

Gravity and geoid estimate in South India and their comparison with EGM2008

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Abstract

The geopotential model EGM2008 has been tested in the Southern part of India by fitting gravity data. These data have been collected by the National Geophysical Research Institute of India and have been also used to estimate the geoid in this region. For the comparisons a total of 16013 gravity values have been considered. Previous global geopotential models have been also computed on these gravity points to analyze their performance as related to EGM2008. Furthermore, this new model has been compared with the local geoid estimate that is available in this region. The results prove that, in terms of gravity anomaly, in the Southern India region, EGM2008 is better than any other existing model. As for the geoid undulation, the differences between the local South India geoid and EGM2008 are less than 2 m (in absolute value) and are partially correlated with the topography.

1. Introduction

The EGM2008 is the last geopotential model estimated at the agreement NGA/NASA. This estimate, with maximum degree 2160, proved to be very effective in modeling different functionals of the anomalous potential. We present a comparison over the Southern India region using a quite large data base collected by National Geophysical Research Institute of India. The gravity field of this area is quite regular and its structure is mainly connected to the topography; in fact the major variations are in the area $10^{\circ} \leq \varphi \leq 12^{\circ}$, $76^{\circ} \leq \lambda \leq 78^{\circ}$ where the principal relieves are concentrated. The topography varies from sea level to high mountains (about 2500 meters) and the area is surrounded by deep ocean. Land gravity is known inside the area $8^{\circ} \leq \varphi \leq 15^{\circ}$, $74^{\circ} \leq \lambda \leq 81^{\circ}$ where 16013 gravity values were measured.

Over this area, a local geoid has been recently computed by the National Geophysical Research Institute of India in co-operation with IGeS (International Geoid Service). This is an updated and detailed geoid which was computed using the “remove-restore” technique and collocation.

Both gravity and this geoid estimate were used to check for the accuracy of EGM2008 in this area

2. Fitting different geopotential models with gravity data in South India.

The distribution of the gravity point values used in the comparison is shown in Figure 1. Data density is not uniform; however, the global coverage is satisfactory since there are only limited data gaps (as compared to the whole area). The data base contains 16013 gravity values.

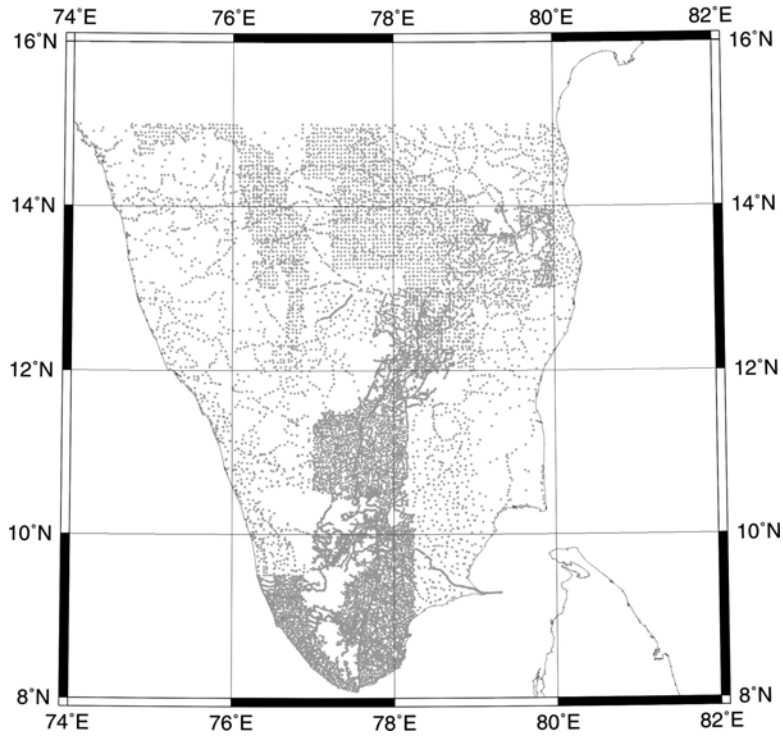


Figure 1. The gravity data base in South India.

Point positions refer to WGS84; gravity is in IGSN71 and the adopted normal field is GRS80.

Different available geopotential models have been used to reduce these gravity data in order to be compared to EGM2008.

The considered models are:

- EGM96 (Lemoine et al., 1998)
- GPM98CR (Wenzel, 1998)
- EIGEN_GL04C (Förste et al., 2007)
- EGM2008 (Holmes and Pavlis, 2008).

For each model, the gravity effect has been computed using the full coefficient expansion. The statistics of the data and those of the residuals obtained using the tested models are listed in Table 1.

Gravity	E (mgal)	σ (mgal)	Min (mgal)	Max(mgal)
Δg_{fa}	-33.93	29.13	-120.93	192.77
$\Delta g_{fa} - \Delta g_{EGM96}$	-6.45	21.85	-94.46	182.32
$\Delta g_{fa} - \Delta g_{GPM98CR}$	-7.56	22.42	-83.08	200.56
$\Delta g_{fa} - \Delta g_{GL04C}$	-6.08	21.65	-92.55	183.23
$\Delta g_{fa} - \Delta g_{EGM2008}$	-0.08	10.88	-112.54	79.40

Table 1 – Gravity and residuals statistics (after model reduction)

The statistics show that EGM2008 is able to describe the gravity field of this area better than the other considered models. The standard deviation of EGM2008 residuals is, roughly speaking, one third the value of the unreduced data. When using the other models, the standard deviations of the residuals decrease only to about two third of the original value. Particularly, the GPM98CR model, which is complete to degree and order 720, gives, as compared to EGM96 and EIGEN_GL04C, the worst result. Furthermore, the EGM2008 residuals have also a very small mean, less than one tenth of mgal. The plot of the residual values after EGM2008 reduction is shown in Figure 2.

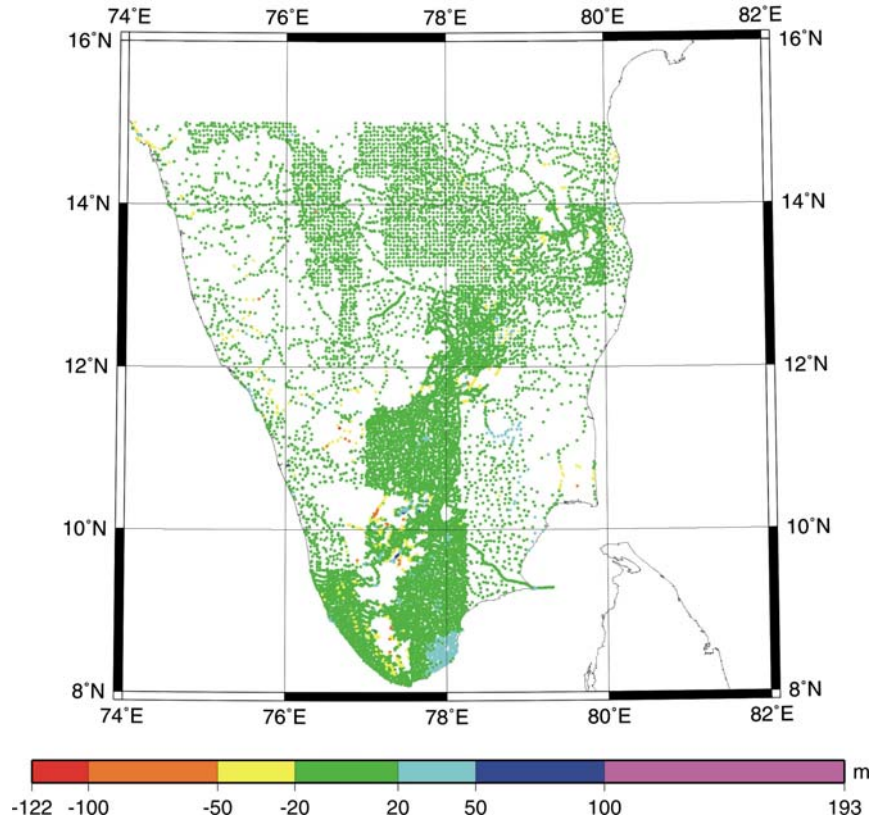


Figure 2. The gravity residuals after EGM2008 reduction

Most of the residuals are in the range $[-20 \text{ mgal}, 20 \text{ mgal}]$ and only some gravity lines have larger residuals (probably related to unreliable data). This plot can be compared with the one displaying e.g. the EIGEN_GL04C residuals (see Figure 3).

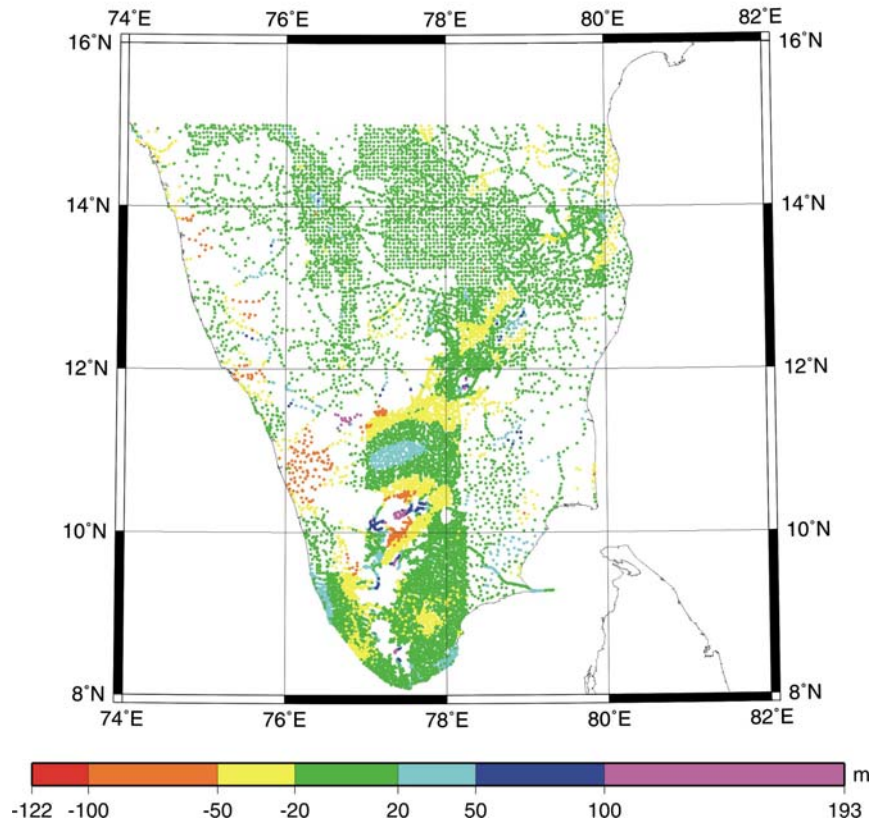


Figure 3. The gravity residuals after EIGEN_GL04C reduction

As one can see in Figure 3, the residuals show a higher degree of variability. Equivalent results have been obtained using all the other tested models.

EGM2008 model includes a higher frequency signal as compared to the other models, so a smoother residuals gravity field is obtained. This also reflects in the statistics of Table 1.

Assuming that this high frequency signal is basically due to the terrain effect, one should obtain results which are similar to EGM2008 by removing also the RTC effect while using the “lower” frequency geopotential models.

A further computation has been then carried out to get the residuals after RTC reduction. This has been done for the EIGEN_GL04C model only, the one giving the better results (if EGM2008 is not considered).

RTC effect has been computed using the TC software of the GRAVSOFT package (Tscherning et al., 1994). The DTM used in the computation has been obtained by merging SRTM3 and the 1'×1' NOAA bathymetry (see next paragraph).

The residual statistics are listed in Table 2.

Gravity	E (mgal)	σ (mgal)	Min (mgal)	Max(mgal)
$\Delta g_{fa} - \Delta g_{gl04C} - \Delta g_{RTC}$	-1.10	15.69	-85.26	83.01

Table 2 – Residuals statistics after EIGEN_GLC04 model and RTC reduction.

Even though there is an improvement in the residual statistics, we have better results using EGM2008 only.

Thus, the full remove step based on EIGEN_GL04C gives a result which is poorer than the one obtained using the EGM2008 model only.

3. The comparison between EGM2008 and the South India geoid estimate.

The height anomaly implied by the EGM2008 model has been compared with a recent geoid estimate available over the Southern region of India.

The South India Geoid estimate is an updated computation in this area. It is based on a gravity data base which is assembled using the 16013 land gravity values described in the previous paragraph and gravity at sea derived from altimetry (Andersen et al, 2005). The global gravity data base consists of 63968 values.

The estimation procedure is the “remove-restore” technique (Tscherning, 1994) and the residual geoid component has been computed using the Fast Collocation approach (Bottoni and Barzaghi, 1993).

The reference global geopotential model adopted in the computation is the EIGEN_GL04C model, complete up to degree and order 360.

The RTC effect has been estimated using a DTM which has been obtained by merging SRTM3 (Farr et al., 2007) and a 1'×1' NOAA bathymetry (<https://128.160.23.42/dbdbv/dbvquery.html>). In such a way, over the area $4^{\circ} < \varphi < 16^{\circ}$, $72^{\circ} < \lambda < 83^{\circ}$ a 100m× 100m DTM was derived, plotted in Figure 4.

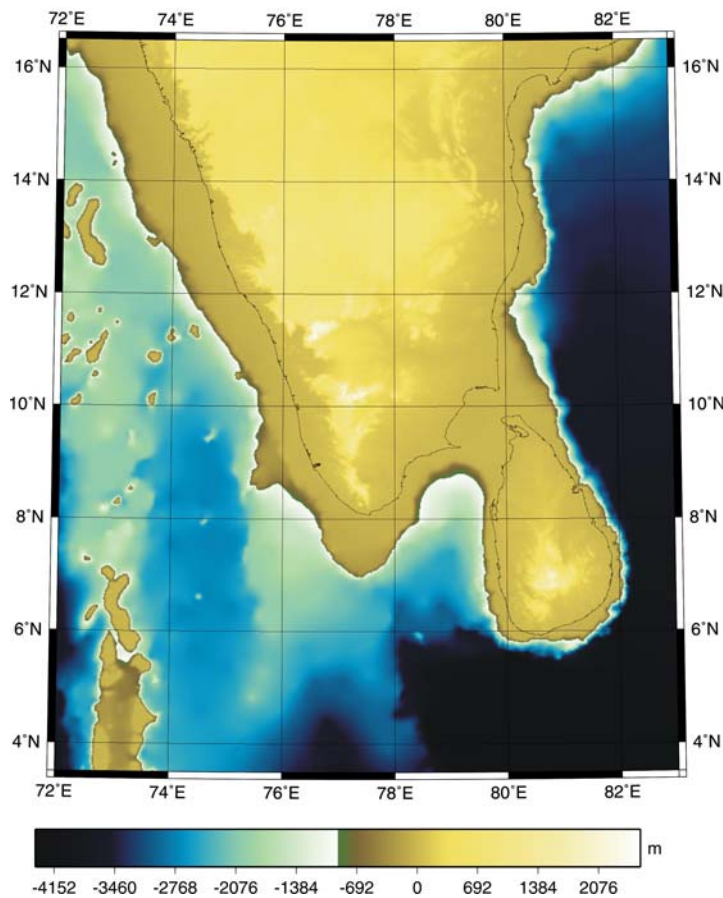


Figure 4 – The South India DTM

RTC effect has been computed using the TC software of the GRAVSOFT package (Tscherning et al., 1994).

Residual gravity data were then gridded over a regular $2' \times 2'$ geographical grid covering the area $6^\circ < \varphi < 14^\circ$, $74.5^\circ < \lambda < 80.5^\circ$.

Statistics of the remove step are presented in Table 3.

	Δg_0 [mGal]	$\Delta g_0 - \Delta g_M$ [mGal]	Δg_r [mGal]	Δg_r^G [mGal]
#	63968	63968	63968	43621
E	-39.40	-0.89	0.42	-0.55
σ	31.92	17.59	14.96	14.80
Min	-173.79	-92.66	-132.96	-84.14
Max	192.77	183.14	83.01	72.75

Table 3- Statistics of the remove step
($\Delta g_r = \Delta g_0 - \Delta g_M - \Delta g_{RTC}$; Δg_r^G = gridded residual gravity)

The empirical covariance of the Δg_r^G values is plotted in Figure 5 together with the best fit model function which has been adopted for computing the residual geoid undulation by fast collocation.

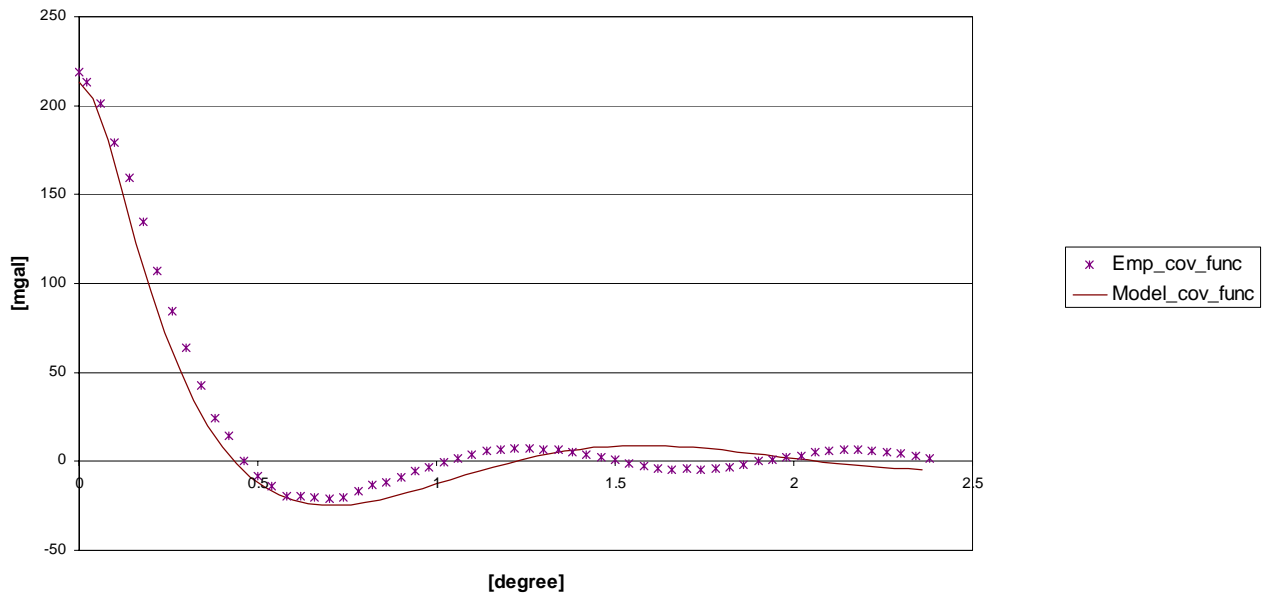


Figure 5 – The empirical covariance of Δg_r^G and the best fit model

The final geoid estimate, given on the same regular grid used for gravity, is shown in Figure 6.

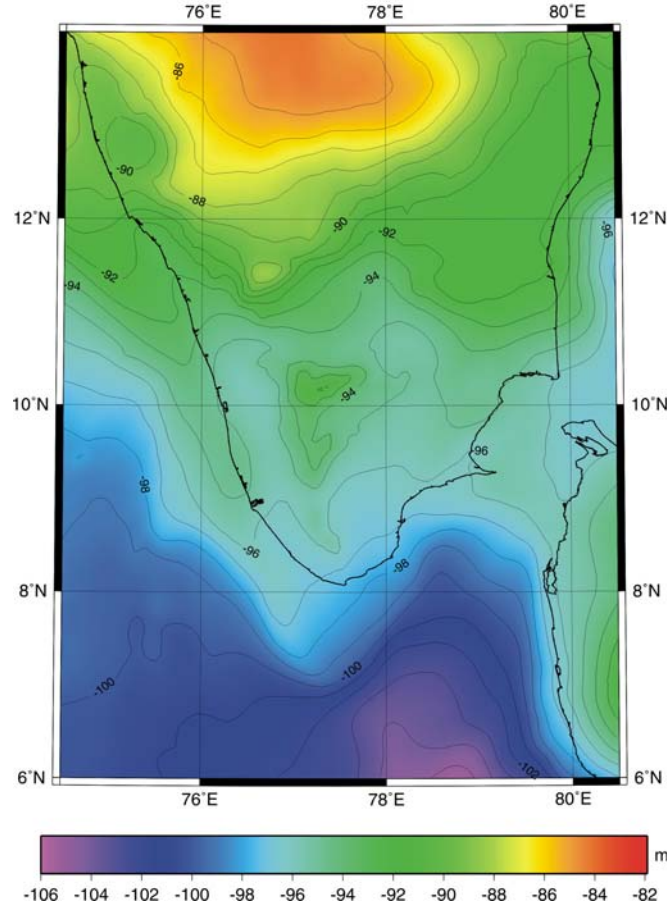


Figure 6 – The South India Geoid (equidistance = 1m)

The South India Geoid undulation deepens from north to south; this behaviour should be related to the geophysical structures of the area. It is still possible to single out on the Geoid the configuration of the main relieves in the area $10^{\circ} \leq \varphi \leq 12^{\circ}$, $76^{\circ} \leq \lambda \leq 78^{\circ}$ and of the deepest waters in its southern part.

This geoid estimate has been compared to EGM2008 height anomaly which has been computed on the same grid.

The statistics of the differences, after datum shift, are described in Table 4. The equation used to account for datum shift is the one described in Heiskanen and Moritz (1990):

$$\begin{aligned}
 N_{tot} &= N_{EGM2008} + \Delta N(\theta, \lambda) = \\
 &= N_{EGM2008} + dx \sin \theta \cos \lambda + dy \sin \theta \sin \lambda + dz \cos \theta \\
 \theta &= 90^{\circ} - \varphi \quad (dx, dy, dz) = \text{datum shift parameters}
 \end{aligned}$$

	E (m)	σ (m)	Min (m)	Max(m)
$N_{tot} - N_{EGM2008} - \Delta N$	0.00	0.22	-1.51	1.08

Table 2 – Statistics of the residuals in geoid undulation after datum shift.

The plot of these residuals are given in Figure 7. The area with the higher discrepancies is the one included in $10^\circ < \varphi < 12^\circ$, $76^\circ < \lambda < 78^\circ$. This is a region with high mountains (see Figure 4) and it is reasonable to assume that EGM2008 is not able to model completely the terrain signal, as it is the case for the estimated local geoid.

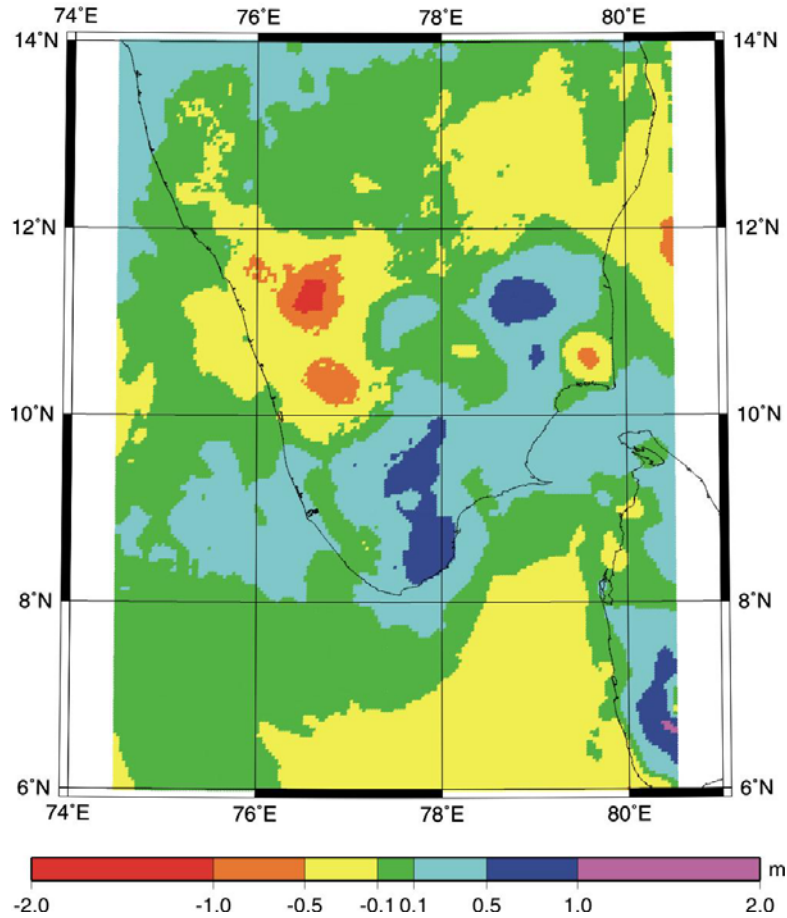


Figure 7 – Undulation differences between geoid estimate and EGM2008 after datum shift.

Another area where one can see high frequency differences is in $10^\circ < \varphi < 12^\circ$, $78^\circ < \lambda < 80^\circ$. In this area, the correlation of discrepancies with terrain signal is less clear and only the maximum in the North-Western part could be related to that. Also, medium frequency differences are present in the whole area. However, this is only a relative comparison between the two geoid estimates. Only a check using GPS/levelling can prove which is the best estimate. Unfortunately, at the moment, no data of this kind are available for this area.

4. Conclusions

In the Southern part of India, EGM2008 and other three global geopotential models, EGM96, GPM98CR and EIGEN_GL04C, have been used to reduce a set of 16013 gravity data. The statistics of the gravity residuals prove the high accuracy of EGM2008 which is the best fit model. The other tested models, are practically equivalent. Thus, it seems that the high frequencies in GMP98CR (complete to degree and order 720) don't give any substantial contribution over this area. Also, EGM2008 gives better results even if RTC is applied in combination with EIGEN_GL04C model. A further comparison has been carried out using a geoid estimate available in this area. Most of the high frequency differences

can be explained in terms of terrain effect. Furthermore, a medium frequency residual field, having a variation around 1 m, is clearly visible. Comparison with GPS/leveling data, not available at the moment, could give a deeper insight on these discrepancies.

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