9. Conclusion

Gravity and deformation observations are used many times at volcanoes to investigate the mechanism of volcanic activities and to improve the possibilities to predict hazardous volcanic eruptions. Within the project "MERAPI" the impact of these methods in cooperation with other geophysical procedures have to be tested. Normally the gravity and height data lack due to insufficient accuracy and reliability. Gravity changes are mostly determined by using a single gravimeter during a single observation campaign. No redundancies and accuracy controls are available.
It was tried therefore to collect reliable data of gravity and height changes by up to 4 gravimeters in parallel and by geodetic high precision GPS-observations. For that purpose a repetition network was established in August 1997 consisting of 23 stations. The gravity values as well as the heights of the stations were observed five times till August 2000 by using up to four LaCoste&Romberg gravimeters and geodetic Trimble and Leica-GPS-receivers.
The obtained gravity and height changes are much smaller as previously assumed and given in the literature. In coincidence with other observations as tilt observations the changes of the height and gravity field around Merapi are very small. Only at the summit significant changes are found. Obviously Merapi was between 1997 and 2000 an "open system", where gases and magma can extrude without any hindrance. The danger of an explosive hazardous eruption of the volcano was very low during this time window, even if several gravitational dome collapses have occurred.
In this thesis some possibilities are investigated how gravity and deformation changes can contribute to the following questions:

- which mechanism causes the observed residual gravity changes
- can models of the volcano Merapi hitherto published help to explain the gravity changes.

For that purpose programs have been developed to compute the vertical gravitational attraction of different geometric bodies (primitives) as sphere, cube or cylinder, using the software package "MATLAB".
For the estimation of the vertical attraction of a "thick vertical cylinder" two different formulas have been tested, which deliver the same result within the necessary computation accuracy.
The interpretation of observed gravity changes was carried out in two steps. First the gravity changes at the summit stations along the crater rim were analyzed. These stations show the largest gravity changes. Model of the volcano edifice as given by Beauducel and Cornet, (1999) and Müller et al. (1999) were used as base and modified in four steps. In these models a magma chamber in depth of about 8600 m below surface feeds a conduit up to the summit. The models differ concerning the following points to each other:

- The conduit is modeled as a dipping thin rod between magma chamber and the summit of Merapi, whereby the magma chamber is located about 2000 m southeast of the summit.
- The conduit is a vertical thin rod.
- The conduit is modeled by a thick vertical cylinder

- The conduit is a thick vertical cylinder surrounded by 10 further concentric cylinders to model the hydrothermal system of Merapi.

Gravity changes are explained by different levels of magma within the conduit. Empty space with density of air = 1.293 kg/m^3 is filled with magma with densities = 2400 kg/m^3. These models work quite well; however they explain only the gravity changes at the summit stations. Gravity changes at the stations more far away from the summit are not influenced by the filling of the conduit with magma.

However gravity changes at the summit stations allow quiet well to determine changes of the magma levels within the conduit. Analysis of all gravity changes shows a permanent increase of the magma level between 1997 and 2000.

Gravity changes at stations far away from the summit can be explained by changes in the hydrothermal system of Merapi volcano. From electromagnetic exploration methods a conductivity model of Merapi's subsurface was developed. Zones of low resistivity are explained thereby with layers saturated with fluids (Müller et al, 1999). These layers are modeled by 10 vertical cylinders concentric around the summit of Merapi. The subsurface layers of Merapi have a high pore volume (between 10%-20%) as determined by different seismic experiments. It exists the possibility that the pores are filled with fluids and that the fluid contents of the layers are changing in time and space. The density changes within the cylinders are determined using the linear optimization program "lsqlin" of MATLAB. As target function the L_2-norm was used. Additional constraints concerning the density of the particular layers have been introduced and tested.

The results show that the largest density changes are obtained for the cylinders (and layers) where resistivity is lowest and therefore the biggest pore volume and fluid content exists.

Generally the observation of height and gravity changes can be used to determine the status of a volcano. The volcanic system is "open", only small changes in space and time especially at the summit occur. A closed system will generate large deformations and gravity changes due to the increase of pressure inside the volcano edifice. Gravity observations therefore also can give information if the status of a volcano becomes critical.

Gravity changes can be used to check the reliability of volcanic models, determined with other method. However in the present state it is not possible to use gravity observations as stand alone method. Gravity observations have to be integrated always with other methods as electromagnetic, tilt and or seismic observations.