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Modelling a city's minuscule changes

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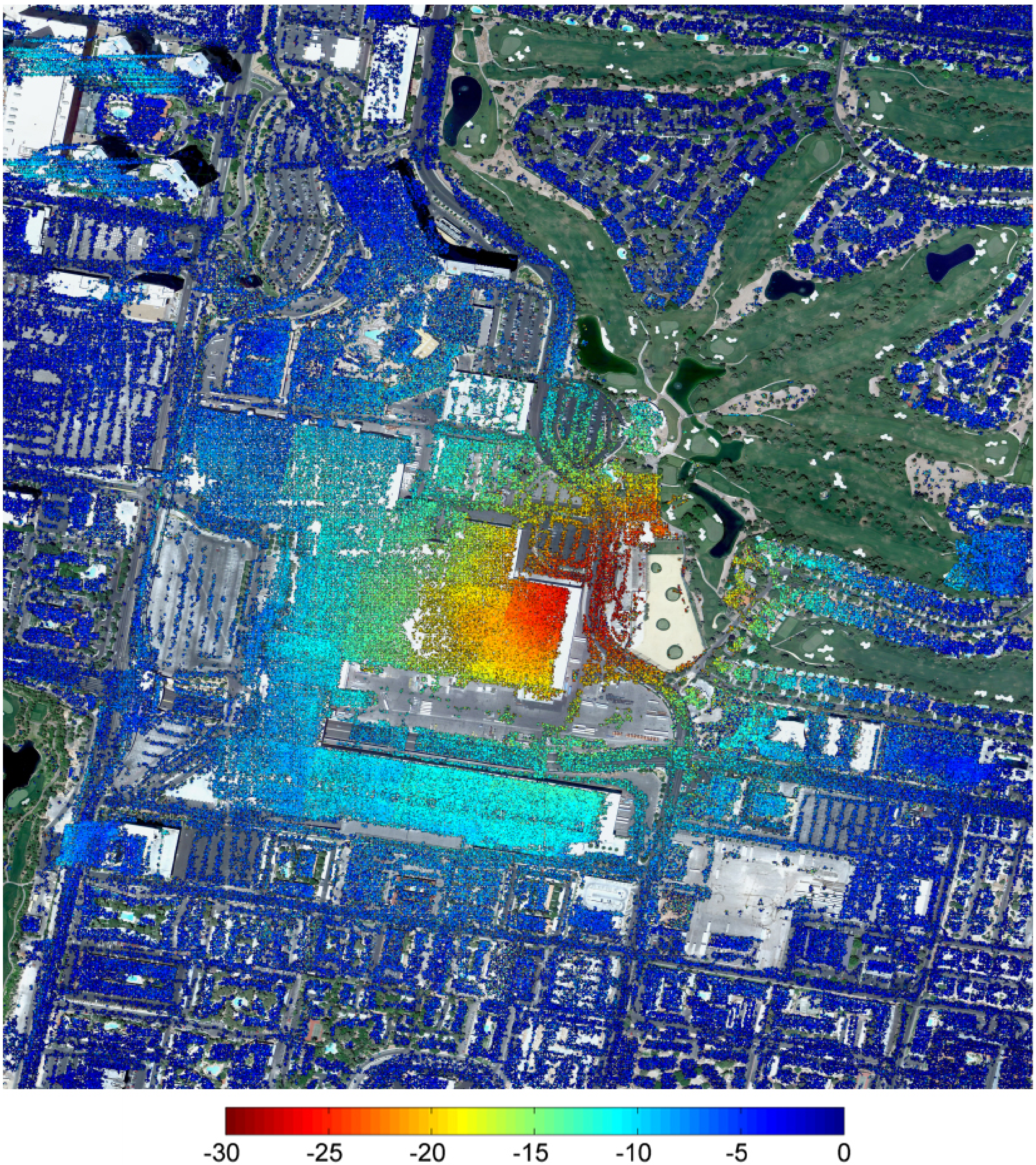

Using a combination of satellite imagery and computer modelling, the Zhu team can predict buildings' deformations at the millimeter scale. This image shows deformation estimates around the Las Vegas Convention Center. Credit: Xiaoxiang Zhu and the SiPEO team, Technical University of Munich

By using 3D models, computational scientists can create precise, static representations of a city. However, cities, much like living things, are almost always in motion. Major construction projects—from new buildings to public transportation infrastructure—seismic events, or shoddy construction can quickly alter a city's properties both above and below ground.

A team of researchers led by Technical University of Munich (TUM) Professor Dr. Xiaoxiang Zhu recognized that accurately modeling cities for risk management purposes needed a fourth dimension, time. To put "in motion" a three-dimensional, high-resolution computational model of a city's downtown, though, the team needed the help of supercomputers.

"Static three-dimensional models of cities are well-established, in particular in Europe," said Zhu. "What we now work on measuring are temporal changes down to the centimeter or millimeter scale to observe whether areas of buildings have been disturbed by uplift or subsidence."

Uplift and subsidence are the motion of the Earth's surface based on changing conditions underground that can move structures upward (uplift) or downward (subsidence). Using some of the most advanced satellite imaging technology on Earth and the Leibniz Supercomputing Centre's (LRZ's) SuperMUC machine, Zhu's team takes satellite snapshots of these tiny changes, then uses these images to make computational models it can put in motion.

In the process, the team reconstructed the first-ever model illustrating an entire city in four dimensions. The team's research was recently given the best paper award from IEEE Transactions on Geoscience and Remote Sensing at the end of July.

Reconstructing construction risks

The team's research starts high above the clouds. Using some of the most advanced civil observation satellites available, such as the German Aerospace Center's (DLR's) TerraSAR-X and TanDEM-X, the team employs a method called SAR tomography (TomoSAR) to get its 3D images.

To measure buildings' changes, these satellites must shoot waves to the surface of the earth, in turn measuring the distance between the satellite and the buildings in the area in question—the shorter the wavelength, the more accurate the measurements. The Zhu team uses images that have been created using 3 centimeter waves.

The satellite takes about 11 days to revisit the same spot on the Earth, then takes an image from a slightly different position, allowing the researchers to combine these images into a 3D model. Further, since the images are taken at different times, such precise measurements allow the researchers to look for "deformation parameters" by noting even the tiniest changes—in this context the so-called fourth dimension—in a building's distance from the satellite.

The researchers then get to work on putting these images in motion. Each image is roughly 10,000 by 5,000 pixels, and the team has to do calculations for each pixel. The team has done work on datasets for several cities—Las Vegas, Berlin, Shanghai, Beijing, Washington D.C.

and Paris—and has datasets ranging from roughly 25 images to 550.

The team's compressive sensing method is one of the keys in generating these high-quality 4D models. In simple terms, by using compressive sensing, the researchers benefit from "sparsity" in the model, or the fact that they are only recreating a three-dimensional model of the Earth's surface rather than the planet's entire volume. This enables the researchers increase the resolution in their models by up to 25 times what they could do simulating the Earth's volume.

"The prices we paid for these world-record-accurate 4D city models are computational expenses," said Zhu. "For each pixel, we are solving an expensive convex optimization problem with a dimension of hundreds times millions. This is only possible with high performance computing."

The team used 26 million core hours on LRZ's SuperMUC system. These models are very memory-intensive, and the team used SuperMUC's "fat island" so it could focus its reconstructions on the machine's 8,200 cores with very high memory-per-core.

Round and round we go

By being the first team to create 4D models from satellite imagery data, the team has helped blaze a trail for more detailed, beneficial city monitoring methods. In creating its various city models, the team found that the Las Vegas convention center was showing noticeable subsidence, with the ground sinking approximately 30 millimeters per year in some places.

As cities continue to grow larger and become ever-more populous, more high-resolution images are taken from space, and computing power continues to grow, the team feels confident that its methods will be employed more frequently, leading to safer construction work and advanced notice of buildings that are beginning to show signs of structural risk and, in turn, danger.

The team was awarded another GCS computer allocation for 2017, receiving 20 million core hours on LRZ's SuperMUC system. Zhu indicated that the team planned to open the team's datasets to the community so other researchers could study its approach and hopefully continue to add to the growing body of modeling work done in the field.

With access to next-generation machines, the team hopes to generate global 4D models at this level of accuracy and increasingly incorporate more intricate data such as sediment types around buildings. Such global data sets would lead to a giant leap for urban geography research as well as helping city planners, decision makers, and stakeholders make more informed decisions. Along with the support of GCS, Zhu recently secured a 1.5 million Euro grant to support her research towards this goal, and her European Research Council grant project "So2Sat" kicked off on September 1, 2017.

Provided by Gauss Centre for Supercomputing