Development of gravity variation map for Sri Lanka using MRF based super resolution approaches on grace gravity data

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Abstract

The Gravity field of the Earth is the most important measure that provides it's inner and outer mass balances. The problem of homogenous Gravity data coverage used to measure the gravitational field is the cost and effort required in such observations with the use of expensive gravimeters. Hence the possibilities to use open source Gravity data for such studies could be a handful. Yet the spatial resolution of the Gravity data represented in regular tessellation structures adds on limitations. This study attempts to sharpen the resolution (super-resolution) of the GRACE (Gravity Recovery and Climate Experiment Satellite Mission) Open source Gravity data, based on the principles of the Markov Random Fields (MRF) for the Sri Lanka Region. It further stresses the importance of the prior probability estimation for the Gravity data classification and super resolution. Three datasets have been used for this study, they are the GRACE only Gravity field models GGM05s, BGI (International Gravimetric Bureau)Gravity database (both open source data) and the CG-6 gravimeter observation especially for the "Balangoda" region for the validation purposes. Mathematical relationships between different parameters were executed in the study and are presented. The Markov Neighborhood Normalization was applied to the Gravity data and further the maximum likelihood classification (MLC) with prior and without prior estimations was applied to the data separately. It was observed that better results could be obtained with the prior estimations in the classification process using the MRF neighborhoods. Trend analysis between Gravity and Elevation shows that the Southern part of Sri Lanka has lower gravitation than the northern parts. Further the central Hill region shows the lowest Gravity readings for the island. It is obvious that for these trend analyses the resolution of the Gravity is a concern. Finally it has been observed that according to the theoretical relation between Gravity and the elevation, the results for the southern parts of the island obtained by the study has certain deviations than the rest. The final super resolution Gravity map was compared with EGM2008,GECO,EIGEN-6C4-2014 and Tongji-Grace02s Gravity models and it preserves the same pattern carried out by the original data and it shows minimized mean error with TongjiGravitymodel. Further the CG-6 observation was also compared with BGI land Gravity data to validate the BGI open source data.

*Keywords:*Gravity, GRACE & BGI Gravity data, Super Resolution, MRF,Open Source Data

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1 INTRODUCTION

1.1 Background

Determining theshape of the earth, based on Gravityas the parameter is an important area of Science. The new generation of Gravity field of the earth measurements are redirected to the satellite based Gravity observations because the cost-effective and effort required for such observations of homogenous Gravity data with Gravity meters. It is hard to say whether these methods are suitable for developing countries. The satellite based observation partially fulfills these requirements and provides an accurate long wavelength measured Gravity field of the earth with open source (Reigber et al.,1996; Tapley et al., 1996).Absolute and relative Gravity meters provide variation of the Gravitational field at specific locations on surface of the earth to define density profile. But this process is time consuming for large scale estimations hence an alternative is satellite based Gravity observations.

The low Gravity point on Sri Lanka, Sripada (Adams peak) was discussed through a novel “Funtains of paradise” (Dr. Arthur C Clerk,1979). Similarly GRACE determines Sri Lanka to be lowest point of the Gravity on earth by 2003 or somewhere closer to that. Hence comparing to other regions of the world, Sri Lanka is a special case for Gravity studies.

1.1.1 Satellite Gravity mission

The Gravity field measurement is handled in a few techniques such as terrestrial and ship borne surveys. These techniques provide a better accuracy compare with space-borne technique. However, gravimeter based techniques have some limitations in terms of the distribution of the data and data inconsistencies. (Xu et al.,2007), Therefore , the advancement of the space-borne techniques are likely being chosen to defineGravity measurement technique of the earth because it can give a global and regular coverage with higher homogeneous quality.

1.1.1.1 GRACE

The objective of the GRACE mission is to obtain accurate estimation of the mean and time-variable parameters of Gravity field variations of the Earth, for a period of five years. This objective is achieved by making continuous measurements of the change in distance between twin spacecraft, co-orbiting in ≈ 500 km altitude, near circular, polar orbit, spaced ≈ 220 km apart, using a microwave ranging system (GRACE L-2 Product User Manual,2012).GRACE will be able to detect minute fluctuations in the gravitational field further Gravity maps of GRACE will have a spatial resolution of about 300 km on the ground (www.science.nasa.gov, 2001). The monthly based Gravityanomaly was made by GRACE with geoid height accuracy of 2 to 3 millimeters at a spatial resolution less than 400 km (D. Tapley, 2004).

GRACE static field geopotential coefficients averaged over long time series and CSR released RL 5.0 level 2 data at spatial resolution 500km(along)x 500km(across) (Bettadpur, S. 2007). GRACE data are good to 1µGal only over length scales longer than 500-1000km, whereas Superconducting Gravimeters are good to the same accuracy (or better) at a single point (Jacques Hinderer). To recover the highly accurate staticGravity field of earth by using data of GRACE satellite is one of the recenttopics in Geodesy.

CG-6 is an automated relative Gravity meter that has a worldwide measurement range of over 8.000mGals and a reading Resolution of 0.0001mGal. This enables the user to operate in both, detailed micro-Gravity surveys and large-scale regional or geodetic surveys and it provides the locational information with GPS technology.(Scintrex Ltd Product Manual P/N:800700).

1.1.2 Super resolution satellite data

Coarser resolution GRACE open source data provides the general Pattern of the Gravity variations. Sri Lanka has 65,600km^2 total land area and 830 miles of coastline. Because of the small area, Spatial Resolution of the GRACE is not suitable for Gravity variation studies inside the Sri Lanka. To identify the Gravity variation along Sri Lanka Super Resolution Gravity map is required. Markov Random Fields which provides a context base image restoration is quite useful in this directive.

1.1.3 Open source Gravity data and Softwares

Open data enhances collaboration, participation and social innovation to the developing country. The economy can benefit from easier access to information. It's contributing to the development of innovative services, further Open source Gravity data was provided by International center for Global Earth Models (ICGEM) with deferent spatial and temporal resolution. Observed land and seaGravity data was anopen source data produced by (BGI). These are web based service and comprehends, these type of Open source data set cost effective affect required for Gravity based studies for developing country. The study completely based on GRACE free data source as well as open source programming environment R 3.4.1 as well as the open source GIS software environment QGIS. Mainly the statistical analysis was made with Programe R and Matlab.

R 3.4.1 open source programming environment is an easy to handle storage with rapid processing time period. QGIS was applied to prepare the maps and making of Raster images.

2 STUDY AREA AND THE DATA PREPERATION

The MRF neighborhood based Super resolution technique was tested using GGM05s 25Km spatial resolution Gravitydata. The main study area was selected as the whole island of Sri Lanka in the center of the Indian Ocean. WhileBalangodasituated at the Sothern central slopes of the island was selected as the sample area to validate the results with the CG-6 Gravity meter ground observations.

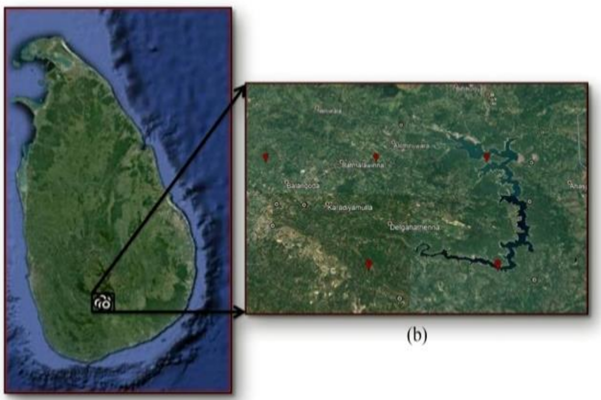

Figure 1: Google map image of the study area. For (a) Super resolution (b) CG-6 gravimeter observation

2.1 GGM05s model, BGI data preparation

Global Geopotential model has been produced from the Spherical harmonics coefficient data type (A tugi, 2016) the GGM05s Gravity model was estimated to spherical harmonic degree 180, using approximately 10 years of observations. Below

Figure 2 shows the GRACE Gravity data and BGI interpolated observed Gravity data.

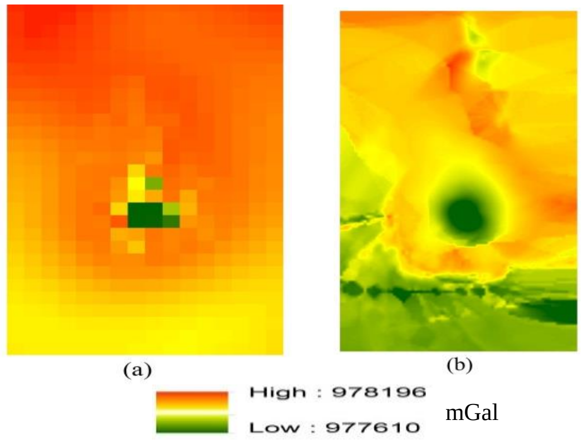

Figure 2: (a) GRACE 25Km spatial resolution Gravity data, (b) Observed Gravity with spatial resolution 5Km

Trend analysis was performed in the study area along the profiles to the Satellite Gravity and observed Gravity data. The Statistical parameters mean and variance were generated for the maximum likelihood Classification (MLC). The classification was done with and without prior probabilistic estimation. The importance of prior estimation was identified and probabilistic relationship was initialized between GRACE Gravity and observed Gravity data within the neighboring pixels.Empirical Bayesian Kriging (EBK) interpolation technique was applied to observedGravity data to resample 5Km spatial Resolution, to apply the super resolution technique to the courser resolution data. The 5x5 moving window was fixed to the random variables and 2x2 moving window was fixed to coarser resolution Gravity data by considering the distribution of the Gravity data in the study region. The mean value ratio between the windows was applied to find the super resolution final map.

The final map value was considered as Absolute Gravity value to made a Gravity surveying with Relative Gravity meter(CG-6) and observation was processed with Geosoft software and final output was compared with BGI data based subset and super resolution. Final map was compared with other models. Following figure 3 shows the General methodology of the research.

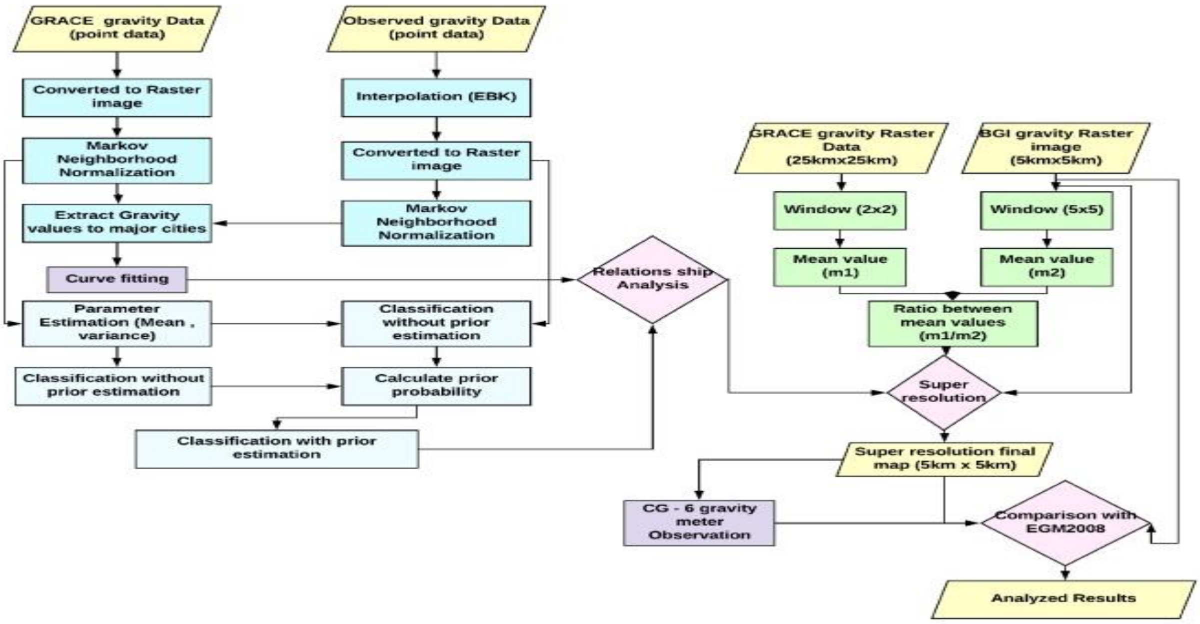

Figure 3:General Methodology chart

3 EXPERIMENTAL RESULTS

Results of the Gravity variation in Sri Lanka, using super resolution technique for Gravity data and experimental results of the CG-6 Gravity meter observations are shown in results.

3.1 Elevation and Gravity variation along Sri Lanka

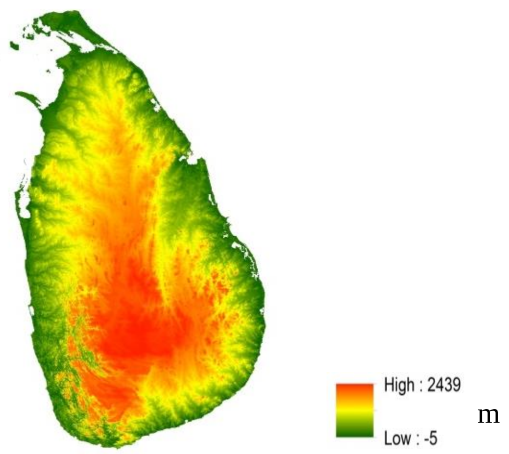

Figure 4 :SRTM elevation (in m) model for Sri Lanka

Gravity of the specific location highly depends on the mass distribution of that location. Figure 4 shows thetopographyof the Sri Lanka and itselevation changes between -5m to 2439m from Mean Sea Level (MSL) according to SRTM (Shuttle Radar Topography Mission) Digital elevation model (DEM) with spatial resolution 30m.Figure 5 explains Gravity and elevation changes with respect to latitude along Sri Lanka.This result shows the Gravity differs between the Northern part and Southern part of the Sri Lanka but elevations are approximately same between two regions. This result shows Gravity variation of Southern part of Sri Lanka exceptional for gravitational theory.Mathematical model was applied to fit GRACE Gravity data and elevation. The fit explains high variance occur when elevation range in 600m to 800m. The best fit First order Polynomial gives adjusted R-Square with 0.9986 and RMSE 3.454. Coefficients are,p1 = -0.28 (-0.282, -0.2779) and p2 = 9.781e+05 (9.781e+05, 9.781e+05) with 95% confidence bounds.

3.2 Trend analysis on GRACE Gravity data.

Below Figure shows GRACE Gravity map with Row (A1-AB1), column (A1-A16) index to trend analysis on Gravity data for Sri Lanka.

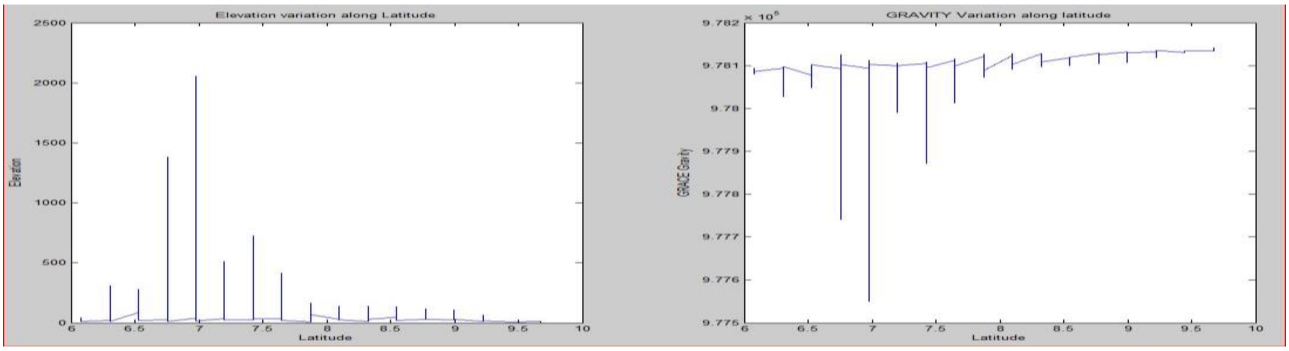

Figure 5:Elevation and Gravity variation with Latitude

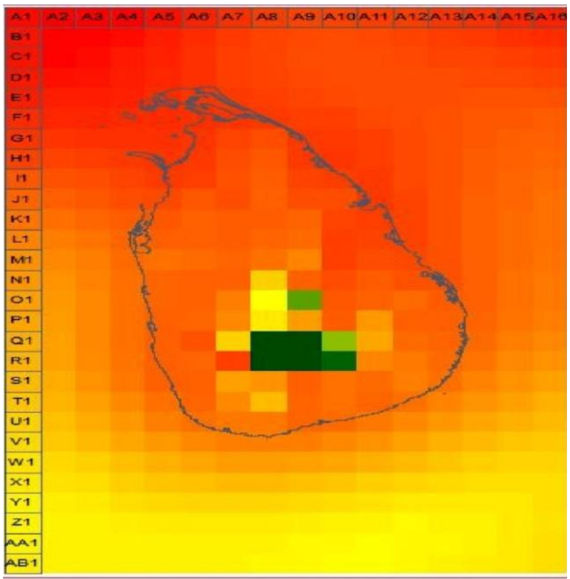

Figure 6: Row and Column Index map for trend analysis

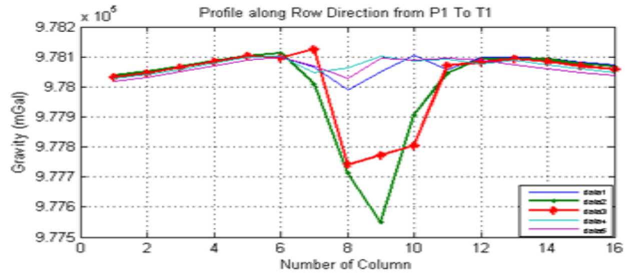

Figure 7: column wise profile of GRACE Gravity data from P1 to T1

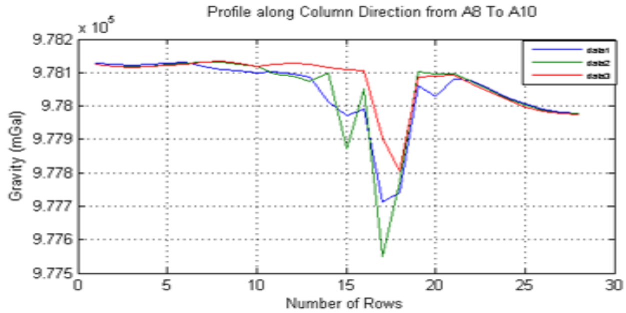

Figure 8: Row wise profile of GRACE Gravity data from AB to A10

Figure 7 shows Gravity pattern change from Ocean to Land mass and Ocean with 25Km spatial resolutionand ocean regions Figure 5 Elevation variation shows approximately same pattern from North and South but the Gravity variation differ from north to south. The sudden changes on Gravity append inside the land area Figure 7 highlighted line indicates sudden drops through smooth line.According to the results, Southern part of Gravity, lower than Northern part of the Gravity. Similar trend analysis results were showed, by observed Gravity data. So observed Gravity data was selected as random variable to super resolution process.Further analysis on Figure 7 and 8, shows central hill and Southern part of Sri Lanka getting low Gravity than other surrounding region and between two types of GravitydataPiecewise polynomial was fit with smoothness parameter p=0.7072 with adjusted R-square: 0.9742 and RMSE: 14.23. This curve fit **Error! Reference source not found.** gives best estimation rather than other polynomial fit.

3.3 Markov Neighborhood Normalization

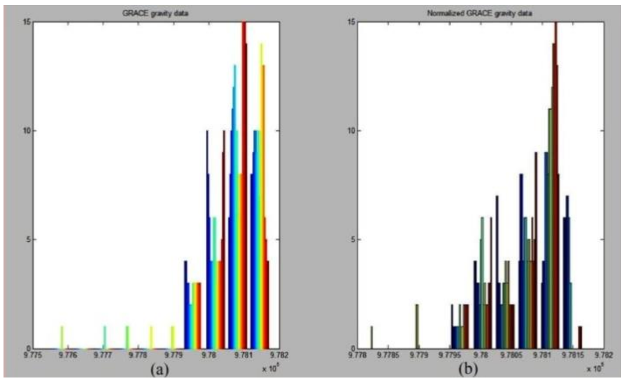

Figure 9: Histogram analyses between(a) GRACE Gravity data and (b) Markov neighborhood normalized data

Above Figure shows histogram analysis between GGM 05s data and Markov neighborhood normalization applied data. It shows best probability of relationship between the neighborhood pixels.

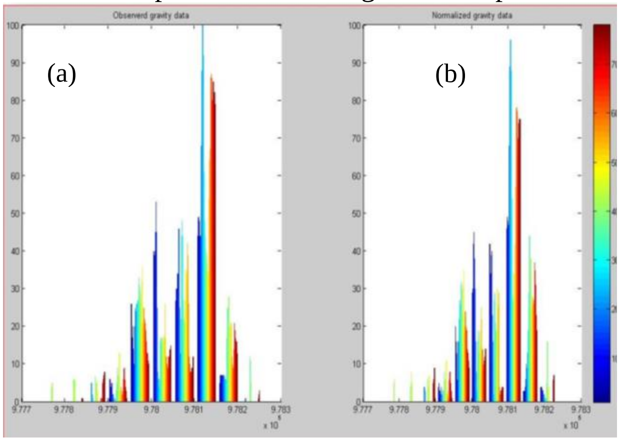

Figure 10: Histogram analyses between (a) ObservedGravity data and (b)Markov neighborhood normalized data

Figure 9and Figure 10 preserve same pattern and it shows the probability relationship between the neighboring cliques of both dataset.

3.4 Maximum likelihood Classification

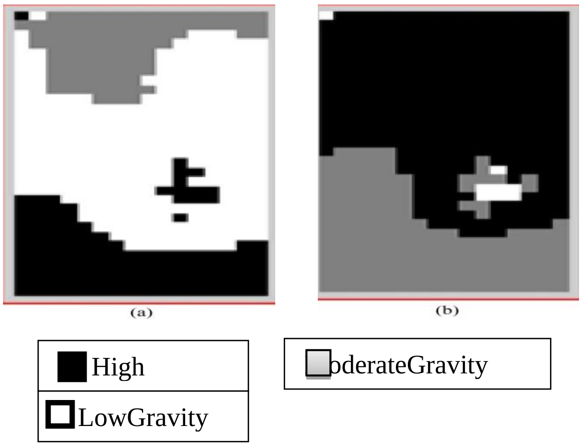

Figure 11: (a) maximum likelihood classification without prior estimation.(b) normal distribution probability classification.

Result shows how classification depends on the prior estimation.TheFigure 11 (a) classification was done according to the Eq. (1), without prior estimation Gravity data was classified.

$$P = -\log z - \left(\left(\frac{1}{z}\right) * (x-y)^2\right) \quad (1)$$

It follows a Gaussian distribution. Eq. (2) was applied to classify the Gravity data and the result is shown in Figure 11 (b).

$$P = \frac{e^{-\frac{(x-y)^2}{2*z}}}{\sqrt{2*\pi*z}} \quad (2)$$

Where,

P= Probability
z = variance
x = mean
y = variable

3.5 Comparison between observed and GRACE Gravity data for major cities

The high deviation occurred when elevation is high. Some of observed Gravity points exactly coincide with satellite Gravity data. The two sets of Gravity data deviate with mean error 19.8194 mGal and standard deviation 46.243.

3.6 Super resolution

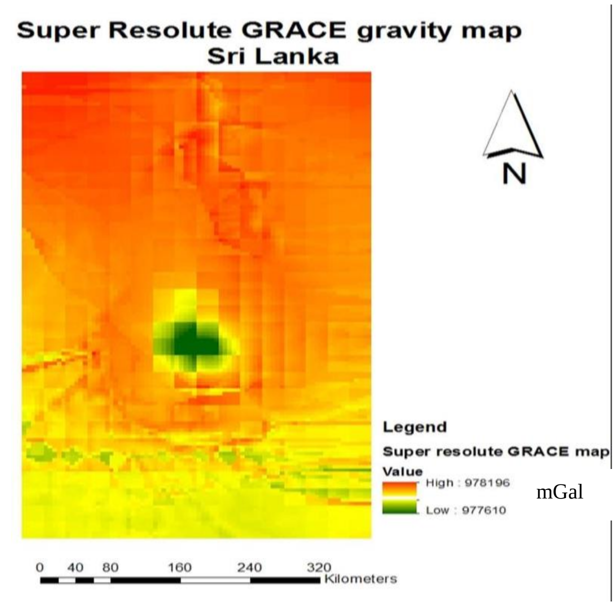

Figure 12: Super resolute final map with 5Km spatial resolution

3.7 Validation

EGM2008 shows mean error -2.6573mGal and standard deviation 36.6059 with GGM05s model.

Table 1:Comparison of the mean error for the Super resolution Gravity model and the conventional Gravity models

	GGM05s – 2014-Degree 180-S(GRACE)		EGM 2008 (Degree 2190-A,G,S(GRACE)		EIGEN - 6C4-2014 (Degree2190 A,G,S(Gose) ,S(GRACE), S(Legeos))		GECO 2015 (Degree2190 - EGM2008,S (Goce)		Tongji-Grace02s – 2017 (Degree180-S(GRACE)	
Resolution(Km)	25	5	25	5	25	5	25	5	25	5
Mean error (mGal)		3.52	2.90	2.68	2.98	2.60	2.95	2.72	2.63	2.40
Standard deviation		34.68	34.15	35.75	34.63	35.82	33.91	35.51	32.47	32.91

Table 2:Comparison of mean error for the GGM05s model with resent model

	GGM05s – 2014-180-S(GRACE)	EGM 2008 (2190-A,G,S(GRACE)	EIGEN -6C4-2014 (2190 A,G,S(Gose),S(GRACE),S(Legeos))	GECO 2015 (2190-EGM2008,S(Goce)	Tongji-Grace02s – 2017 (180-S(GRACE)
Resolution(Km)		25	25	25	25
Mean error (mGal)		-2.13	-2.07	-2.16	-2.82
Standard deviation		37.06	37.49	36.96	32.39

The final super resolution data and original data was compared with recently developed Gravity models, that the mean error and standard deviation shows in the **Error! Reference source not found.**and **Error! Reference source not found.**. Here the validation shows between two different spatial resolution. Comparing with coarser resolution, the super resolution gives best estimation with recent and higher degree models. Validate with 2017 model(Tongji-Grace02s), super resolution technique applied datagives minimum mean error than original coarser resolution data.

4 CONCLUSIONS AND DISCUSSION

Here briefly analyzed, how Open source Gravity data helps to the Gravity based studies, Further study investigates the Relationship between the Gravity and elevation in Sri Lankan region, the importance of the prior estimation to the Gravity data classification, Super-resolution on coarser resolution Gravity data and CG-6 Gravity meter observations.The testing was done using GRACE and BGI observed Open source Gravity dataset.The trend analysis on the Gravity data shows the Southern part of Sri Lanka shows low Gravity than the Northern part of Sri Lanka but both are nearly equal elevation, it is exceptional for gravitational theory.

The Markov neighborhood normalization and importance of prior estimation to classification was analyzed for the Gravity data. Without prior estimation, testing was done on Gravity data; the results show classification errors. After applying the prior probability the classification was done correctly. This two testing were used to analyze probability relationship with neighboring pixels, it shows the best relationship between the neighboring pixels with coarser resolution data and Random variables.Super-resolution final map shows the same pattern has original coarser resolution image that preserves the same pattern of Gravity variation and minimizing mean error. The results depend on the accuracy of the random variables.The super resolution shows more deviation in the highest elevation area and lowest deviation in low elevation area because highest elevation consisting areas are few. This method well applicable for the large regions to obtain higher accurate Gravity model with finer resolution this final map will helps to study about Gravity based modelling.

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Experience

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Moratuwa
January-2018 - April-2018

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GIS for the study the infectious diseases and delineation of potential Risk area
Research activities and Statistical based Analysis

Education

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Belihuloya,Sri Lanka.
completed in 2018

Special in Photogrammetry and Remote Sensing
GPA -3.45
Research:Super resolution GRACE Gravity Data a case study for the development of Gravity variation map for Sri Lanka.

Advanced level
Highlands central college
Hatton,Sri Lanka.
2012

Physical Science: Z-Score -0.8049

Skills

Instrumental Skills: Familiar with Total Station (SOKKIA, Trimble),Familiar with Theodolites, level Instruments, Familiar with GPS(Trimble, leica) and GNSS, Familiar with CG-6 Gravity meter and Familiar with Spectroradiometer .
Computer Skills: CAD software's (AutoCAD,Civil3D,ZWCAD),ArcGIS (ArcMap, Arcscene, ArcGlobe, ArcCatalog),ERDAS IMAGINE ,MATLAB,C++,JAVA, HTML, JavaScript and JQuery, programme R and Database Management System.

Projects

Web based project for Surveying Application in University
Triangulation - Part of Academic project of B.Sc. (Surveying Science).
GIS for the study the infectious diseases and delineation of potential Risk area - ACCIMT
Spectral Signature data collection to Spectral bank of ACCIMT

Achievements

Participant on 4th International Exhibition for Young Inventors at Yogyakarta, Indonesia (2007).
Best Student of the year 2008

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