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Time series analysis of Mexico City subsidence constrained by radar interferometry

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In Mexico City, subsidence rates reach up to 40 cm/yr mainly due to soil compaction led by the over exploitation of the Mexico Basin aquifer. The Mexico Valley, an endoreic basin surrounded by mountains, was in the past covered by large lakes. After the Spanish conquest, the lakes have almost completely disappeared, being progressively replaced by buildings of the current Mexican capital. The simplified hydrogeologic structure includes a superficial 50 to 300 m thick lacustrine aquitard overlying a thicker aquifer made of alluvial deposits. The aquitard layer plays a crucial role in the subsidence process due to the extremely high compressibility of its clay deposits separated by a less compressible sand layer where the biggest buildings of the city are anchored. The aquifer over-exploitation leads to a large scale 30m depression of its piezometric level, inducing water downwards flow in the clays, yielding compaction and subsidence.

In order to quantitatively link subsidence to water pumping, the Mexico city subsidence needs to be mapped and analyzed through space and time. We map its spatial and temporal patterns by differential radar interferometry, using 38 ENVISAT images acquired between end of 2002 and beginning of 2007. We employ both a Permanent Scatterer (PS) and a small baseline (SBAS) approach. The main difficulty consists in the severe unwrapping problems mostly due to the high deformation rate.

We develop a specific SBAS approach based on 71 differential interferograms with a perpendicular baseline smaller than 500 m and a temporal baseline smaller than 9 months, forming a redundant network linking all images: (1) To help the unwrapping step, we use the fact that the deformation shape is stable for similar time intervals during the studied period. As a result, a stack of the five best interferograms can be used to reduce the number of fringes in wrapped interferograms. (2) Based on the redundancy of the interferometric data base, we quantify the unwrapping errors for each pixel and show that they are strongly decreased by iterations in the unwrapping process. (3) Finally, we present a new algorithm for time series analysis that differs from classical SVD decomposition and is best suited to the present data base. Accurate deformation time series are then derived over the metropolitan area of the city with a spatial resolution of 30 × 30 m.

We also use the Gamma-PS software on the same data set. The phase differences are unwrapped within small patches with respect to a reference point chosen in each patch, whose phase is in turn unwrapped relatively to a reference point common for the whole area of interest. After removing the modelled contribution of the linear displacement rate and DEM error, some residual interferograms, presenting unwrapping errors because of strong residual orbital ramp or atmospheric phase screen, are spatially unwrapped by a minimum cost-flow algorithm. The next steps are to estimate and remove the residual orbital ramp and to apply temporal low-pass filter to remove atmospheric contributions.

The step by step comparison of the SBAS and PS approaches shows both methods complementarity. The SBAS analysis provide subsidence rates with an accuracy of a mm/yr over the whole basin in a large area, together with the subsidence non linear behavior through time, however at the expense of some spatial regularization. The PS method provides locally accurate and punctual deformation rates, but fails in this case to yield a good large scale map and the non linear temporal behavior of the subsidence. We conclude that the relative contrast in subsidence between individual buildings and infrastructure must be relatively small, on average of the order of 5mm/yr.