In the study area, 35 of the 49 sinkholese circumferences were circular. The main morphometric parameters of these cover-collapse sinkholes are represented in Fig. 4. The eccentricity of sinkhole circumferences(the major-to-minor axis ratios of sinkholes) is usually 1-2; values greater than 2 are rare. The sinkhole diepths range from 1 to 2.5 m. The azimuths of the long axes of all sinkholes show a general 0° —180° and 120° —300° alignment. Generally, it is assumed that orientation of the long axes of sinkholes is controlled by structural and tectonic constraints(Bauer, 2015).

Table 1 The dimensions and dates of sinkholes

ID	Shape	Diameter or Major axis/ Minor axis	Major axis direction	Date and time	Depth	ID	Shape	Diameter or Major axis/ Minor axis	Major axis direction	Date and time	Depth
1	Circle	2.8		Nov-14	0.9	25	Ellipse	0.9/0.6	0	Nov-14	0.5
2	Circle	7.8		Nov-14	0.8	26	Circle	1.7		Nov-14	1
3	Circle	3.1		Jun-14	0.9	27	Ellipse	1.8/0.9	120	Nov-14	1
4	Circle	4.9		Nov-14	1	28	Circle	3.3		Nov-14	1
5	Circle	3.2		Nov-14	1	29	Ellipse	1.3/1		Nov-14	0.98
6	Ellipse	13.4/7.2		Nov-14	1.2	30	Ellipse	2.2/1.5	205	Oct-14	1
7	Circle	2.6		Nov-14	2	31	Circle	2.6/1.8	345	Oct-14	0.9
8	Circle	3.2		Nov-14	1.5	32	Circle	1		Nov-14	1
9	Circle	4.5		Nov-14	0.8	33	Ellipse	2.1/1.3	280	Jan-15	1.5
10	Circle	4.8		Nov-14	0.9	34	Ellipse	3.7		Dec-14	2

7. Response to comment:

Chapter 3.2 has a rare title, if its non-invasive it can said that, if it geophysical prospecting or survey it can said that, but if authors use non-intrusive geophysical prospecting, It is because they are going to describe geophysical techniques that are in some cases intrusive (indirect and from passive techniques, or potential techniques) against other techniques that involve to generate perturbations (active techniques) in the area.

But both approaches are used, but described in this chapter, I suggest just saying Geophysical survey, or indirect characterization, or geophysical techniques that should be a better description than used in this moment.

Response: It has been corrected as follows:

3.2 Non-invasive geophysical prospecting

8. Response to comment:

This sentence does not have sense "However, it has its own shortcomings that the depth of surface-based GPR detection is generally 3-5 meters in southern China".

GPR penetration depends on the central frequency of the used antennas, and from the state and characteristics of the soil, in this sense, this generalization does not mean anything.

It can be described usual penetrations at different contexts with different antennas, but in this moment the sentence as described does not give any robust description or background of the used geophysical technique.

Line 151, GPR is not a continuous technique, it measures at very low steps between pulses, but it is not a continuous technique.

Please correct including the triggering interval of survey.

Response: The inappropriate description of GPR has been corrected in chapter 3.2.1

▪ **3.2.1 Surface-based GPR**

Ground Penetrating Radar (GPR) surveys are a non-invasive type of geophysical technique which offer a very high resolution abilities in order to locate and characterize the sedimentological information of subsoil (such as soil-cavities and the presence of active subsidence, and so on) *(Lei et al., 2008; Anchuela et al., 2009; Chalikakis et al., 2011)*. ~~In GPR profiles, information can be identified by changes in color, which are related to the amplitude of the recorded wave at each point. However, this technique has been found to have its own shortcomings, due to the fact that the depths of surface-based GPR detections were generally found to be only 3 to 5 m in southern China.~~ In the present study, 20 surface-based GPR (Ground Penetrating Radar) profiles with a total length of 3 km were conducted in the study area, as detailed in Fig. 2. The ~~continuous~~ GPR profiles were collected utilizing a SIR3000 GPR instrument manufactured by the Geophysical Survey System Inc. (GSSI) in the United States, equiped with a 100 MHz bowtie bistatic antenna. The triggering interval in the GPR profiles was 5cm.

9. Response to comment:

I should expect at chapter 3, a description of what has been done, in which point each profile, technique and approach has been carried out, it is just a general description without data to compare or to evaluate where each approach has been carried out, and where they can be compared.

Response: It has been modified at chapter 3.

10. Response to comment:

at 4.2 soil layer (how authors have interpreted the soil thickness by micro-tremors and electrical resistivity techniques?).

At this chapter (4.2.1) there is mixture of source data without evaluation of how the integration of ert, seismic method and boreholes is integrated.

Authors show a plot from topography of the substratum without an evaluation of presented data in order to know how it has been carried out and how the different data sources have been interpreted.

"Based on limited borehole data, microtremor exploration could estimate sediment thickness, making 359 thus possible to reconstruct the bedrock morphology beneath the whole study area"

It required to be described how the data has been interpreted and used, in this moment it is just said that authors have integrated such information without referring how.

Response: The depth of the soil in the study area was obtained by drilling and microtremor exploration. The specific modifications are as follows:

3.2.2 ~~Micro-tremors~~ Microtremorexploration

In microtremor exploration, three-component microtremor seismic noise recording was carried out at a given site. Suitable portions of microtremor records free of interference from events of local or teleseismic origin were Fourier transformed to obtain a horizontal component H and a vertical component V of the ground motion spectra. The Nakamura technique of microtremor exploration, also known as the H/V ratio method, is a widely used passive seismic technique by researchers for obtaining overburden sedimentary layer thicknesses (Dinesh et al., 2010). The detailed process of microtremor exploration in the study was as follows: Firstly, single-station micro-tremor data came from a Tromino 3G seismograph were collected from the 318 sites. The sites were spaced 10 m apart; Secendly, the prominent resonant frequencies in the H/V spectrum for each measuring point was extracted; Thirdly, the relationship of the prominent resonant frequencies in the H/V spectrum and sediment thickness was obtained based on microtremor data measured beside 6 boreholes in the study area; Finally, Quaternary soil thickness of the collapse area was estimated according to the resonant frequencies.

4.2.1 Quaternary soil thicknesses

The drilling profiles showed that the thicknesses of the quaternary soil layers in the collapsed intensive area ranged between 9 and 14.2 m in Fig. 8. ~~In order to obtain a comprehensive understanding of the Quaternary soil thicknesses in the study area, a contour map of the buried depths of the ground bedrock was obtained by utilizing a micro-motion inversion method in Fig. 5b.~~ With the Nakamura technique of microtremor exploration, the thicknesses of the sediment of 318 sites spaced 10 m apart in the area are obtained. Based on interpolation mothed ,a map of the buried depths of the ground bedrock was drawn in Fig. 6b. In the southwestern area of the site, the bedrock was determined to be between 12 and 15 m in depth. In the other areas of the site, the thicknesses of the soil layers averaged approximately 10 m. The majority of the collapses had occurred in the areas where the depths of bedrock had varied greatly.

11. Response to comment:

Anomalies from fig. 6 are not describes but they are not compared if they can be directly compared, comes from different areas, or even they are parallel or coincident,

Response: It is illustrated and modified in figure 7 and at chapter 4.3.

Two parallel profiles(Ⅰ-Ⅰ' and Ⅱ-Ⅱ'), with a total length of 500 m and spacing of 30 m, were conducted in the study area.

12. Response to comment:

The ert profiles do not have information about residuals and iterations, neither they present a comparable scale.

Response: It has been modified at chapter 3.

In the final model of ERT (electrical resistivity tomography), a root mean square error (RMSE) of 2.1% was reached in the fifth iteration in the Ⅰ-Ⅰ' profile. In the Ⅱ-Ⅱ'' profile, the RMSE obtained was 2.7% in the fifth iteration. Using a logarithmic scale to represent the resistivity values, the Ⅰ-Ⅰ' and Ⅱ-Ⅱ' profiles of of ERT (electrical resistivity tomography) revealed ~~The results of this study's field investigations confirmed~~ that there was a high resistance zone(600~1000 Ωm) ~~in Quaternary alluvial layers (Qal, sand)~~ on the southern surface of the study , and a low resistivity zone (50~80 Ωm) indentified on the northern surface of the study area in Fig. 7b and 7e. The results of this study's field investigations confirmed that the high resistance zone represented Quaternary alluvial layers (Qal, sand) and the low resistivity zone represented Quaternary residual soil layers (Qel, clay).

13. Response to comment:

At the discussion chapter is said that "The punctual information derived from the drilled boreholes could be extended laterally by the borehole geophysical investigations (e.g. Single-hole radar and Cross-hole radar)."

However it requires to be compared and evaluated, something that has not been done between some of the used techniques, and moreover in the case where this interpretation can be more evident, e.g. fig. 7, it has not been evaluated in the text, just to fix together the results.

Response:

The related content is modified and added in the section4.3 and in fig.8

“The single-hole reflection surveys correlate well with fractures and fracture zones observed in core logs and cross-hole radar image in Fig. 8.”

“Due to the rotational symmetry of non-directional antennas operating in straight boreholes, the georadar data on their own do not provide sufficient information to determine unambiguously the locations of reflectors not intersected by the boreholes. To compensate for this limitation, constraints from other observations are necessary”

14. Response to comment:

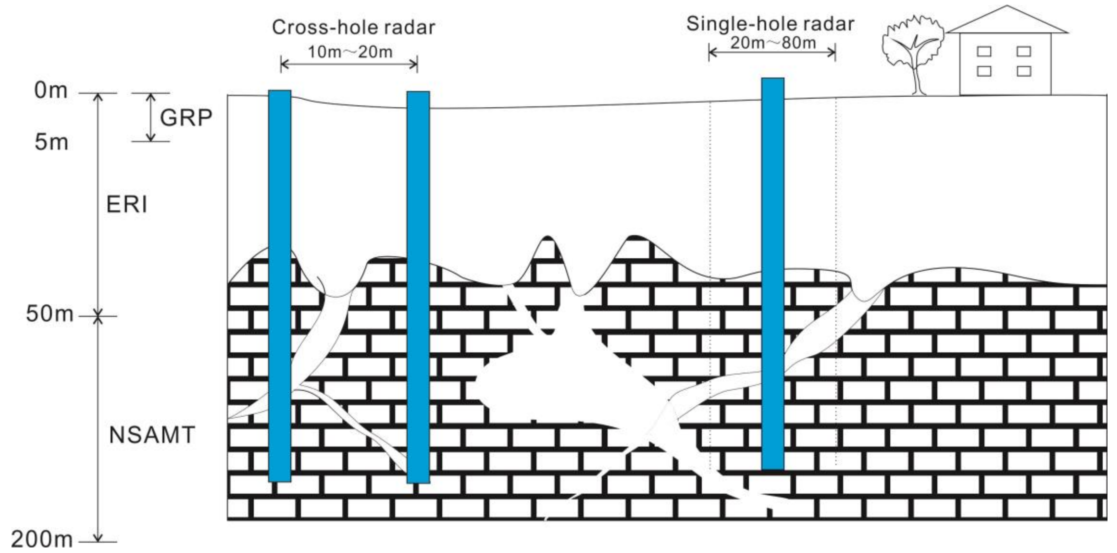
Authors indicate that at L368 "These techniques were tried to constitute an advantageous synergistic approach in the study", that is what a reader should expect to find in this kind of articles, but sadly it has not been done.

Response:

The related content is modified in the section5 and fig. 10

The ambiguity and limitation of A single geophysical technique could be reduced by additional geological data. It was a well know fact that the penetration depth of the GPR method was dramatically reduced the attenuation produced on the electromagnetic waves by certain types of materials (mainly high clay content, water saturated rocks). the ERT technique is able to image the subsurface resistivity structure in spite of the presence of clayey water-saturated materials, providing useful information when the GPR technique fails. In the study, the maximum investigation depth reached with the 100MHz GPR was 5 m where as the ERT has provided a greater depth of 0-50 m. ~~In addition, t he ERI and NSAMT profiles had revealed imaging shallow fault zone structures at the overburden karst area sites. In addition, t he ERI and NSAMT profiles had revealed imaging shallow fault zone structures at the overburden karst area sites.~~ In addition, the NSAMT sections were found to have poor measurement effects in the range of 0 to 50 m, and good exploration effects in the range of 50 to 200 m. Meanwhile, the ERI sections had satisfactorily imaged the general geometry of the karst structures in the range of 0 to 50 m. ~~The subsurface cavities and deformation structure clouds were detectable with the GPR, but only up to a limited depth range of 2 to 5 m.~~ In relation to the resolution of the other two techniques, GPR had a better vertical and horizontal resolution than ERT and NSAM, and thus it is possible to obtain more detailed information for small targets or thin layers using the electromagneticmethod. The ERI and NSAMT profiles could reach greater depths than GPR, but with lower resolution. They had revealed imaging shallow fault zone structures at the overburden karst area sites.

(a)



(b)

TECHNIQUE, APPROACH METHODOLOGY	Optimal detection depth range	Potential results
Surface-based GPR high frequency（100MHz）	0～5m	Soil caves,karst caves, Soil disturbance
Electrical resistivity imaging (ERI)	0～50m	Soil caves,karst caves
Natural source audio frequency magnetotellurics (NSAMT)	50～200m	Fault zone structures
Microtremor exploration（H/V ratio method）	0～50m	soil thickness,depth of bedrock
Single-hole radar	10～40m radius range with borehole as the center	karst caves, The karst fissure
Cross-hole radar	The range between the two holes 10～20m	karst caves, The karst fissure

Fig. 10. Integrated analysis of the different techniques and approaches:(a)diagrammatic sketch of geophysical method framework in cover-collapse sinkhole analyses; (b) Characterization of the differen techniques and approaches, a table with the optimal detection depth range of each technique and potential results

In the present study, the aforementioned techniques were examined in order to determine the most advantageous synergistic approach in the study area. It was expected that the limitations observed in each examined method would be balanced out by the advantages observed in the other methods in Fig. 10.

15. Response to comment:

At L375 and next, authors evaluate the triggering effect from water levels changes in the appearing of sinkholes in the area.

This is another subject that can be interesting discussed, as in this moment there is a temporal correlation between the collapse and a change in the water level, however it must to be compared with the involved processes that produce the collapse. Do changes in the water level produce variation in solution? Does a decrease in water level destabilize previous cavities? Does the water pumping produces internal erosion due to an increase of the water hydraulic gradient? These subjects require to be evaluated.

Response: The analysis of groundwater monitoring data has been modified and enriched in the section5.3 .

~~hazard assessments.~~ The interpretations of the groundwater level monitoring data allow the hydrogeological behaviors of the groundwater to be accurately reconstructed. Hydrodynamic monitoring methods focus on the potential relationships between hydrological behaviors and the development of cover-collapse sinkholes. ~~As a result, the kinematics of the subsidence phenomena can be assessed.~~ In the study area, the hydrodynamic monitoring data show that the groundwater fluctuated dramatically and its flow direction changed during the period of karst collapse. It is generally acknowledged that the dramatic fluctuation in water level would expand and destabilize previous soil cavities due to an increase of the water hydraulic gradient.

16. Response to comment:

Moreover at hidden karst (cover or mantled karst) the surficial information cannot give straightforward interpretations of the deep karstic processes, in this sense the description that the mapping of ground displacement can serve to identify the location of future cover-collapses is not proof and can recommend approaches that are not devoted to predict collapses in the area.

Response: This section has been modified. The content of the manuscript about the prediction of karst collapse by ground subsidence had been modified in the section5.3.

In addition, the accurate mapping of ground displacements may serve to ~~identify the locations of future cover collapse sinkholes and~~ guide future intensive field investigations of karst sinkhole. ~~Therefore, it was found in this study that monitoring of ground anomalous vertical movements by~~ Interferometric Synthetic Aperture Radar (InSAR) analysis could be an effective approach to ~~monitor ground anomalous vertical movements~~ detection processes to areas where significant changes are occurring. In this study, accouding to there is no ground subsidence after a major collapse event.

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