Session: Gravimetry and Geoid

# Gravity and Height References in the São Paulo state

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SIRGAS
Sistema de Referencia Geocéntrico para las Américas
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# INTRODUCTION


Unified Height System

Geohazard Monitoring

Sea level Change, variability and Forecasting

Geodetic Space Weather Research

## IAG 2015

- IAG Resolution (No. 1) for the definition and realization of an International Height Reference System (IHRS).
- IAG Resolution (No. 2) for the establishment of a Global Gravity Reference System.

# INTRODUCTION

## INTERNATIONAL GRAVITY REFERENCE SYSTEM

**1) International Gravity Standardization Net 1971 (IGSN71)**

- 24.000 → relative gravity meters;
- 200 → pendulum gravity meters;
- 10 → balistics gravity meters;
- Accuracy: 100 µGal.

**2) IGSN71 in Brasil**

- 20 relative measurements;
- Accuracy: ≅ 50/100 µGal.

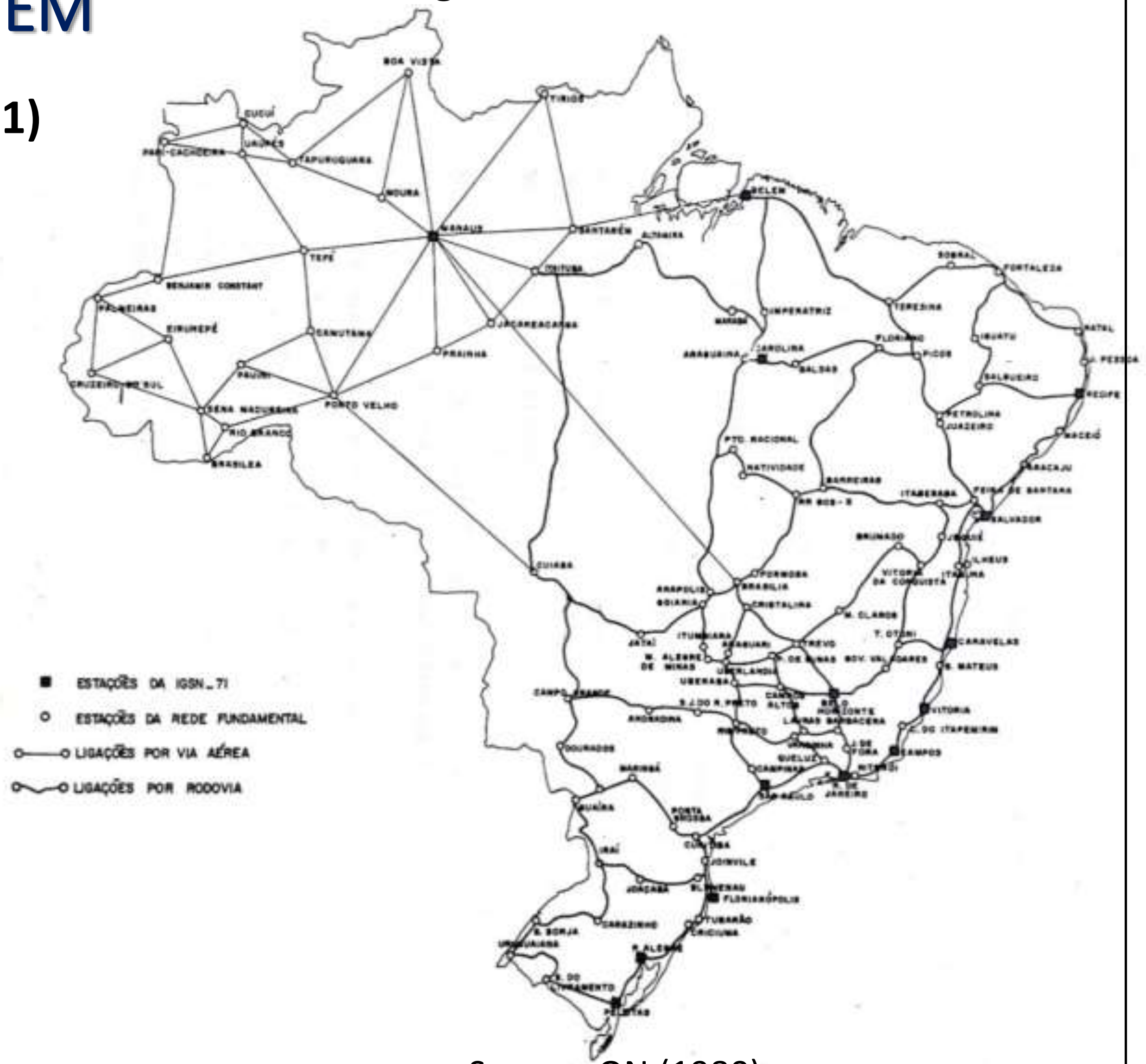
**3) Brazilian Fundamental Gravimetric Network**

- 620 gravity stations (ON).

**4) Further gravimetric data**

- IBGE
- IGC
- EPUSP
- UFPR
- PETROBRAS

**Fig. 1** – BFGN 1980.




Source: ON (1980).

# INTRODUCTION

## GRAVITY REFERENCE SYSTEM (GRS) IN SÃO PAULO

**1) Hannover University**

- Jilag#3

Accuracy: 100 µGal
Number of stations: 1

**2)Observatorio Nacional**

- A10#11

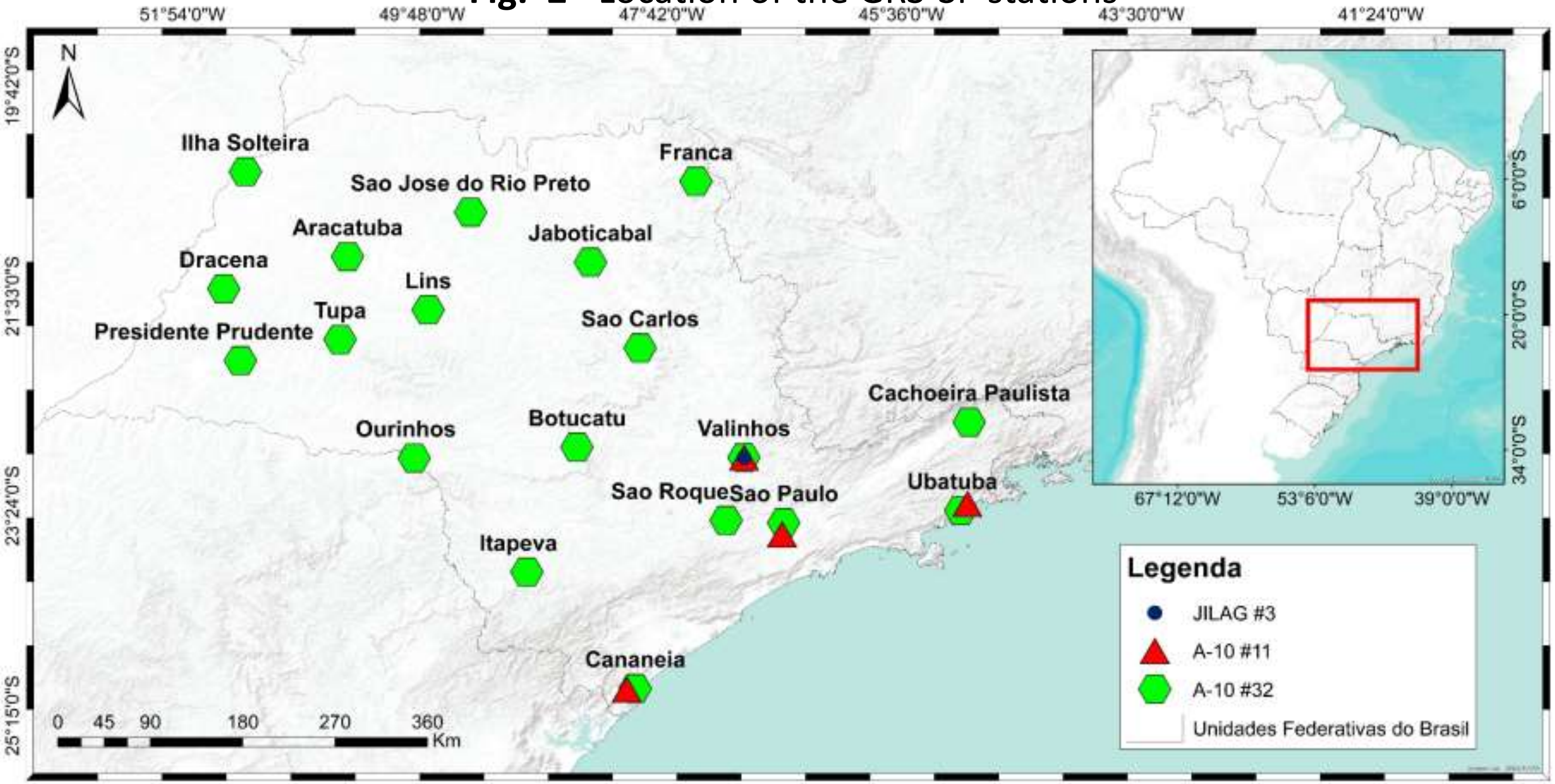
Accuracy: 10 µGal
Number of stations: 4

**3) CENEGEO/IGC/LTG**

- A10#32

Accuracy : 10 µGal
Number of stations : 15

**Fig. 2**– Location of the GRS-SP stations



# OBJECTIVE

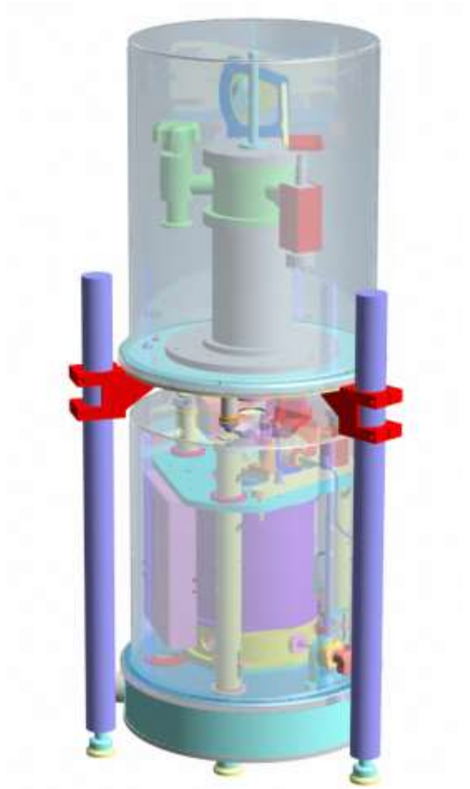
- To quantify and to analyze the connection of the gravimetric densification network of São Paulo state to the Gravity Reference System (GRS).
- To contribute to IHRF by computing the gravity potential at four stations: Presidente Prudente (PPTE), São José do Rio Preto (SJRP), São Carlos (EESC) and Botucatu (SPBOP).
- To analyze the residuals (geopotential model and RTM) in the study area.

# METHODOLOGY

## The connection of the relative gravimetric network to the Gravity Reference System of São Paulo

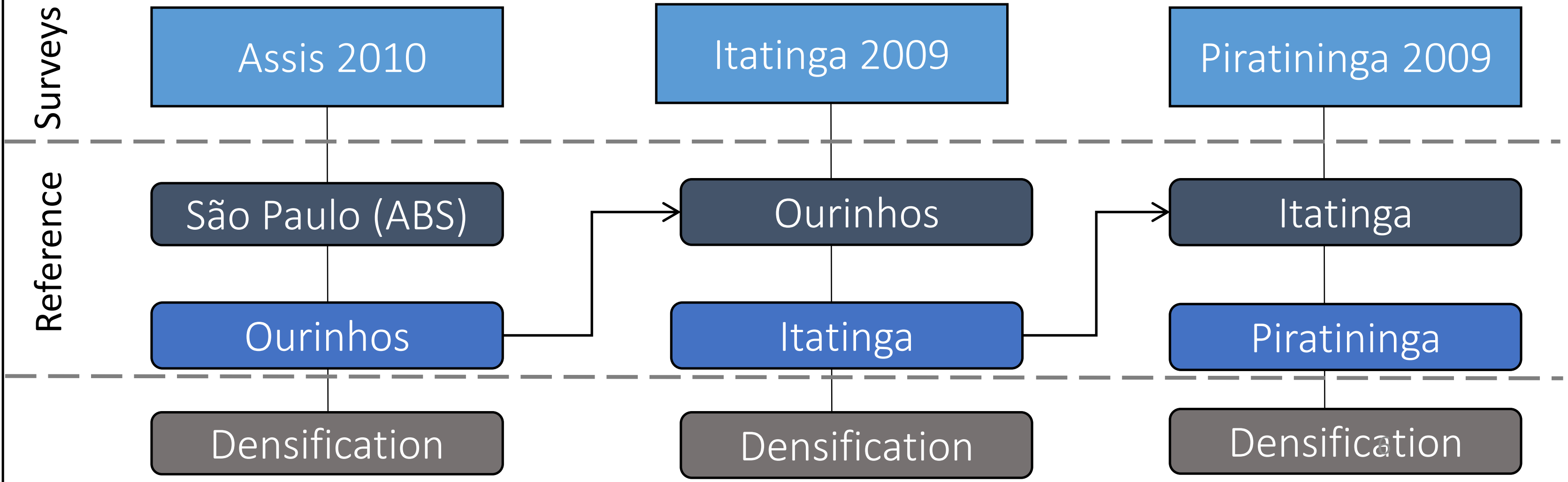
- Analysis of the absolute gravity measurements.
- Connection of the relative gravimetric network:
  - ➢reprocessing;
  - ➢application of an off-set according to gravity reference;
  - ➢field survey.

Fig. 3– A-10 Gravity meter.



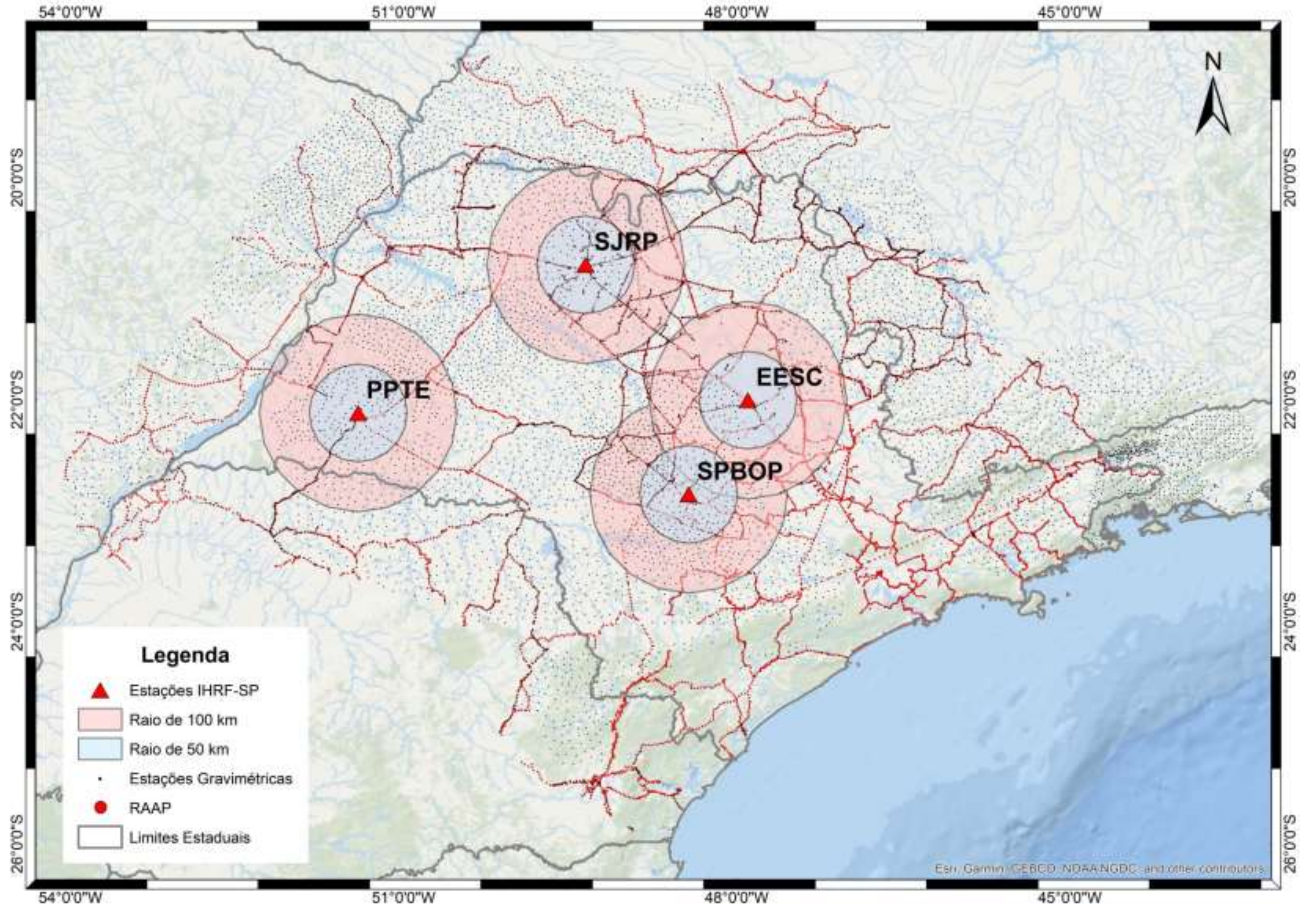
Source: Micro-g LaCoste.

Fig. 4 – Schem of the of gravimetric network update.



# STUDY AREA

Fig. 5– IHRF stations.



# METHODOLOGY

## Disturbing Potential

- Geopotential model:
  - ➢ GOCO05S nmax=200
  - ➢ GOCO05S nmax=100
- Residual Terrain Model:
  - ➢ ALOS
- Ocean gravity disturbances:
  - ➢ SAND14

$\delta g_{RESIDUAIS}$

- $\delta g_{RES\,(\delta g - g_{GGM(nmax100)})}$
- $\delta g_{RES\,(\delta g - g_{GGM(nmax:200)})}$
- $\delta g_{RES\,(\delta g - g_{GGM(nmax:100)} - \delta g_{RTM})}$
- $\delta g_{RES\,(\delta g - g_{GGM(nmax:200)} - \delta g_{RTM})}$

$$T_{RES} = \frac{R}{4\pi} \iint H(\psi)\delta g_{RES} \partial\sigma$$

- $T_{RES(\delta g - \delta_{g_{GGM(nmax:200)}})}$
- $T_{RES(\delta g - \delta_{g_{GGM(nmax:100)}})}$
- $T_{RES(\delta g - \delta_{g_{GGM(nmax:100)}} - \delta g_{RTM})}$
- $T_{RES(\delta g - \delta_{g_{GGM(nmax:200)}} - \delta g_{RTM})}$

# RESULTS

## Gravimetric Survey

Table 1 - Gravimetric stations linked to the SGR-SP (mGal).

| Relative stations | g previous | g updated |
|---|---|---|
| Penápolis | 978559.61 | 978559.59 |
| Rinópolis | 978579.98 | 978579.96 |
| Santa Rita do Pardo | 978577.08 | 978577.09 |
| Registro | 978876.58 | 978876.53 |
| Presidente Epitácio | 978627.24 | 978627.36 |
| Jales | 978513.50 | 978513.59 |
| Leme | 978553.10 | 978553.15 |
| Mococa | 978526.28 | 978526.24 |
| Presidente Prudente | 978596.78 | 978596.65 |
| Frutal | 978486.57 | 978486.50 |
| IAG- Agua Funda | 978638.08 | 978638.04 |
| Estátua do Ipiranga | 978644.99 | 978644.91 |
| Museu do Ipiranga | 978636.56 | 978636.45 |
| São José dos Campos | 978605.58 | 978605.59 |
| Queluz | 978639.74 | 978639.71 |

**Fig. 6-** Ipiranga momument.

**Fig. 7-** Queluz.

# RESULTS

## Updated gravimetric network of São Paulo

**Table 2-** Statistics of the updated gravimetric network (mGal)

| | |
|---|---|
| Minimum | 0.00 |
| Maximum | 0.28 |
| Mean | 0.05 |
| Standard Deviation | 0.05 |
| Number of stations | 4704 |

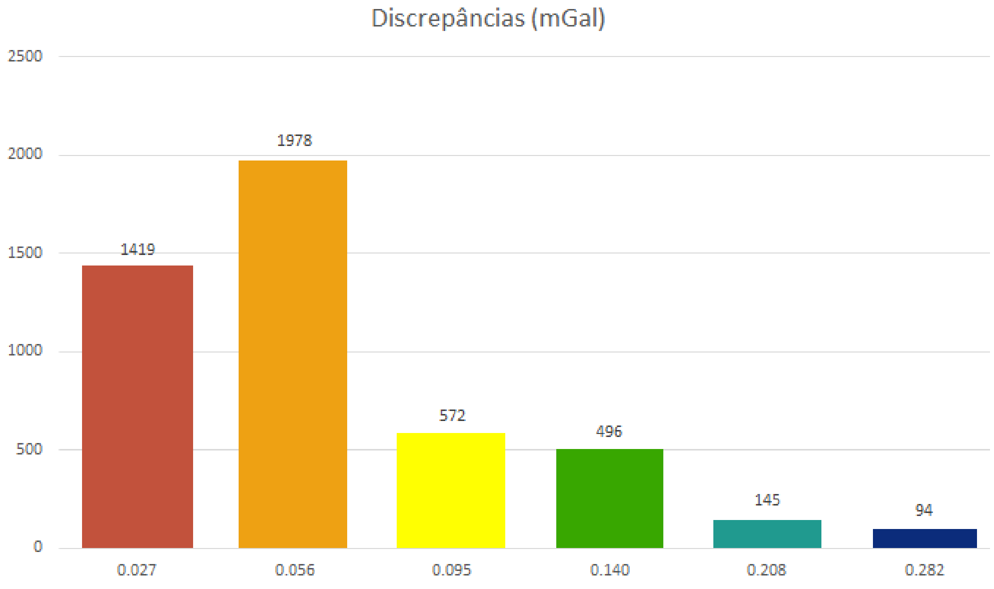
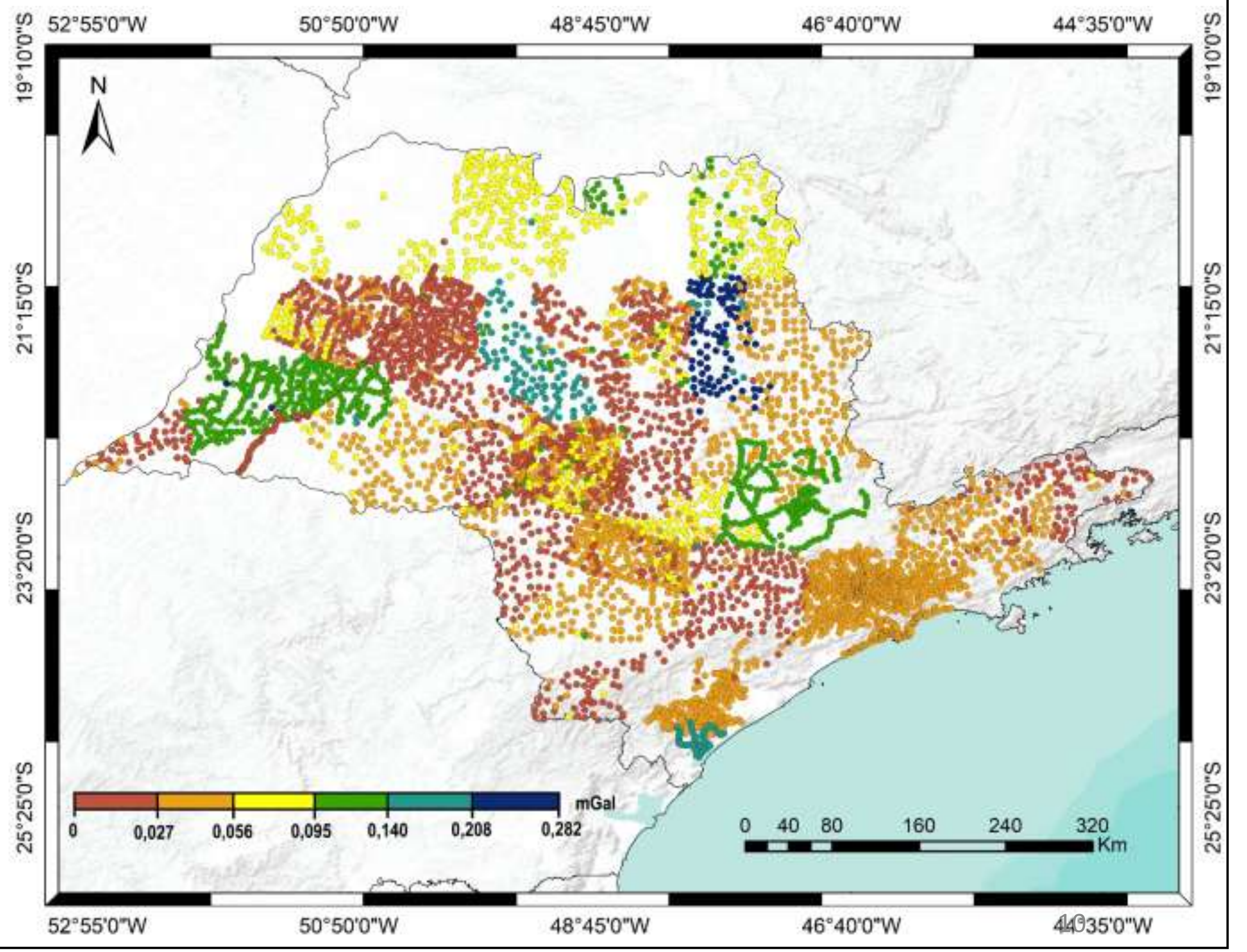


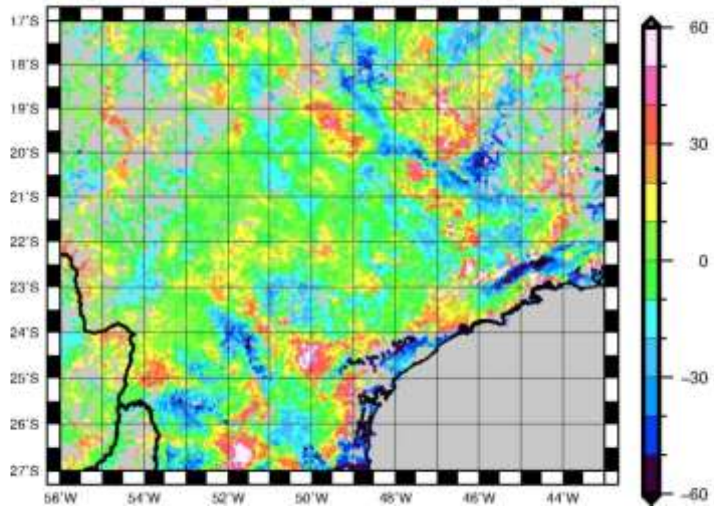

**Fig. 8** – Discrepancies of the gravimetric stations with the connection to SGR-SP.



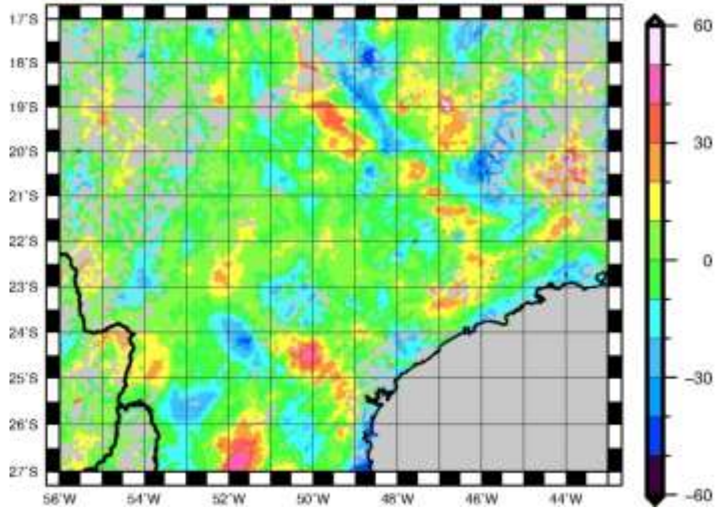
# RESULTS

**Fig. 9-** Gravity Disturbances Residuals (1- No RTM-MGG100 ;2- RTM reduced –MGG100; 3- No RTM-MGG200 ;4- RTM reduced –MGG200;

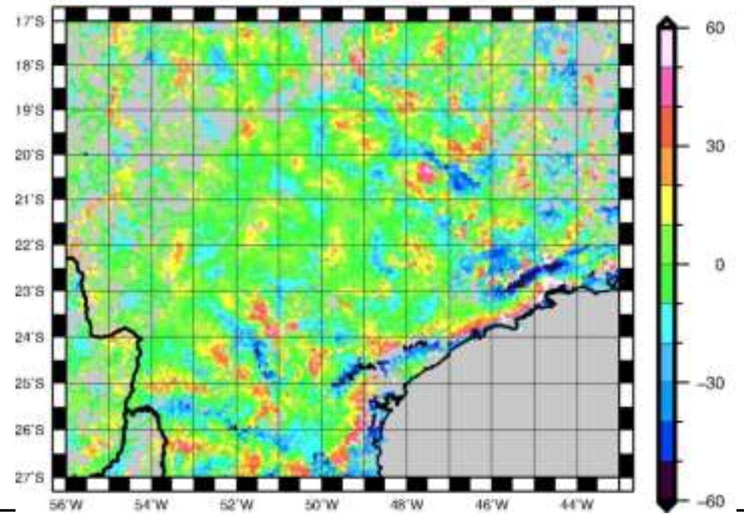
**1**



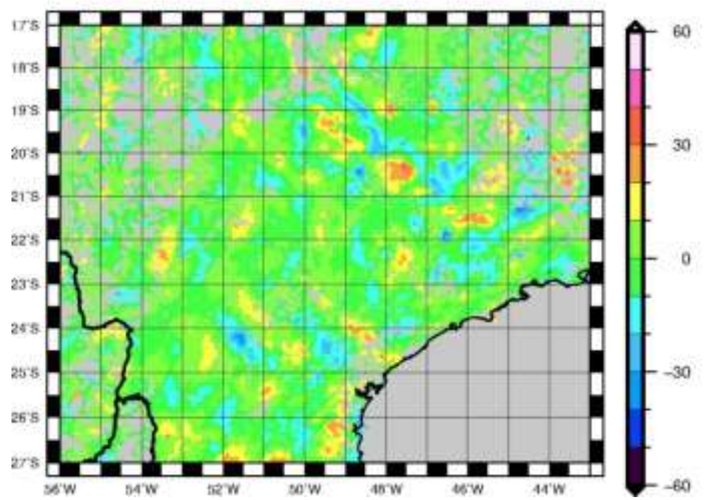

**2**




**3**



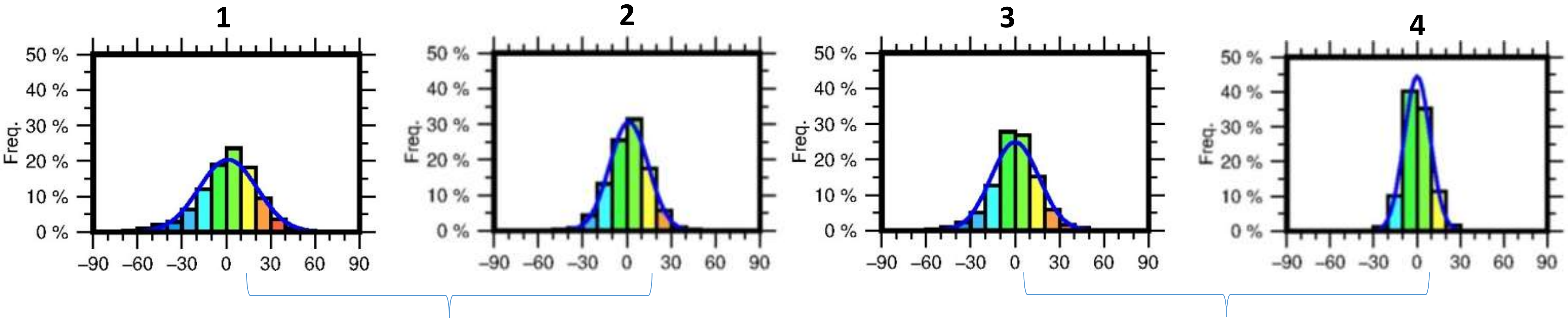

**4**



# RESULTS

## Statistics of the residual gravity disturbances in the study area

**Fig.10-** Gravity Disturbances Residuals (1- No RTM-MGG100 ;2- RTM reduced –MGG100; 3- No RTM-MGG200 ;4- RTM reduced –MGG200).




$nmax$: 100

$nmax$: 200

**Fig. 11-** Gravity disturbances residuais obtained by RTM reduction.

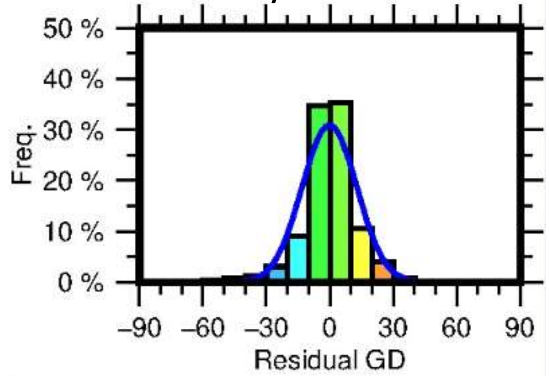



**Table 3** – GDR statistics (mGal).

| Statistics | $\delta g_{RES\ (RTM)}$ | $\delta g_{RES\ (nmax:100)}$ | $\delta g_{RES\ (nmax:200)}$ |
|---|---|---|---|
| Mean | -0.16 | 1.22 | -0.01 |
| Median | 0.14 | 2.98 | 0.17 |
| Standard Deviation | 12.92 | 19.6 | 16.02 |
| RMSD | 12.92 | 19.64 | 16.01 |
| Positive Maximum value | 137.33 | 108.60 | 112.18 |
| Negative minimum value | -110.26 | -89.80 | -89.91 |

# RESULTS

## São José do Rio Preto

**Fig. 12-** Gravity Disturbances Residuals (1- No RTM-MGG100 ;2- RTM reduced –MGG100; 3- No RTM-MGG200 ;4- RTM reduced –MGG200;

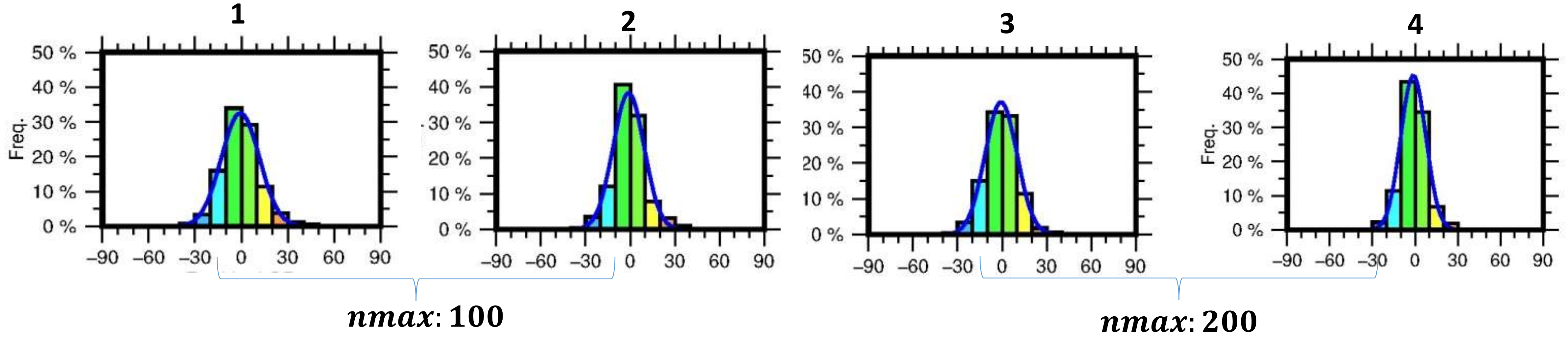



**Table 4** – GDR statistics- São José do Rio Preto (mGal).

| Statistics | $\delta g_{RES\,(RTM)}$ | $\delta g_{RES\,(nmax:100)}$ | $\delta g_{RES\,(nmax:200)}$ |
|---|---|---|---|
| Mean | 0.46 | -0.65 | -0.78 |
| Median | 0.15 | -1.19 | -0.85 |
| Standard Deviation | 5.88 | 12.26 | 10.77 |
| RMSD | 5.90 | 12.27 | 10.79 |
| Positive Maximum value | 21.24 | 50.59 | 53.64 |
| Negative minimum value | -24.56 | -48.75 | -43.47 |

# RESULTS

## São José do Rio Preto

**Table 5** – Disturbing potential ($T$) ($m^2s^{-2}$).

| GOCO05S | $\mathbf{ggm}_{(\mathbf{nmax100})}$ | | $\mathbf{ggm}_{(\mathbf{nmax200})}$ | |
|---|---|---|---|---|
| $\delta\mathbf{g}_{\mathbf{RES}}$ | **RTM reduced** | **no RTM** | **RTM reduced** | **no RTM** |
| $T_p$ | -62.778 | -62.852 | -64.723 | -64.192 |

- The $T_p$ differences between RTM and without RTM are less than 0.6 $m^2s^{-2}$.

- The $T_p$ differences between order and degree are around 1.6 $m^2s^{-2}$.

**Fig. 13-** R.G.D. RTM reduced. nxm:100.

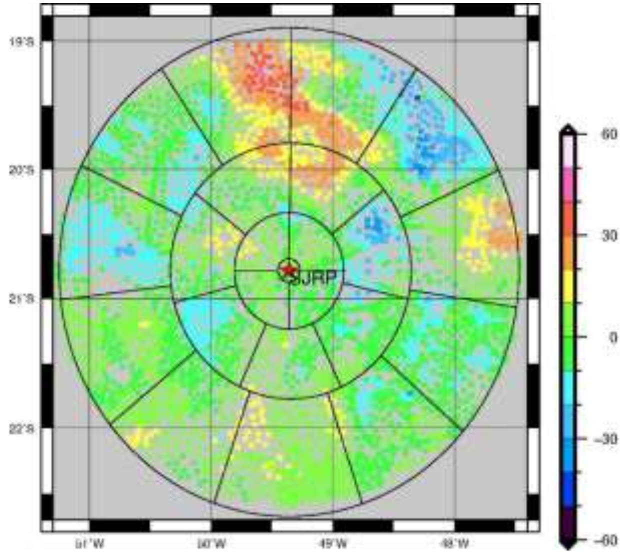



**Fig. 14-** R.G.D. RTM reduced. nxm:200.

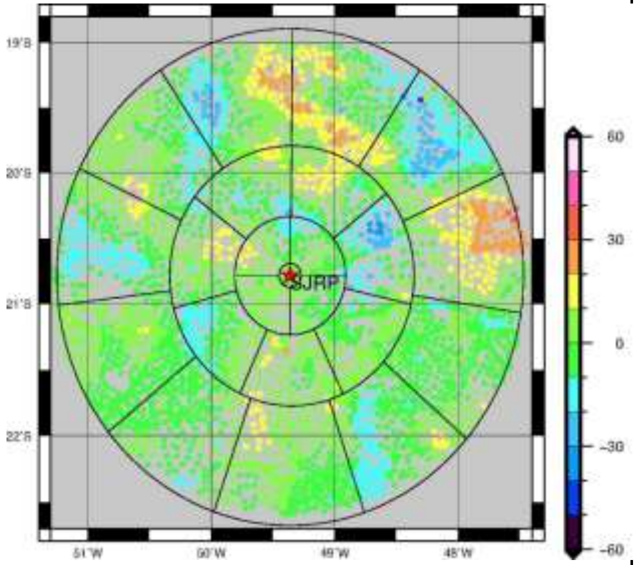
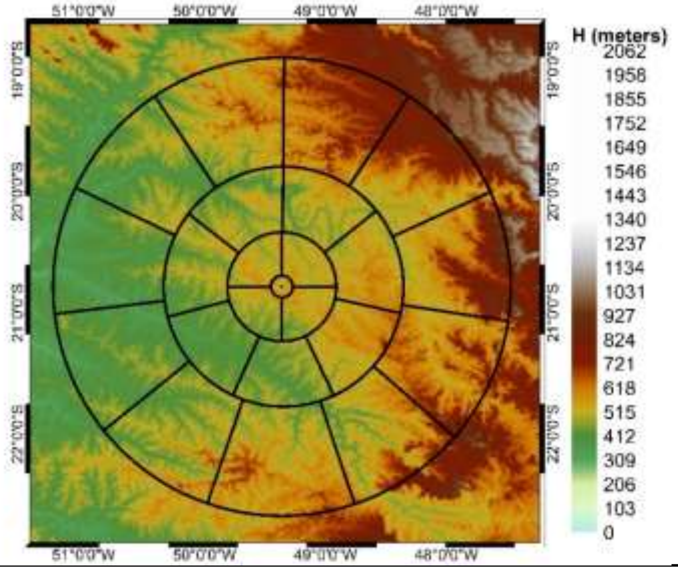


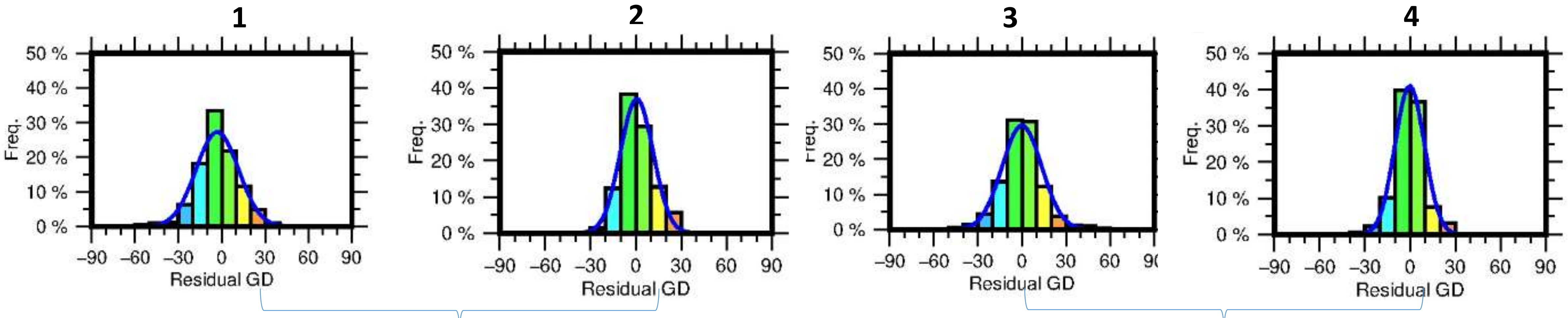

**Fig. 15-** Digital Terrain Model ALOS.



# RESULTS

## São Carlos

**Fig. 16-** Gravity Disturbances Residuals (1- No RTM-MGG100 ;2- RTM reduced –MGG100; 3- No RTM-MGG200 ;4- RTM reduced –MGG200).




$nmax: 100$

$nmax: 200$

**Table 6** – GDR statistics- São José do Rio Preto (mGal).

| Statistics | $\delta g_{RES\ (RTM)}$ | $\delta g_{RES\ (nmax:100)}$ | $\delta g_{RES\ (nmax:200)}$ |
|---|---|---|---|
| Mean | 0.23 | 0.86 | -0.01 |
| Median | -0.75 | -0.91 | -0.24 |
| Standard Deviation | 10.75 | 14.47 | 13.52 |
| RMSD | 10.75 | 14.50 | 13.52 |
| Positive Maximum value | 61.03 | 76.69 | 53.64 |
| Negative minimum value | -110.26 | -41.87 | -50.4 |

# RESULTS

## São Carlos

**Table 7** – Disturbing potential ($T$) ($m^2s^{-2}$).

| GOCO05S | $ggm_{(nmax100)}$ | | $ggm_{(nmax200)}$ | |
|---|---|---|---|---|
| $\delta g_{RES}$ | RTM | without RTM | RTM | without RTM |
| $T_p$ | -53.372 | -56.021 | -60.267 | -57.855 |

- The $T_p$ differences between RTM and without RTM are around 2.5 $m^2s^{-2}$ .
- The differences between the GGM are 6.9 $m^2s^{-2}$ using RTM reduction and 1.8 $m^2s^{-2}$ without using.

**Fig. 17-** R.G.D. RTM reduced. nxm:100.

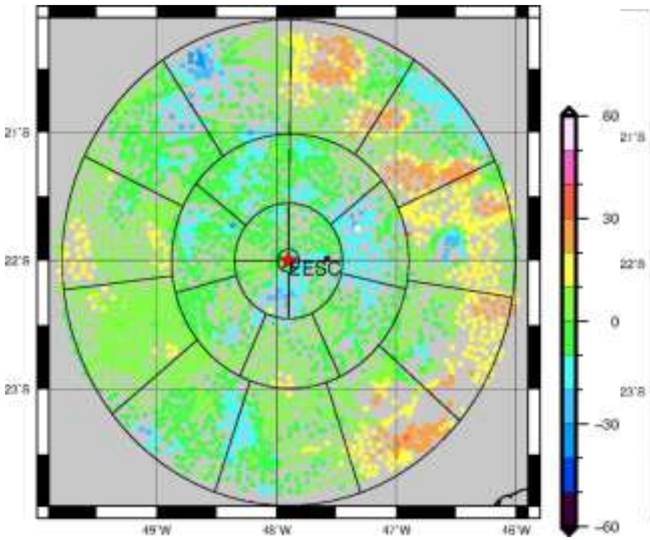



**Fig. 18-** R.G.D. RTM reduced. nxm:200.

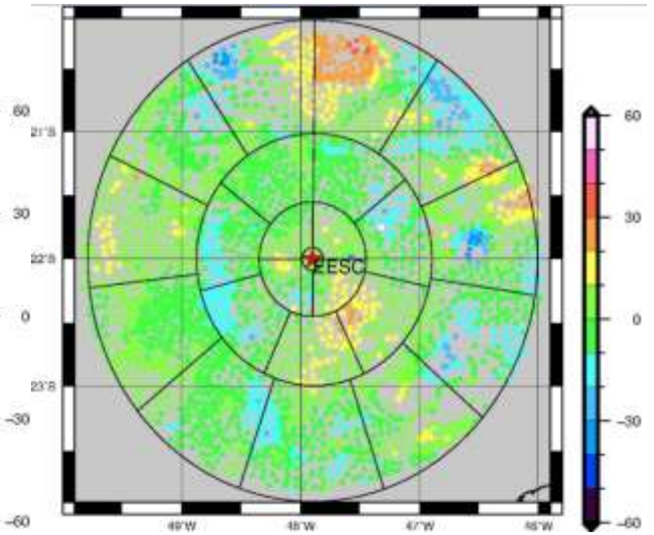
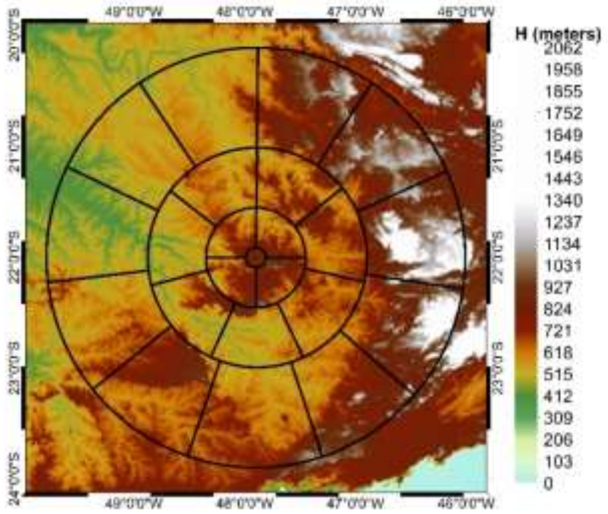



**Fig. 19-** Digital Terrain Model ALOS.



# RESULTS

## Botucatu

**Fig 20-** Gravity Disturbances Residuals (1- No RTM-MGG100 ;2- RTM reduced –MGG100; 3- No RTM-MGG200 ;4- RTM reduced –MGG200;

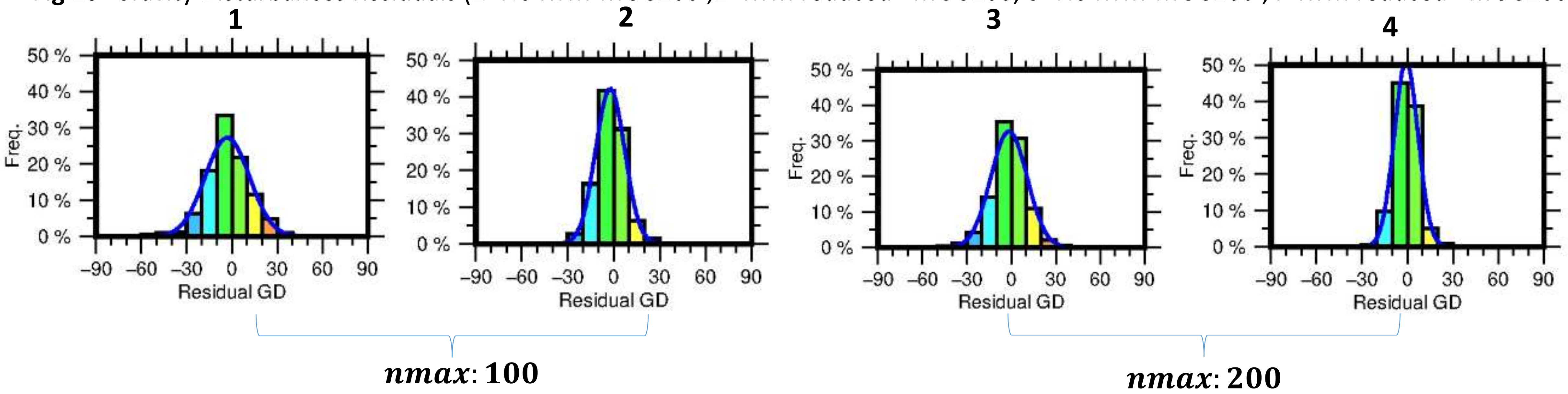



**Table 8** – GDR statistics (mGal).

| Statistics | $\delta g_{RES\ (RTM)}$ | $\delta g_{RES\ (nmax:100)}$ | $\delta g_{RES\ (nmax:200)}$ |
|---|---|---|---|
| Mean | -0.80 | -3.12 | -1.66 |
| Median | -1.24 | -3.45 | -1.35 |
| Standard Deviation | 10.82 | 14.65 | 12.23 |
| RMSD | 10.85 | 14.98 | 12.34 |
| Positive Maximum value | 55.09 | 48.69 | 56.23 |
| Negative minimum value | -110.26 | -78.42 | -76.08 |

# RESULTS

## Botucatu

**Table 9** – Disturbing potential ($T$) ($m^2 s^{-2}$).

| GOCO05S | $ggm_{(nmax100)}$ | | $ggm_{(nmax200)}$ | |
|---|---|---|---|---|
| $\delta g_{RES}$ | **RTM reduced** | **no RTM** | **RTM reduced** | **no RTM** |
| $T_p$ | -46.556 | -47.787 | -49.265 | -47.900 |

- The $T_p$ differences between RTM and without RTM are around 1.3 $m^2 s^{-2}$ .
- The differences between the GGM are 0.11 $m^2 s^{-2}$ using the RTM and 2.7 $m^2 s^{-2}$ without using.

**Fig.21-** R.G.D. RTM reduced. nxm:100.

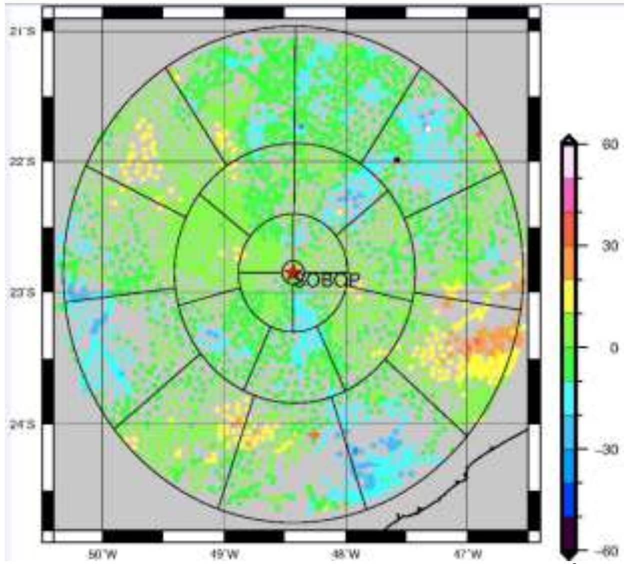



**Fig. 22-** R.G.D. RTM reduced. nxm:200.

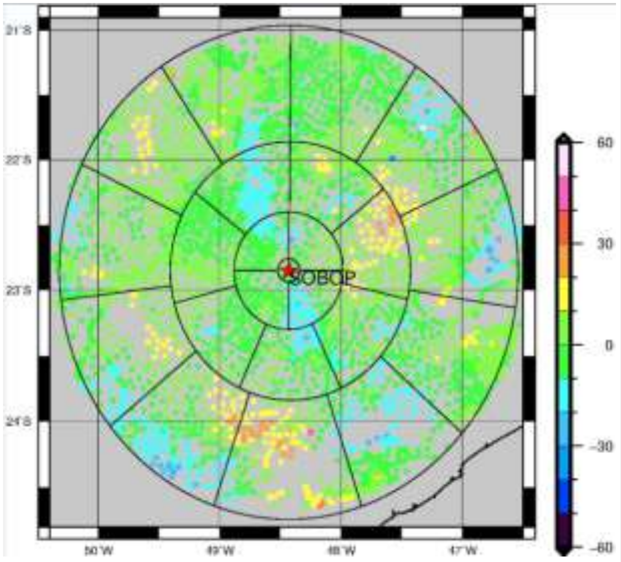
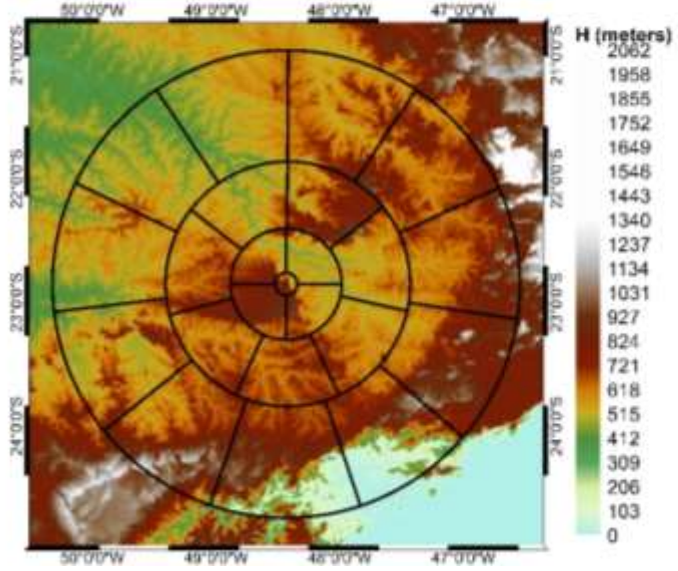



**Fig. 23-** Digital Terrain Model ALOS.



# RESULTS

## Presidente Prudente

**Fig 24-** Gravity Disturbances Residuals (1- No RTM-MGG100 ;2- RTM reduced –MGG100; 3- No RTM-MGG200 ;4- RTM reduced –MGG200;

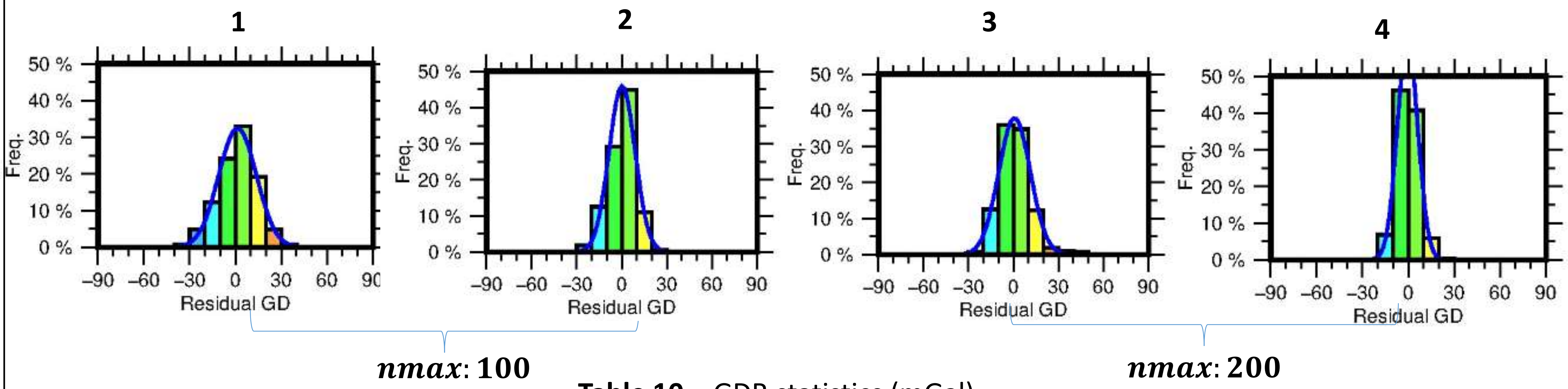



**Table 10** – GDR statistics (mGal).

| Statistics | $\delta g_{RES\ (RTM)}$ | $\delta g_{RES\ (nmax:100)}$ | $\delta g_{RES\ (nmax:200)}$ |
|---|---|---|---|
| Mean | 1.22 | 1.45 | 0.76 |
| Median | 0.72 | 2.13 | 0.13 |
| Standard Deviation | 7.20 | 12.3 | 10.54 |
| RMSD | 7.30 | 12.39 | 10.57 |
| Positive Maximum value | 50.00 | 46.23 | 53.06 |
| Negative minimum value | -26.96 | -40.77 | -30.54 |

## Presidente Prudente

**Table 11** – Disturbing potential ($T$) ($m^2 s^{-2}$).

| GOCO05S | $ggm_{(nmax100)}$ | | $ggm_{(nmax200)}$ | |
|---|---|---|---|---|
| $\delta g_{RES}$ | **RTM reduced** | **no RTM** | **RTM reduced** | **no RTM** |
| $T_p$ | -50.507 | -50.760 | -46.734 | -46.693 |

- The RTM reduction wasn't significative.
- The $T_p$ results show a difference around 4 $m^2 s^{-2}$ between GGM.

**Figura 25-** R.G.D. with RTM. nxm:200.

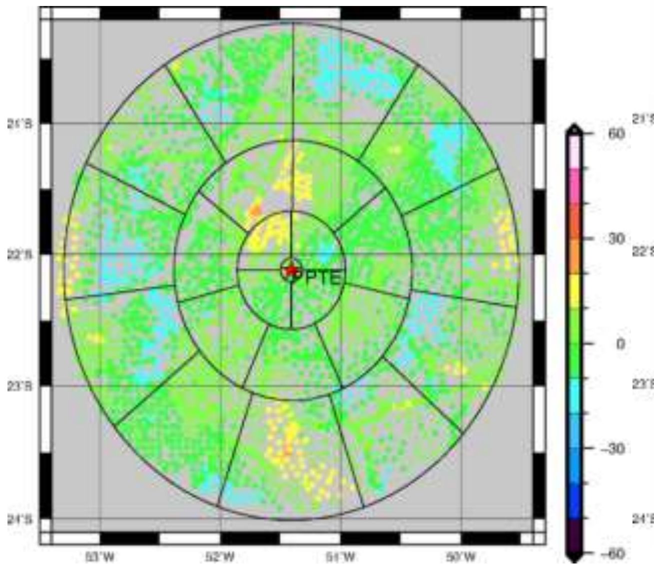



**Figura 26-** R.G.D. without RTM. nxm:200.

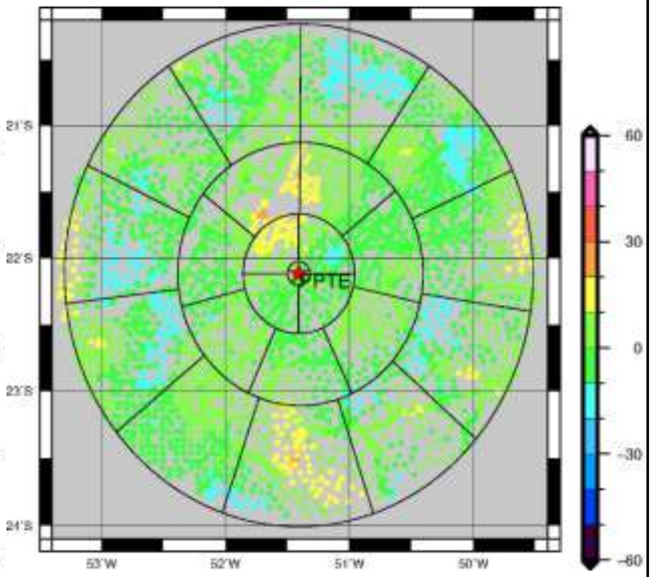
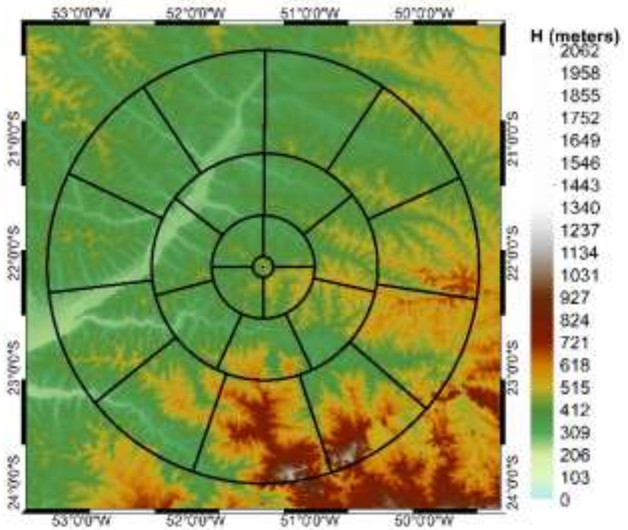



**Figure 27-** Digital Terrain Model ALOS.



# RESULTS

**Table 12** – Gravity potential (m/$s^2$).

| GOCO05S | $ggm_{(nmax100)}$ | | $ggm_{(nmax200)}$ | |
|---|---|---|---|---|
| $\delta g_{RES}$ | **RTM reduced** | **no RTM** | **RTM reduced** | **no RTM** |
| Botucatu | 62628896.80 | 62628895.57 | 62628894.09 | 62628895.45 |
| São Carlos | 62628672.19 | 62628669.54 | 62628665.29 | 62628667.70 |
| P Prudente | 62632532.03 | 62632531.77 | 62632535.80 | 62632535.84 |
| S J do Rio Preto | 62631481.77 | 62631481.69 | 62631479.82 | 62631480.35 |

**Table 13** – Normal Height (m).

| GOCO05S | $ggm_{(nmax100)}$ | | $ggm_{(nmax200)}$ | |
|---|---|---|---|---|
| $\delta g_{RES}$ | **RTM reduced** | **no RTM** | **RTM reduced** | **no RTM** |
| Botucatu | 813.0869 | 813.2127 | 813.3638 | 813.2242 |
| São Carlos | 836.0919 | 836.3626 | 836.7965 | 836.5500 |
| Presidente Prudente | 441.5713 | 441.5972 | 441.1858 | 441.1816 |
| São José do Rio Preto | 548.9545 | 548.9621 | 549.1533 | 549.0990 |

IBGE $H_N$ = 436.3673

# Final Considerations

- The gravity distribution for IHRF in São Paulo is an example on what has to be done at other stations.

- An ideal coverage may be difficult to reach in many cases.

- The present geopotential models have a small commission error up to d/o 250 and the ommission error will decrease from that order (ICGEM).

- The present tendency based on the results is to adopt d/o for the MGG of up to nmax:200 with an integration radius of, approximately, 100 kilometers.

- A further study will be performed to investigate different geopotential the models.

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