Rapidly accelerating subsidence in Maceió (Brazil) detected by multi-temporal DInSAR analysis

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Overview

Motivations of the study:

- Maceió municipality is suffering **severe geological instability** related to mining activities near the cost of the Mundaú Lagoon;
- **Fractures on both buildings and roads** have intensified mainly in Pinheiro neighborhood since the beginning of 2018, especially after **strong rainfall event** on 15th of February 2018 and a **seismic shock** of local magnitude 2,4mR on 3rd of March 2018;
- **Geodetic ground measurement are not available**;
- **Historic and updated geodetic InSAR measurements have not been provided yet**.

Our goals:

- Detect the **onset** of the instability;
- Track the **temporal and spatial evolution** of the instability;
- Estimate the **cumulative subsidence** rate;
- Estimate possible **horizontal deformations**;
- Have an overview understanding of the evolution of the **source of the subsidence**.

Methods:

- **Multi-temporal DInSAR analysis** (SBAS technique) using multi-sensor SAR data from 10.2003 up to 03.2020;
- **Geophysical modelling** (Mogi and Okada) to model the evolution of the source;
- **2D geomechanical modelling** to simulate 2 real salt-cavities, their stages of instability and the possible future development evolution of the surface displacement.

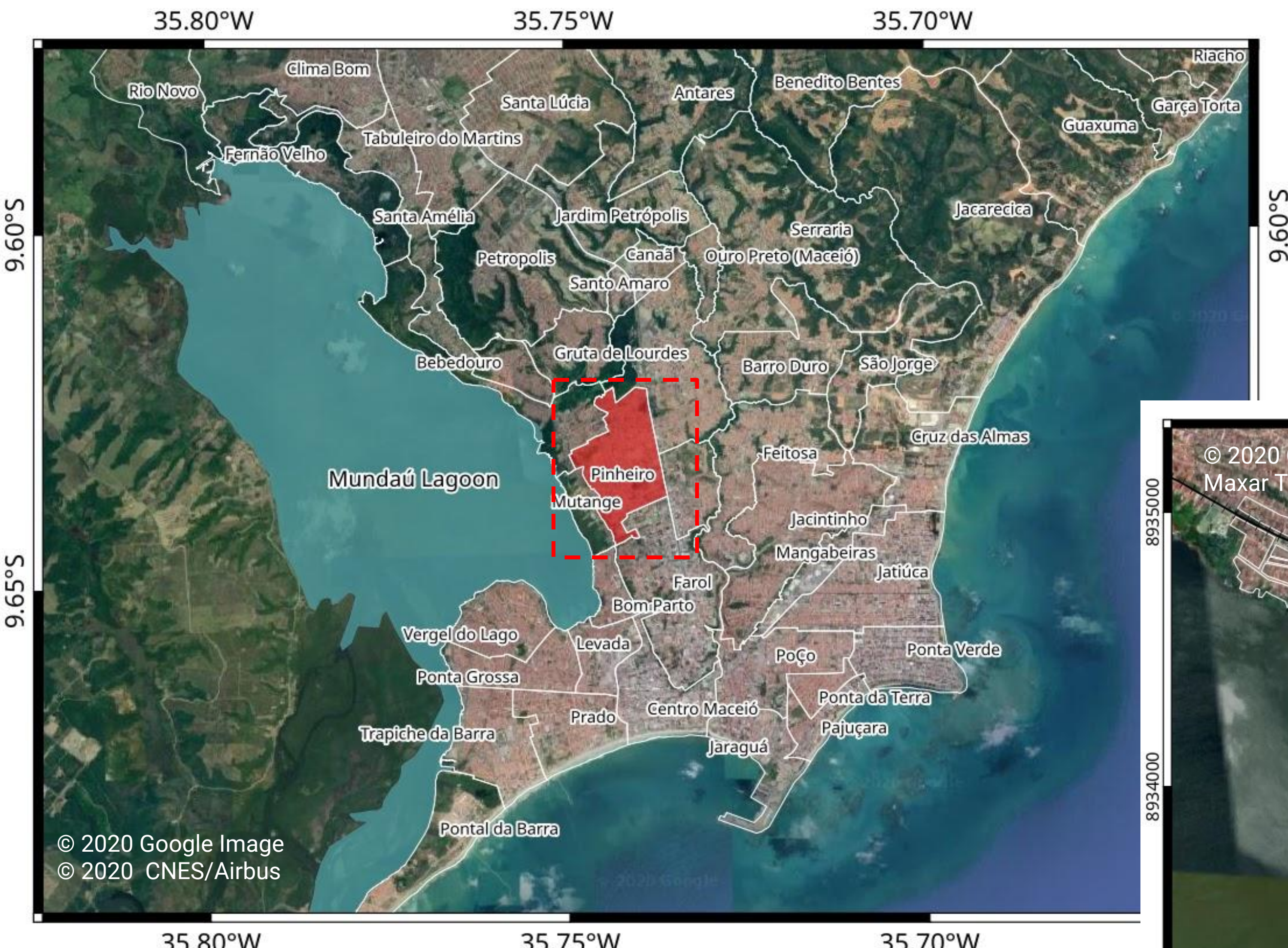
Area Of Interest

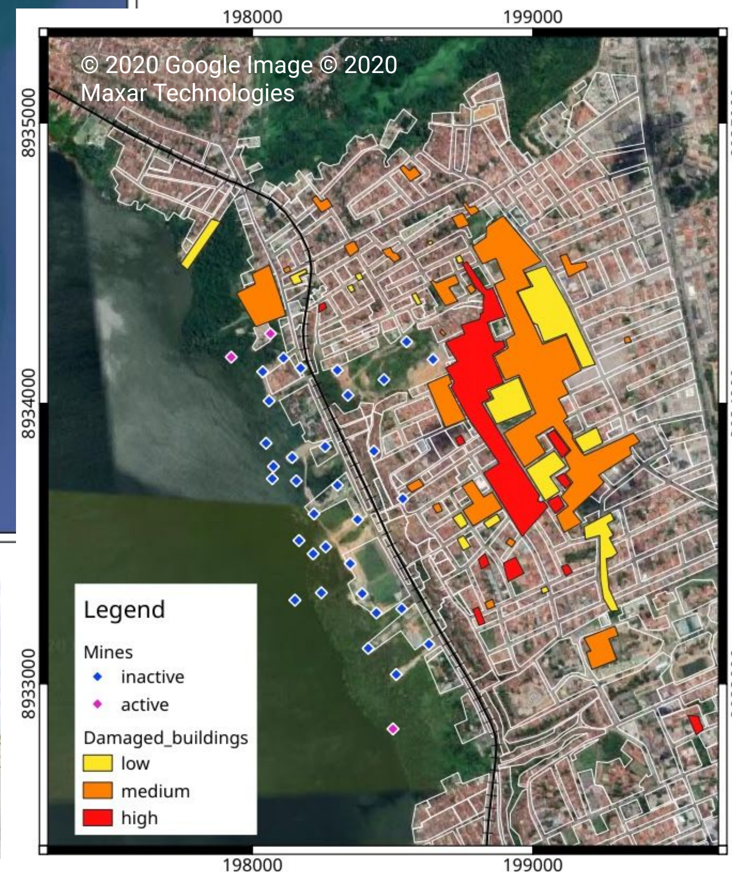
Maceió is the capital of Alagoas (Brazil)

Tot. population ~ 1 million inh.

Pinheiro pop. ~ 10.500 inh.

Mutange pop. ~ 1.500 inh

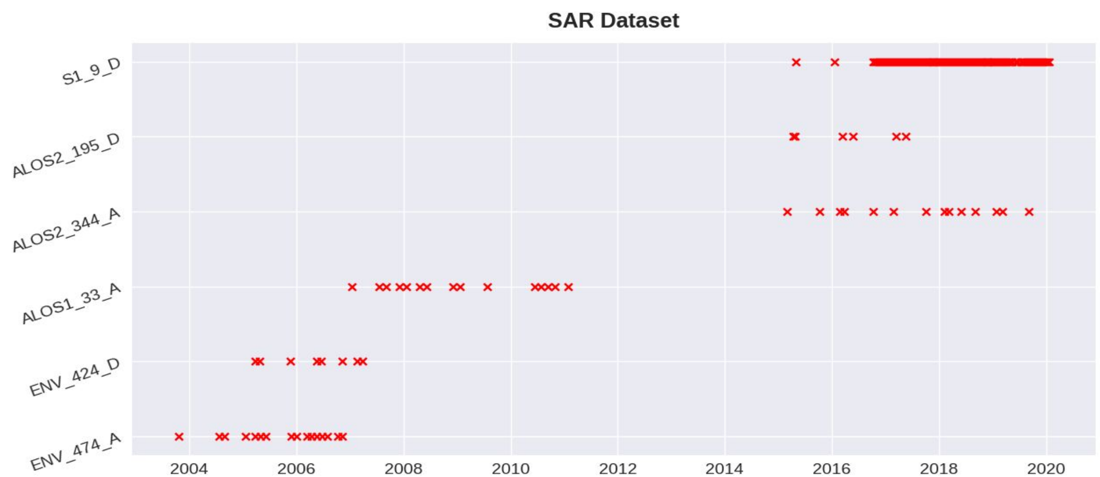




Dataset

mission	orbit path	band	alos (°)	ILOS (°)	N.° of images	period
ASAR ENVISAT	ASC	C (5.331 GHz)	24.4	76.8	15	25/07/2004 - 12/11/2006
ASAR ENVISAT	DESC	C (5.331 GHz)	23.8	-77.7	8	23/03/2005 - 28/03/2007
ALOS-1 POLSAR	ASC	L (1.2 GHz)	37.1	78.8	16	17/01/2007 - 28/01/2011
ALOS-2 POLSAR	DESC	L (1.2 GHz)	35	-78.2	6	13/04/2015 - 22/05/2017
ALOS-2 POLSAR	ASC	L (1.2 GHz)	35.4	77.3	13	10/10/2015 - 07/09/2019
SENTINEL-1A	DESC	C (5.331 GHz)	35	77.9	107	07/10/2016 - 08/03/2020

Dataset
[07.2004 - 03.2020]
Data gap
[01.2011- 02.2015]

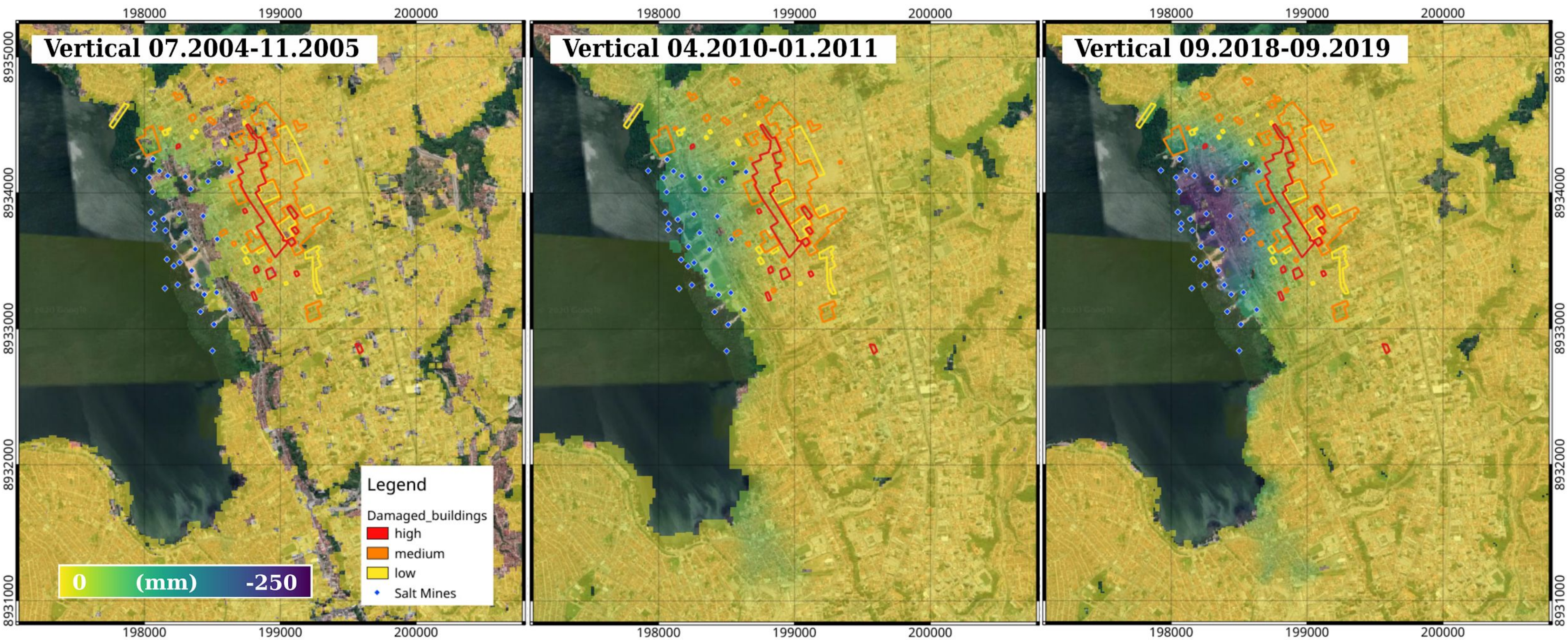


Vertical Displacement

Already in 2004-2005 a 4 cm/year of subsidence appears

The subsidence intensify during the years.

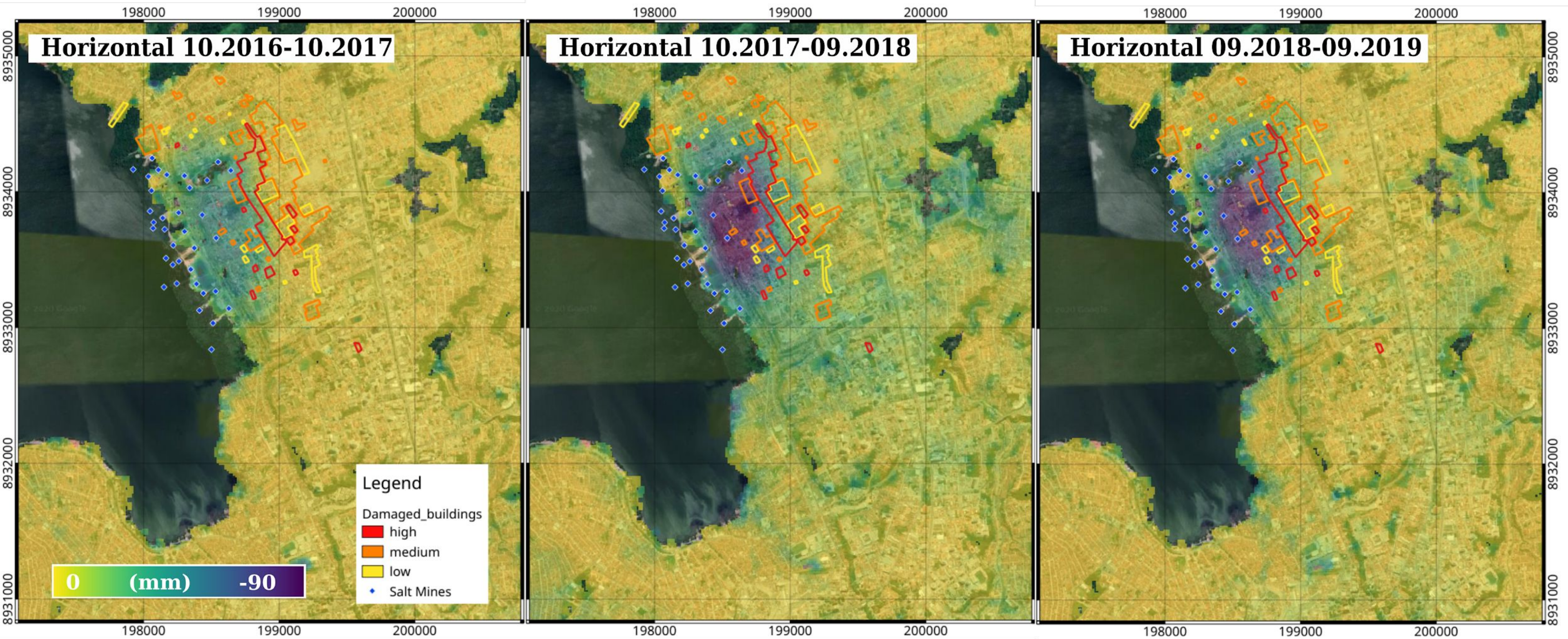
It reach its maximum value of velocity of 24 cm/year in 2018.



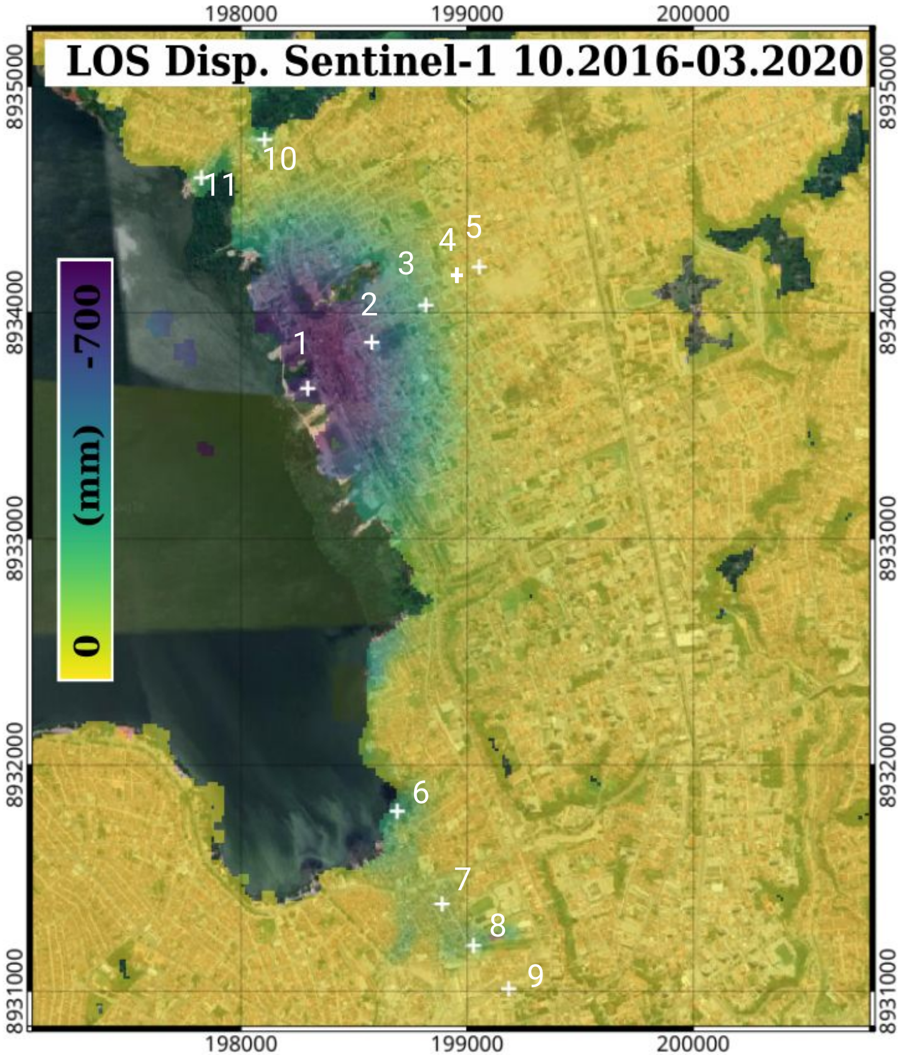
Horizontal Displacement

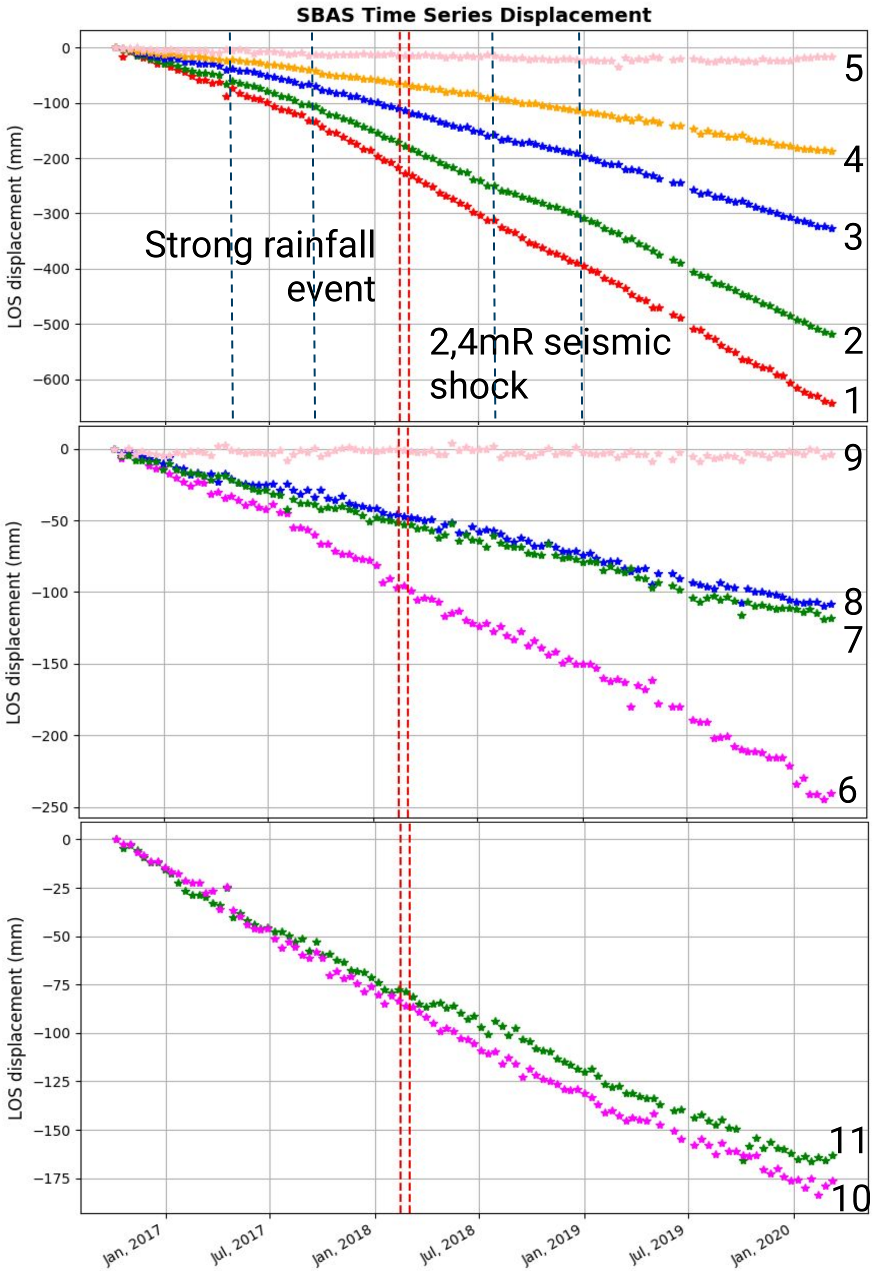
Since the end of 2016 the horizontal velocity is around 4 cm/year westward

It intensify since 2017 to 9 cm/year



LOS Time-Series





Geophysical Modeling

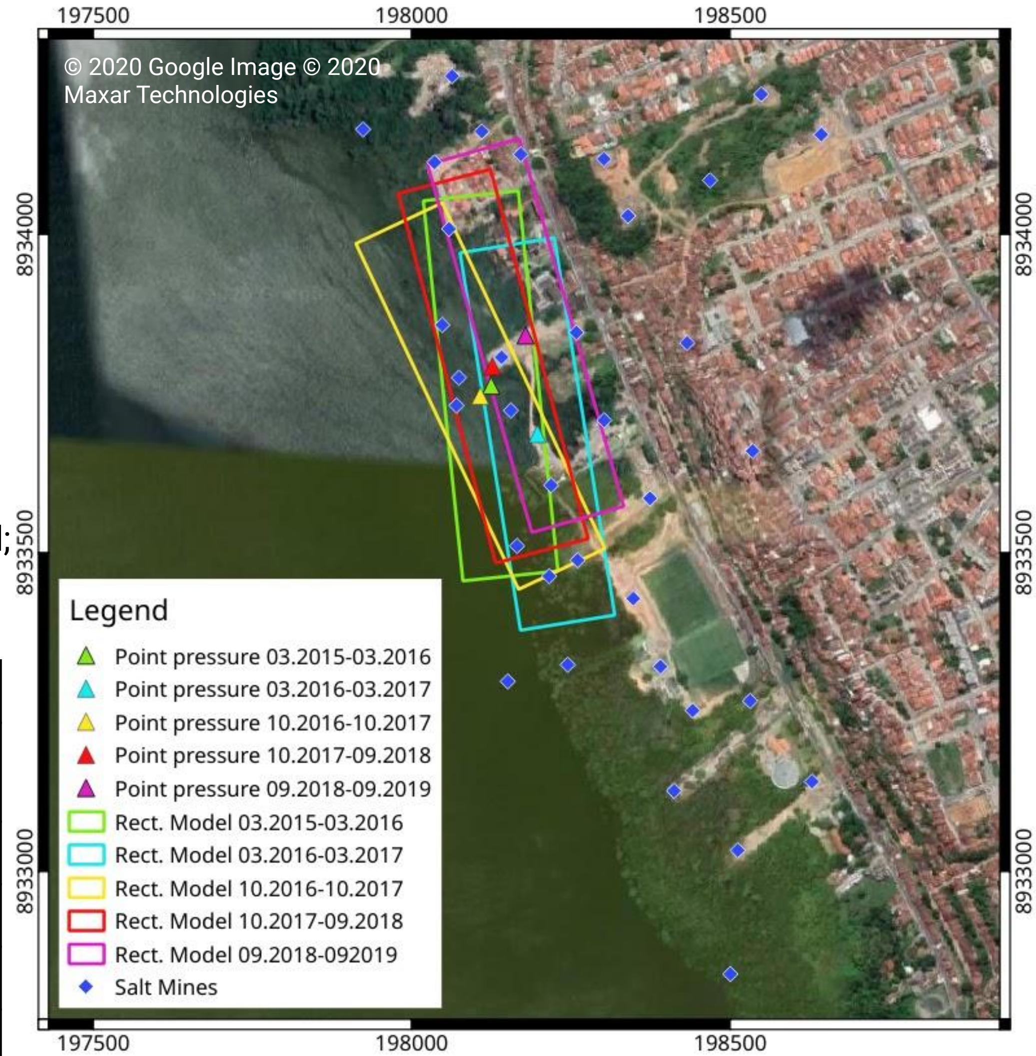
We have many active cavities which contribute to the subsidence, however in this study we assumed a unique source model. Salt mines are located in a depth between 700 and 1000 m and are all close to the Mundaú Lagoon.

point pressure source				
interval	vol (m3)	Depth (m)	East (m)	North (m)
03.2015- 03.2016	-3.87E+05	774	198124	8933762
03.2016- 03.2017	-3.64E+05	730	198198	8933687
10.2016- 10.2017	-5.25E+05	777	198108	8933746
10.2017- 09.2018	-5.80E+05	697	198127	8933793
09.2018- 09.2019	-5.35E+05	653	198179	8933841

Okada model:

- We fixed the location with that from Mogi model;
- We considered horizontal plane (dip=0°);
- We fixed the plane size to 600x150m.

rectangular source-opening 600x150m				
interval	Opening (m)	vol (m3)	Strike (°)	depth (m)
03.2015-03.2016	-3.4	-3.0E+05	176	953
03.2016-03.2017	-3.0	-2.7E+05	171	873
10.2016-10.2017	-4.6	-4.2E+05	155	962
10.2017-09.2018	-5.2	-4.6E+05	165	857
09.2018-09.2019	-4.9	-4.4E+05	164	807



2D Geomechanical Modeling

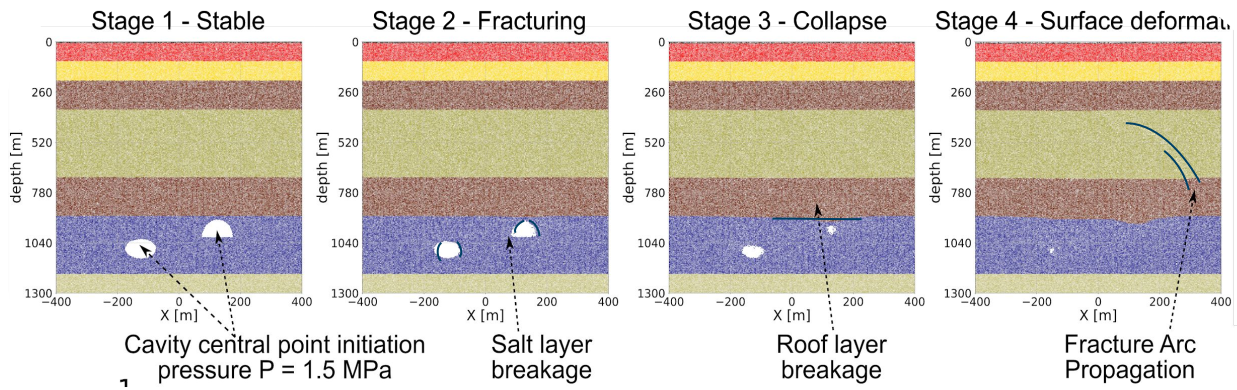
2D distinct element method (DEM) was used to simulate the evolution of two real size cavity models. Four different geomechanical stages were simulated:

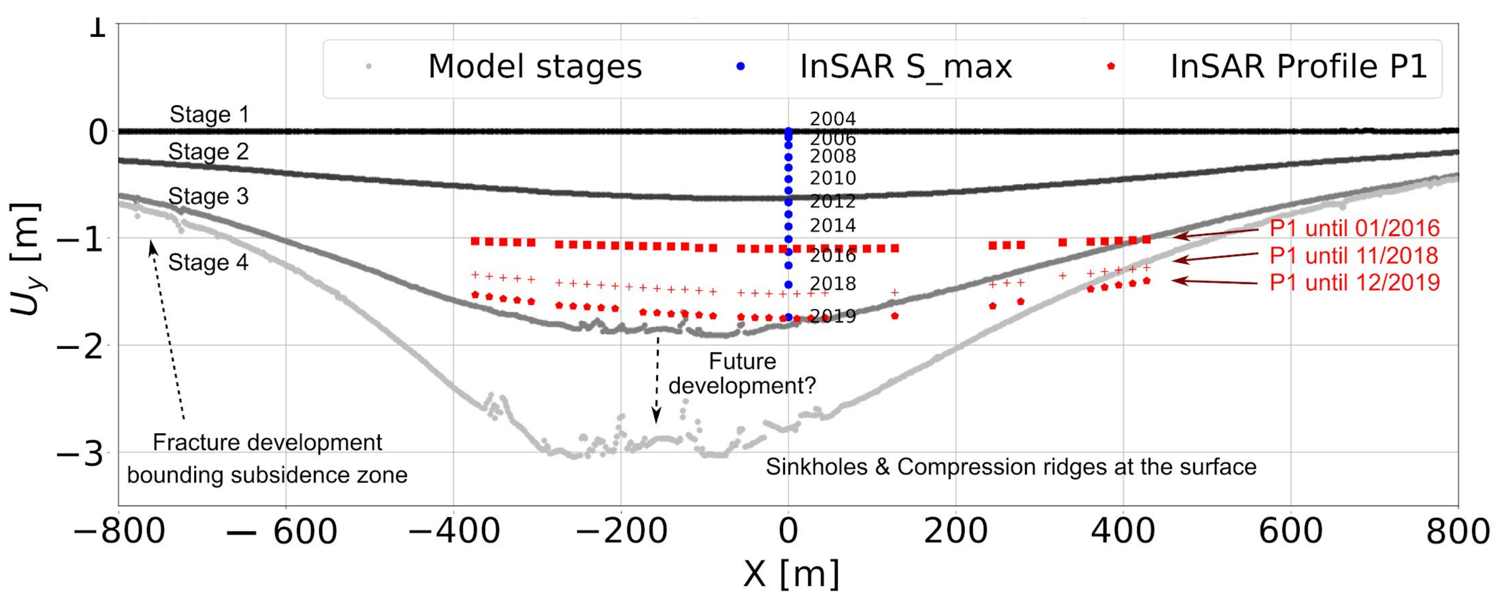
1) initially stable pressurized cavity, with injection pressure of 1.5 MPa;

2) over fracturing and subsidence;

3) total collapse

4) final translation of the deformation to the surface.





Conclusions

Regarding the subsidence phenomena:

- Already in **2004/2005 subsidence started to appear;**
- It has intensified **up to 23/24 cm/year since 2018;**
- A **cumulative max. subsidence** of **1.8 m** was estimated **from March 2015 to March 2020;**
- A **east-west horizontal motion** is estimated **up to 8/9 cm since 2018**;
- Geophysical models show **horizontally stable source**, **upward fracture propagation since 2016/17** and a clear volume change increment since 2016/17;
- Geomechanical models shows good agreement of the simulated subsidence with the DInSAR measurements and they also show upward fracture propagation;
- Based on the geomechanical modelling, in case of a total collapse of the two cavities, an approximate further 1m of subsidence is expected to occur, though no sinkholes.

General conclusions:

- InSAR is a **powerful tool to detect and monitor in time geological instabilities** especially in urban areas due to the higher coherence;
- The availability of archives of historical SAR data allows to obtain **backdated geodetic measurements** and to contribute to understand the onset of geological instabilities;
- The very high temporal resolution and not commercial **Sentinel-1** data provides **very good temporal displacement trend detection**;
- The availability of both **ascending and descending** acquisitions allows also **horizontal component** estimation, which cannot be neglected in urban areas;
- Geomechanical and geophysical modelling (this last based on DInSAR data) provide **good overview understanding of the source time and space evolution**.