Time-lapse gravity: A versatile method for monitoring dynamic processes

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Monitoring dynamic processes such as fluid migration in reservoirs using time-lapse gravity has long been a dream of many potential-field geophysicists. It is only in the last decade or so that significant advances have been made in instrumentation, data interpretation, and integration of multidisciplinary information that the method is not only feasible but has also demonstrated the practicality for a broad range of applications. Compared to other geophysical methods for monitoring subsurface dynamic systems, time-lapse gravity has one important advantage in that the measurements are directly sensitive to the variations in density, which is solely related to the amount of mass changes per volume. In oil and gas reservoirs, for example, such changes are primarily due to fluid movement and substitutions. Thus, while the seismic method may provide unparalleled structural resolution, the time-lapse gravity method has the potential for characterizing the "content", that is the fluid saturation or mass transport within "containers" delineated by seismic images.

Although much of the method has been developed in the context of petroleum reservoirs and CO_2 sequestration systems, time-lapse gravity is scale adaptive and has the potential for monitoring dynamic processed deep in the crust of the Earth. Cumulative changes in these crustal processes over the time scale of several decades increase the observable signal strength and may further enhance the effectiveness of the method. The prospect of low-cost, permanently installable borehole gravity sensors enables us to perform cost-effective, long-term passive monitoring of fluid migration and mass transport in these dynamic systems.

In this paper, we present the basics of time-lapse gravity method, current and emerging gravimeters, and the quantitative interpretation techniques of data through different inversion approaches. We also examine the possible paths toward application of time-lapse gravity in the study of deep dynamic processes in the Earth's crust.