8. Discussion and Interpretation

The observation program between August 1997 and August 1999 was developed under the assumption that large gravity and height changes in the range of $1x10^{-5}$ m/s^2 and 1m will occur on Merapi volcano.

Observed gravity and height changes however are significantly smaller as previously assumed and described in the literature (see Beauducel, 1999 and Jousset, 1996). Reasons for the published large changes are may be:

- All electromagnetic distance observations at Merapi are not reduced for the effects of atmospheric refraction (Young, 2000).
- Many former GPS-observations are carried out mainly only with 1-frequency receivers.
- GPS-observations near the equator are heavily disturbed by tropospheric refraction effects.
- Active telemetry from other observation stations and radio relay systems influence the GPS-receivers even geodetic 2-frequencies receivers as Trimble 4000 SSE and SSi.
- Former gravity changes are observed only with a single gravimeter at a particular profile. No redundancies concerning gravimeters and the number of observations are existing due to lack of time, man power and instruments.

In this context the results presented here give a much more reliable insight in the mechanisms acting on Merapi volcano. The maximum statistical significant changes are observed at the summit station JRA13:

- Gravity increase of about +1787 ± 226 nm/s^2 is obtained between August 1997 and August 2000.
- The largest height change occurred between February 1998 and August 1997 at this station with a subsidence of about -0.470 ± 0.049 m.

All changes at the other stations are smaller and just above the noise level.

The interpretation of the data is therefore not trivial. For the interpretation different programs calculating the vertical gravitational effects of geometric primitives (sphere, cube, cylinder…) using MATLAB were written and tested. Special effort was given to the computation of the gravitational effect of vertical cylinders, where two different formulas (4.14 - 4.16) are tested. Both formulas are delivering identical results. Formula (4.16) offers however the advantage, that the computation point P can be located off axis of the cylinder. It allows the generation of more versatile 3d - models.

Different classes of models were developed and their physical meanings investigated.

The first class of models tries to explain the gravitational changes of stations near to the crater rim. As basis the model by Beauducel (1999) is used and modified concerning different elements. The magma conduit inside the volcano is modeled by an inclined pipe or by a vertical cylinder. The magma chamber is represented by a sphere in 8600 m depth and 137 m radius.

It can be shown that gravity changes at stations at the crater rim can be used to determine the height of magma in the volcano edifice. The results are quiet independent from the geometric form of the magma conduit system as it can be seen in table 8.1.

A semi graphical method allows the determination of magma height with surprising good accuracy. Therefor the installation of gravity stations on the crater rim of Merapi is essential for the application of gravity observations.

Tab.8.1. Magma height in the conduit as determined by gravity changes.

Epoch	Magma Height in the conduit below surface [m]		
	conduit modeled by vertical thin rod	conduit modeled by inclined thin rod	conduit modeled by vertical thick cylinder
August 1997	417.5	436.5	412.5
August 1999	154	177.5	153
August 2000	107	79.5	105

The models show that we have hints for a permanent rise of magma height in the conduit of the volcano. Larger differences are obtained if the inclination of the conduit is allowed. Since permanently magma is extruding from Merapi in the last years, we have to assume that magma level is very near to the surface. May be the main conduit of Merapi is inclined really in southeast direction as proposed by Beauducel (1999).

The second class of models explains the gravity changes far away from the summit of Merapi volcano. Base is the results of active electrical prospecting as resistivity, magnetotelluric and LOTEM observations (Müller et al., 1999). This model explains changes of conductivity in the subsurface with distinct layers filled with fluids within the hydrothermal system of the volcano. Changes of the fluid content will cause mass changes which are connected with density and also gravity changes.

If gravity changes are caused by changes of the fluid contents, the possible density changes can be constrained by the pore volume at the volcano.

Layers of different conductivity have been modeled as thick concentric cylinders with the vertical axis at the volcano's conduit. The densities changes in time inside the cylinders have been determined with the linear optimization program "lsqlin", offered by MATLAB.

Different constraints are introduced. Wegler et al. (1999) have shown that density below Merapi volcano is quite low between 2000 and 2400 kg/m^3. We conclude therefore that in the subsurface layers high pore volume is existing, may be 10%- 20%. If all pore volume are filled with water of density $\rho = 1000$ kg/m^3, the density of the subsurface can vary between $\pm$ 50 kg/m^3. For the computation of the density changes we have varied these constraints.

These models fit quite well the observed gravity data (within the 2σ error bars). The obtained density changes are looking physically reliable.

The results show that density changes and fluid changes connected with them are existing mainly in regions where the inclination of slopes of the volcano's edifice is changing. Density changes near the volcano's conduit are small. Obviously these layers are saturated by water (damp) already.