Localized land subsidence in Surfside during the 1990s and its implications to the collapsed Champlain's South Tower

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The recent tragic building collapse in Surfside, Fla., attracted the world's attention. Our study of local land subsidence in Miami Beach, Fla. and Norfolk, Va. and its contribution to flooding hazard in coastal communities along the U.S. Atlantic coast (Fiaschi and Wdowinski, 2020) suddenly gained attention, as we detected movement of the Champlain's South Tower in the 1990s. Our study was mentioned in thousands of news outlets, but not always with the correct information. The statement is based on many frequent questions I was asked during the week following the building collapse. In the following Q&A, I explain the purpose, methodology, findings, reporting, and implications of our study. I also present a more detailed map of our results, which should be interpreted very carefully, as the space-based movement observations have their limitations.

What was the purpose of the study?
Several coastal communities along the U.S. Atlantic coast have experienced increased frequency of coastal flooding in the past two decades. Coastal flooding can be caused by rising sea level, subsiding land, or both. In this study, we used satellite technology to measure local land subsidence in two coastal communities, Miami Beach, Fla. and Norfolk, Va., which have suffered from increased flooding frequency since the turn of the century. The measured subsidence rates were used to assess areas that are more prone to coastal flooding, as these areas are affected by both sea level rise and land subsidence.

Why use the term 'subsidence' and not 'sinking'?
Subsidence is a slow and gradual downward settling of the Earth's surface. Sinking also describes downward movement of the surface, but typically at a fast rate, as in a sinkhole collapse. Subsidence better describes the slow downward movement of the surface we detected in both Miami Beach and Norfolk.

What causes subsidence? Is it common?
The slow and gradual downward settling of the Earth's surface can be caused by both natural and human-induced processes. Natural processes are typically of deep origin, such as mantle flow, sediment compaction, volcanism, and tectonism and occur over wide areas. Human-induced processes typically occur at shallow depths due to groundwater extraction or soil consolidation and are characterized by localized subsidence patterns.

Subsidence is common along the mid-Atlantic coast due to deep (below 50 miles) and slow flow in the mantle, which represents a delayed response of the mantle to icecap melting in Canada over the past 12,000 years. However, this subsidence pattern is regional, extending from Massachusetts to Georgia. Localized subsidence, as we detected in our study, typically occurs due to soil consolidation as buildings settle.

What methodologies and data were used in the study?
Interferometric Synthetic Aperture Radar, or InSAR, is widely used in the geodesy field to detect and monitor surface changes of land, glaciers and water levels in wetlands. The technology has been widely used to monitor changes induced by processes that may lead to natural disasters including earthquakes, volcanoes, landslides, sinkholes and land subsidence. By comparing two or more radar observations from roughly the same location in space, we can detect small changes of the Earth's surface with centimeter-level accuracy. Over time, changes can be observed with millimeter-per-year accuracy.

For this study, we used data collected by two European satellites ERS-1 and ERS-2 between 1993 and 1999. We used this dataset, because InSAR subsidence results are more accurate with longer observation duration.

What were the findings of the study?
Our study detected local subsidence in both studied coastal communities, Miami Beach and Norfolk. In Miami Beach, the subsidence was rather limited to small areas (<0.2 km^2) and the subsidence rates were 1-3 millimeter-per-year. Most of the subsidence occurred in the western side of the city, which is built on reclaimed wetland, where most flooding events have occurred. Thus, the subsidence in the western side was expected. The one unexpected location of subsidence was in Surfside, where we detected a very localized subsidence pattern centered on the Champlain' South Tower. The geographic description of the results was based on satellite imagery, where the two Champlain Towers look like a single building. Thus, we described this finding in our publication using the following single sentence: "In some locations, as in the eastern part of the city, the detected subsidence is of a 12-story high condominium building (northernmost black circle in Fig. 3A)."

Why was the localized subsidence in Surfside not reported to the city of the building?
This study was published in the scientific journal 'Ocean and Coastal Management' as a research paper. We did not report this finding to city officials or the building's association board at the time of publication, as we were focusing on the effects of flooding in coastal communities. As geophysicists, we were assessing coastal flooding hazards in two communities by detecting and measuring local subsidence. It was not a study on building structures. Additionally, it is common to find building movement in InSAR subsidence studies. A movement of 2 millimeters-per-year is relatively low and not unusual. In our study, finding localized subsidence in the Surfside location was unexpected because of the location. However, the rate of subsidence was within a normal range and not unusual.

How were the findings reported?
Our study focused on land subsidence and coastal flooding hazard. Thus, scientific publications and presentations were aimed at communicating our findings to researchers and officials that deal with sea level rise and coastal flooding hazard. The list of publications and presentations of this study is provided at the end of the document.

What are the implications of our study to the collapsed Chaplain's South Tower?
The tragic collapse of the Champlain condo tower in Surfside, Fla. has left us asking countless questions. Some of the most important questions are: How did this happen? Why did it happen? Answers to these questions will require thorough engineering analyses of the building structure and its failure, which will take time. Our finding that the Champlain's South Tower subsided in the 1990s at a rate of 2 millimeter-per-year cannot explain how or why the building collapsed, because the collapse occurred more than 20 years after the subsidence observations period. However, our finding may provide a hint on processes that may have contributed to the collapse. The observed movement can represent: 1) continuous settlement of the buildings in the ground; or 2) internal deformation within the buildings. As InSAR measures the movement of the buildings, we cannot determine which of the two suggested processes caused the observed movement.

Did you study more recent InSAR data over the Miami area?
InSAR data collection over the Miami area between 2000 and 2015 was sporadic and not sufficient for obtaining accurate results. However, since 2016 the European Space Agency has operated a constellation of two satellites (Sentinel-1A and Sentinel-1B) that collect data in a systematic manner over all continents. The five-year long Sentinel-1 dataset can provide the required accuracy (1 millimeter-per-year) over most continental areas. Two preliminary studies conducted by other research groups detected no movement of the Champlain's South Tower during the 2016-2020 period, as presented in the following links:
https://satsense.com/wp-content/uploads/2021/06/MiamiChamplainTowers-20210626-1.pdf
https://twitter.com/shirzaei/status/1409376660017893377?s=20

Are you able to check subsidence at other locations on the beach?
Our study identified several pockets (<0.2 km^2) of subsidence in Miami Beach. Most of these locations are in the western part of the city, which were expected because that part of the city was built on reclaimed wetlands. The only subsidence signal that we detected along the beaches was in the location of the Champlain's South Tower. From the subsidence perspective, there were no other buildings along the beaches that showed the same pattern. But a finding of subsidence, or lack thereof, simply identifies movement of land and should not serve as a replacement for routine inspections and maintenance of structures.

Can InSAR be used to prevent such events in the future?
Space-based InSAR is an amazing technology that allows us to detect small movements on the Earth's surface over wide areas that cannot be seen with our eyes, or even detected with other precise instruments. InSAR technology can be a useful tool to identify buildings that experience movement over a period of time and could benefit from a closer onsite inspection. However, to increase the use of InSAR technology for building stability monitoring, it will require resources and mechanisms to share information between stakeholders. And ultimately, it would be up to the property owners to decide how to handle the information derived from InSAR.

Publications:

- Fiaschi, S. and S. Wdowinski, (2020). Local land subsidence in Miami Beach (FL) and Norfolk (VA) and its contribution to flooding hazard in coastal communities along the US Atlantic coast. *Ocean & Coastal Management*, *187*, 105078. (https://www.sciencedirect.com/science/article/abs/pii/S0964569119309470?via%3Dihub)
- Wdowinski, S., Oliver-Cabrera, T., and Fiaschi, S.: Land subsidence contribution to coastal flooding hazard in southeast Florida, Proc. IAHS, 382, 207–211, https://doi.org/10.5194/piahs-382-207-2020, 2020.

Formal presentations:

- Miami-Dade Whole Community Planning Workshop on “Collaboration in Disaster Readiness” on 3/6/2019 – I presented the topic of “Sea level rise and increased flooding hazard in Florida”, which included a brief presented the results of our coastal subsidence study.
- Sea Level Work Group of the Southeast Florida Climate Change Compact on 7/8/2019 – I presented the topic of “Florida sea level rise: Regional and local contributions” as part of the preparation of the document “Unified Sea Level Rise Projection Southeast Florida, 2019 UPDATE” (https://southeastfloridaclimatecompact.org/wp-content/uploads/2020/04/Sea-Level-Rise-Projection-Guidance-Report_FINAL_02212020.pdf).
- At the 59th meeting of the Civil GPS Service Interface Committee on 9/16/2019. Presentation is available at (https://www.gps.gov/cgsic/meetings/2019/wdowinski.pdf).

Detailed maps of land subsidence in the area of the Chaplain's South Tower.

Figure 1 shows that the Champlain's South Tower subsided during the 1993-1999 observation period at a rate of ~2 millimeter-per-year. The figure also presents the time series of a single data point located on the eastern side of the building. All other yellow points show very similar subsidence pattern.

Figure 2 shows vertical velocity map of a wider area surrounding the Champlain's South Tower. The map shows a cluster of subsiding points over the Champlain's South Tower and partly in the building north of it. The map also shows subsiding points on the road west of the buildings and on the lawn east of the buildings. However, one must take into consideration that not all points are reliable due to systematic and nonsystematic measurement noise. Although we cannot trust individual measurement points, clusters of points are considered reliable. The cluster of the points in Figure 2 represents the movement of the Champlain's South Tower and possibly the building to the north. The data points on the road and the lawn are not reliable. When we analyzed these data points for the study, we concluded that they represented the movement of the South Tower, which is a 12-story high condominium building.

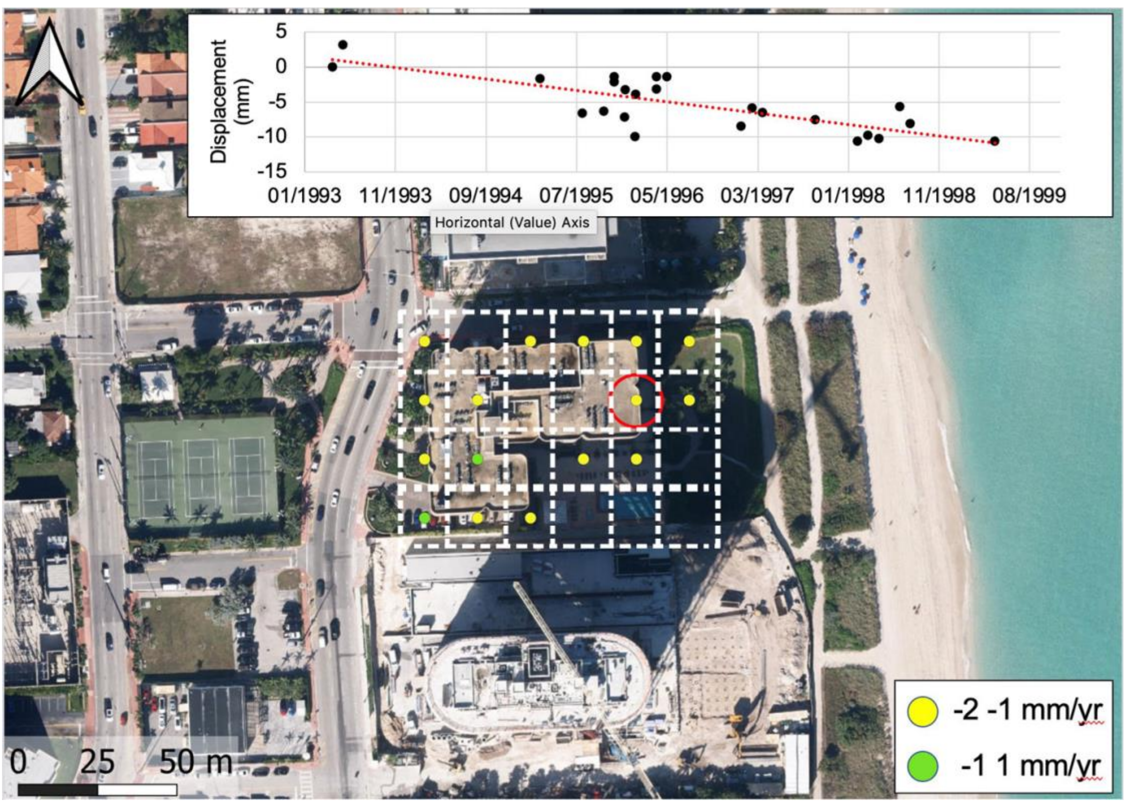

Figure 1: Vertical velocity map of Champlain's South Tower from 1993 to 1999. Green dots represent ground with velocities less than the detection threshold of 1 millimeter-per-year. Yellow velocities represent movements at a rate of 1-2 millimeter-per-year. Each dot represents the velocity of a point with 20x20 m^2 cell (pixel) that provides the strongest radar signal back to the satellite. Cells without dots do not have objects that can return radar signal back to the satellite. The time series at the top of the image shows the displacement history of the data point marked by the red circle.

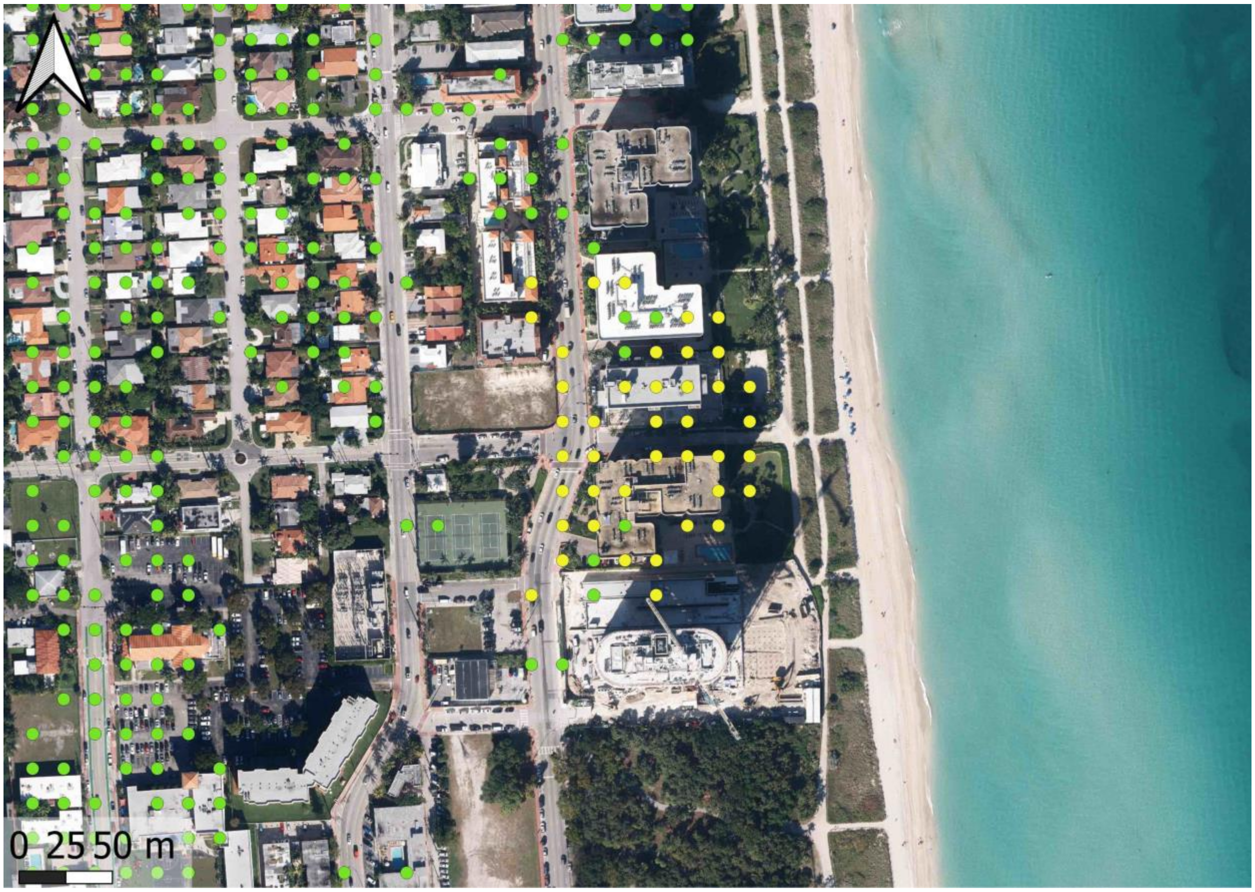

Figure 2: Vertical velocity map of the Surfside area from 1993 to 1999. Green dots represent ground with velocities less than the detection threshold of 1 millimeter-per-year. Yellow velocities represent movements at a rate of 1-2 millimeter-per-year. The velocity data points are located at the center of 20x20 m^2 pixels. The detected velocities did not necessarily occur at the center of the pixel; they can be anywhere within the pixels' area. Large areas have no velocity information, because of the limitation of InSAR to work in fast changing environments, including vegetation, beach, and open water.

Where can I find additional detailed maps?

Shape files with the high-resolution velocity map of the entire Miami Beach study area are available on the FIU Research Data Portal: https://doi.org/10.34703/gzx1-9v95/NTKTST