GTrace: Summary Report

The main goals of the project GTrace were to improve our understanding of terrestrial gravity fluctuations in the form of noise in ground-based gravitational-wave detectors such as LIGO and Virgo, and in the form of signals produced by earthquakes in gravimeters and gravity gradiometers.

GTrace led to significant progress in our analytical understanding of terrestrial gravity perturbations, specifically with respect to seismic, atmospheric, and anthropogenic disturbances. It is possible now to evaluate in detail the gain from constructing future gravitational-wave detectors like the Einstein Telescope underground, or to estimate sensitivity limitations from gravity noise of surface detectors. Major progress has also been made in our understanding of coherent cancellation techniques of gravity noise. An implementation of a cancellation system has been proposed as upgrade for the Advanced LIGO detector, and investigations have also been started for the Advanced Virgo detector. The gravity-noise cancellation technology is essential to extend the observation band of ground-based gravitational-wave detectors towards lower frequencies. This will lead to improvements of parameter estimation for certain types of gravitational-wave signals, especially black-hole binaries, and potentially open the window to new signals that can otherwise not be observed.

In the framework of GTrace, first models of transient gravity perturbations from earthquakes have been calculated. The result is a complete time series of gravity perturbations from the onset of a fault rupture to when the gravity field has settled to a new permanent value after the earthquake. These models have been applied to motivate and analyze earthquake early warning systems assisted by gravity sensors. The idea that was developed in this project is to make use of the fact that gravity changes almost instantly everywhere on Earth with the beginning of a fault rupture. The challenge is to be able to observe these gravity changes in sufficiently short time, which will require a new generation of gravity sensors for the purpose of earthquake early warning. As a proof-of-principle, a search for this gravity change was carried out with existing gravity sensors in Japan using data during the fault rupture of the magnitude 9.0 Tohoku-Oki earthquake in 2011. Strong evidence for a detection of such signal was found, and the previously derived models were essential to validate this first observation of a developing gravity change. The models have been incorporated into numerical codes that are being used to evaluate the prospects of producing warnings of an earthquake within seconds by gravity observations.

Finite-element simulations of seismic fields and associated gravity perturbations have been used throughout the studies of earthquake gravity perturbations, and have also been introduced during this project as a tool to investigate certain aspects of the generation of gravity noise in gravitational-wave detectors by seismic fields. Specifically, the impact of seismic scattering on the performance of noise-cancellation schemes is difficult or even impossible to analyze analytically. These numerical simulations will be essential for the evaluation of potential limits of noise-cancellation schemes for surface and underground detectors.

The main progress with respect to atmospheric gravity noise has been achieved on the analytical side with a new model of gravity perturbations produced by turbulent sound production, and improved understanding of how much atmospheric gravity noise is suppressed underground. Towards the end of

GTrace, first numerical simulations were set up with the goal to model atmospheric gravity perturbations in complex environments, or due to complicated, i.e., turbulent, movement of air mass. The focus of current investigations is to improve the model of atmospheric gravity noise for the Advanced Virgo detector. The long-term goal of these studies is to evaluate prospects of cancellation schemes of atmospheric gravity noise for third-generation, gravitational-wave detectors constructed at the surface, but also for so-called low-frequency gravitational-wave detectors currently being prototyped in the form of atom-interferometric detectors, torsion-bar antennas, or superconducting gravity gradiometers.