Second Workshop of DAAD Thematic Network “Modern Geodetic Space Techniques for Global Change Monitoring” , Luxembourg, 24-28 July 2018

A high-resolution gravity field model based on the GOCE data, altimetry data and EGM2008 derived gravity anomalies

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SCHOOL OF GEODESY AND GEOMATICS

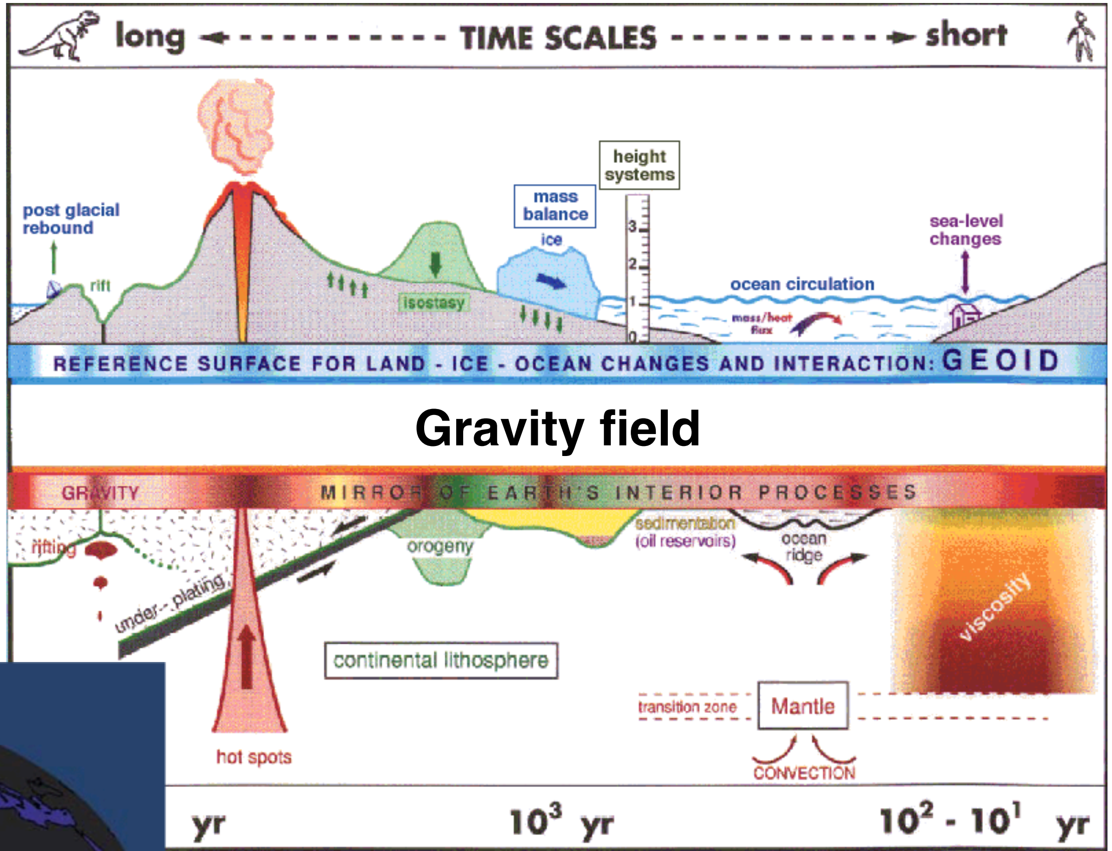
Outline

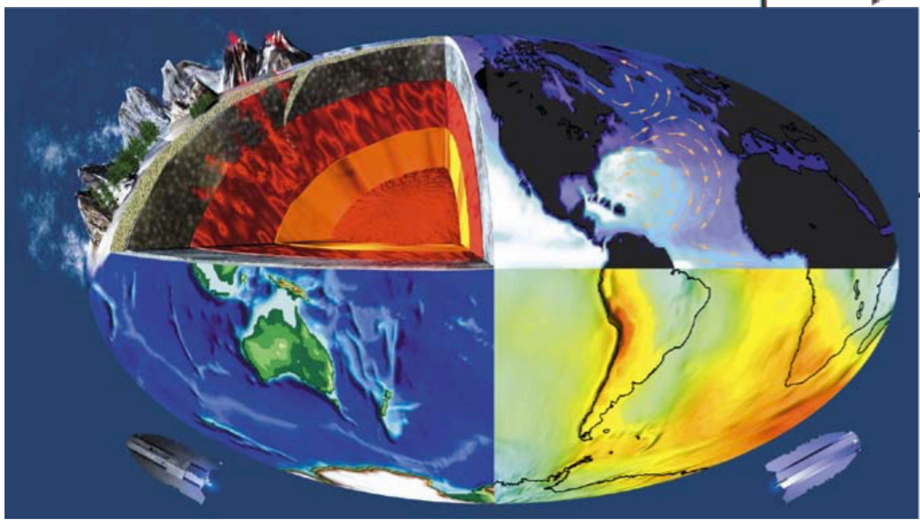
- Introduction
- GOCE satellite gravity field model determination
- Global marine gravity anomalies determination
- High resolution model determination and evaluation
- Conclusions and prospects

Introduction

❖ The applications of static high-resolution gravity field model

- ✦ Solid Earth Physics
- ✦ Oceanography
- ✦ Geodesy
- ✦ Ice Sheets
- ✦ …





Introduction

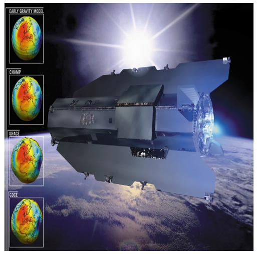
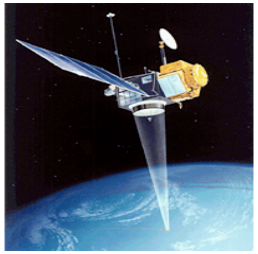
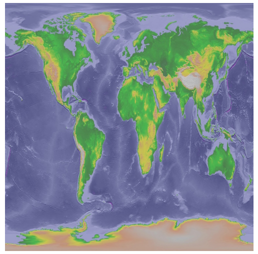
❖ Recent high-resolution gravity field models(ICGEM)

Nr	Model	Year	Degree	Data	References	Download	Calculate	Show	DOI
168	Tongji-Grace02k	2018	180	S(GRACE)	Chen, Q. et al, 2018	gfc zip	Calculate	Show	✔
167	SGG-UGM-1	2018	2159	EGM2008, S(GOCE)	Liang, W. et al., 2018 & Xu, X. et al. (2017)	gfc zip	Calculate	Show	✔
166	GOSG01S	2018	220	S(GOCE)	Xu, X. et al., 2018	gfc zip	Calculate	Show	✔
165	IGGT_R1	2017	240	S(GOCE)	Lu, B. et al, 2017	gfc zip	Calculate	Show	✔
164	IfE_GOCE05s	2017	250	S(GOCE)	Wu, H. et al, 2017	gfc zip	Calculate	Show	✔
163	GO_CONS_GCF_2_SPW_R5	2017	330	S(GOCE)	Gatti, A. et al, 2016	gfc zip	Calculate	Show	✔
162	GAO2012	2012	360	A, G, S(GOCE), S(GRACE)	Demianov, G. et al, 2012	gfc zip	Calculate	Show	✔
161	XGM2016	2017	719	A, G, S(GOCO05s)	Pail, R. et al, 2017	gfc zip	Calculate	Show	✔
160	Tongji-Grace02s	2017	180	S(Grace)	Chen, Q. et al, 2016	gfc zip	Calculate	Show	✔
159	NULP-02s	2017	250	S(Goce)	A.N. Marchenko et al, 2016	gfc zip	Calculate	Show	✔
158	HUST-Grace2016s	2016	160	S(Grace)	Zhou, H. et al, 2016	gfc zip	Calculate	Show	✔
157	ITU_GRACE16	2016	180	S(Grace)	Akyilmaz, O. et al, 2016	gfc zip	Calculate	Show	✔
156	ITU_GGC16	2016	280	S(Goce), S(Grace)	Akyilmaz, O. et al, 2016	gfc zip	Calculate	Show	✔
155	EIGEN-6S4 (v2)	2016	300	S(Goce), S(Grace), S(Lageos)	Förste, C. and Bruinsma, S.L., 2016	gfc zip	Calculate	Show	✔
154	GOCO05c	2016	720	(see model), A, G, S	Fecher, T. et al, 2016	gfc zip	Calculate	Show	✔
153	GGM05C	2015	360	A, G, S(Goce), S(Grace)	Ries, J. et al, 2016	gfc zip	Calculate	Show	✔
152	GECO	2015	2190	EGM2008, S(Goce)	Gilardoni, M. et al, 2016	gfc zip	Calculate	Show	
151	GGM05G	2015	240	S(Goce), S(Grace)	Bettadpur, S. et al, 2015	gfc zip	Calculate	Show	
150	GOCO05s	2015	280	(see model), S	Mayer-Gürr, T. et al, 2015	gfc zip	Calculate	Show	
149	GO_CONS_GCF_2_SPW_R4	2014	280	S(Goce)	Gatti, A. et al, 2014	gfc zip	Calculate	Show	
148	EIGEN-6C4	2014	2190	A, G, S(Goce), S(Grace), S(Lageos)	Förste, Christoph et al, 2014	gfc zip	Calculate	Show	✔
117	GO_CONS_GCF_2_TIM_R1	2010	224	S(Goce)	Pail, R. et al, 2010	gfc zip	Calculate	Show	
116	GO_CONS_GCF_2_SPW_R1	2010	210	S(Goce)	Migliaccio, F. et al, 2010	gfc zip	Calculate	Show	
115	GOCO01S	2010	224	S(Champ), S(Grace)	Pail, R. et al, 2010	gfc zip	Calculate	Show	
114	EIGEN-51C	2010	359	A, G, S(Champ), S(Grace)	Bruinsma, S.L. et al, 2010	gfc zip	Calculate	Show	
113	AIUB-CHAMP03S	2010	100	S(Champ)	Prange, L., 2010	gfc zip	Calculate	Show	
112	EIGEN-CHAMP05S	2010	150	S(Champ)	Flechtner, Frank et al, 2010	gfc zip	Calculate	Show	
111	ITG-Grace2010s	2010	180	S(Grace)	Mayer-Gürr, T. et al, 2010	gfc zip	Calculate	Show	
110	AIUB-GRACE02S	2009	150	S(Grace)	Jäggi, A. et al, 2012	gfc zip	Calculate	Show	
109	GGM03C	2009	360	A, G, S(Grace)	Tapley, B.D. et al, 2007	gfc zip	Calculate	Show	
108	GGM03S	2008	180	S(Grace)	Tapley, B.D. et al, 2007	gfc zip	Calculate	Show	
107	AIUB-GRACE01S	2008	120	S(Grace)	Jäggi, A. et al, 2010	gfc zip	Calculate	Show	
106	EIGEN-5S	2008	150	S(Grace), S(Lageos)	Förste, C. et al, 2008	gfc zip	Calculate	Show	
105	EIGEN-5C	2008	360	A, G, S(Grace), S(Lageos)	Förste, C. et al, 2008	gfc zip	Calculate	Show	
104	EGM2008	2008	2190	A, G, S(Grace)	Pavlis, N.K. et al, 2008	gfc zip	Calculate	Show	
103	ITG-Grace03	2007	180	S(Grace)	Mayer-Gürr, T. et al, 2007	gfc zip	Calculate	Show	

Introduction

❖ Idea for modeling high-resolution gravity field model

Multi-observations

 +  +  +  +  + **Others**

Satellite gravimetry
Satellite altimetry
Ground gravimetry
Airborne gravimetry
Topography
Others
- Prior models(EGM2008)
- Density models

Data processing and fusion

high-resolution gravity field model

SGG-UGM-1: GOCE, EGM2008

SGG-UGM-2

Satellite gravimetry: Global

EGM2008: Land

Altimetry: Ocean

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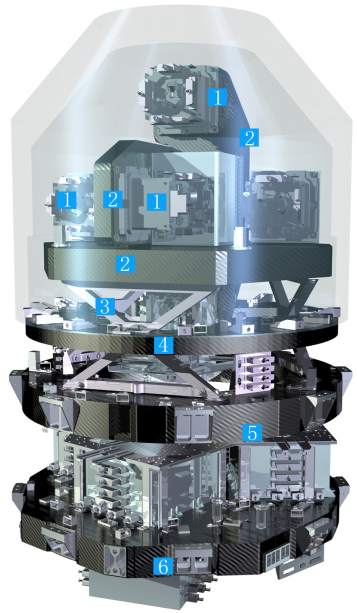
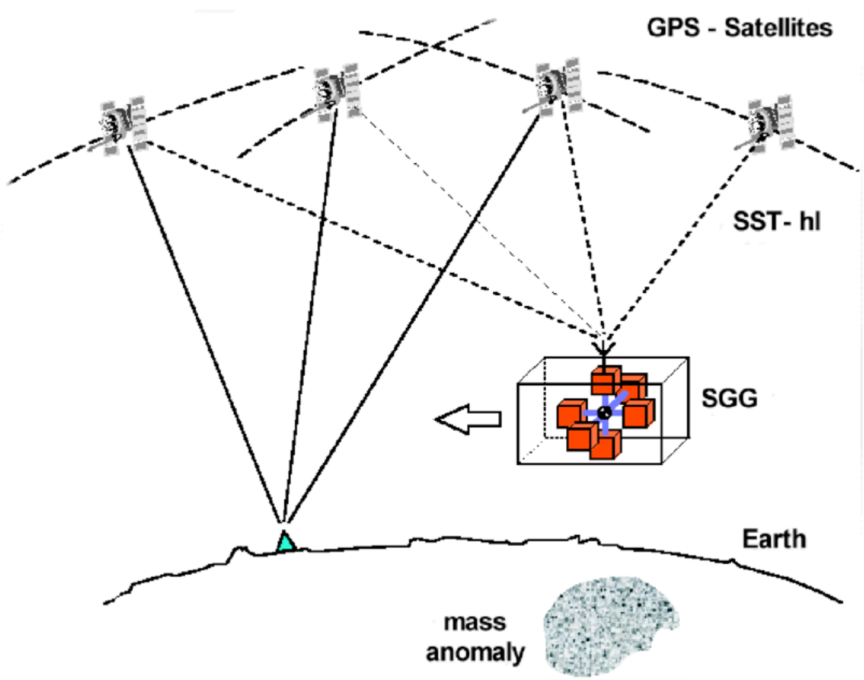
GOCE satellite gravity field model determination

❖ GOCE mission

- ✦ With gradiometer
  (GGT: Gravitational Gradient Tensor)
- ✦ Orbit height: 250km
- ✦ SGG + SST-hl





GOCE satellite gravity field model determination

❖ Data description for GOCE only gravity field model

- ✦ Period:
  - ◉ SGG : 1/11/2009-31/8/2011, ~ 614days(~ 20.5 months)
  - ◉ SST-hl : 1/11/2009-7/5/2010, ~ 188days(~ 6 months)
- ✦ Sampling interval: 1s
- ✦ SGG: EGG_NOM_2 (GGT: V_{xx}, V_{yy}, V_{zz}) in GRF
- ✦ SST: SST_PKI_2, SST_PCV_2, SST_PRD_2
- ✦ Attitude: EGG_NOM_2 (IAQ) , SST_PRM_2 (PRM)
- ✦ Non-conservative force: Common mode ACC (GG_CCD_1i)
- ✦ Background model: tidal model (solid etc.), third-body acceleration, relativistic corrections, ...

GOCE satellite gravity field model determination

❖ Progress strategies

- ✦ Data preprocessing
  - ◉ Gross outlier elimination and interpolation (only for the data gaps less than 40s).
  - ◉ Splitting data into subsections for gaps > 40s
- ✦ The normal equation from SST data
  - ◉ Point-wise acceleration approach (PAA)
    - ‣ Extended Differentiation Filter (low-pass)
  - ◉ Max degree: up to 130
  - ◉ Data: PKI, PCV, CCD
- ✦ The normal equation from SGG data
  - ◉ Direct LS method
  - ◉ Max degree: up to 220

GOCE satellite gravity field model determination

❖ Progress strategies

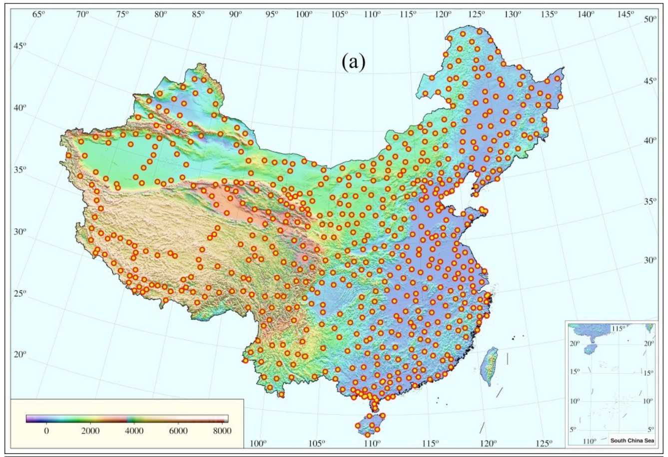
- ✦ The normal equation from SGG data (Cont.)
  - ◉ Data:GGT, PRD, IAQ, PRM
  - ◉ Band-pass filter: used to deal with colored-noise of GGT observations (pass band 0.005-0.041Hz)
  - ◉ Forming the normal equations according to subsections
  - ◉ Spherical harmonic base function transformation instead of transforming GGT from GRF to LNRF
- ✦ Combination of SGG and SST
  - ◉ Max degree: up to 220
  - ◉ The relative weights: VCE used for (V_{xx}, V_{yy}, V_{zz}), Vs SST 1.0
  - ◉ Tikhonov Regularization Technique (TRT) is only applied to near (zonal) terms (m<20)
  - ◉ Least squares inverse by MPI strict inversion

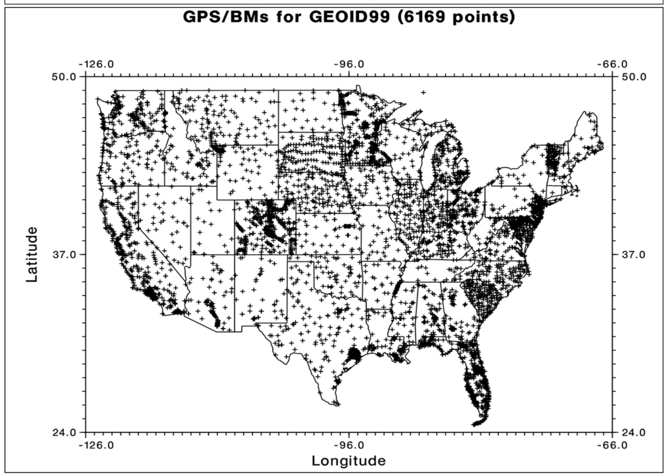
GOCE satellite gravity field model determination

❖ Model validation with GPS-leveling data

✦ Comparing with GPS/leveling data in China (649 points), USA (6169 points)(unit: m), the omission errors after degree 200 are compensated by EGM2008

Model	STD (China)	STD (USA)
GOSG01S	**±0.165**	**±0.283**
GOTIM05S	±0.161	±0.281
GODIR05S	±0.161	±0.281
GOSPW04S	±0.163	±0.283
GOCO03S	±0.164	±0.285
JYY_GOCE02S	±0.160	±0.282
EIGEN-6C2	±0.167	±0.284
EGM2008	±0.240	±0.284





http://doi.org/10.5880/icgem.2018.002

GOCE satellite gravity field model determination

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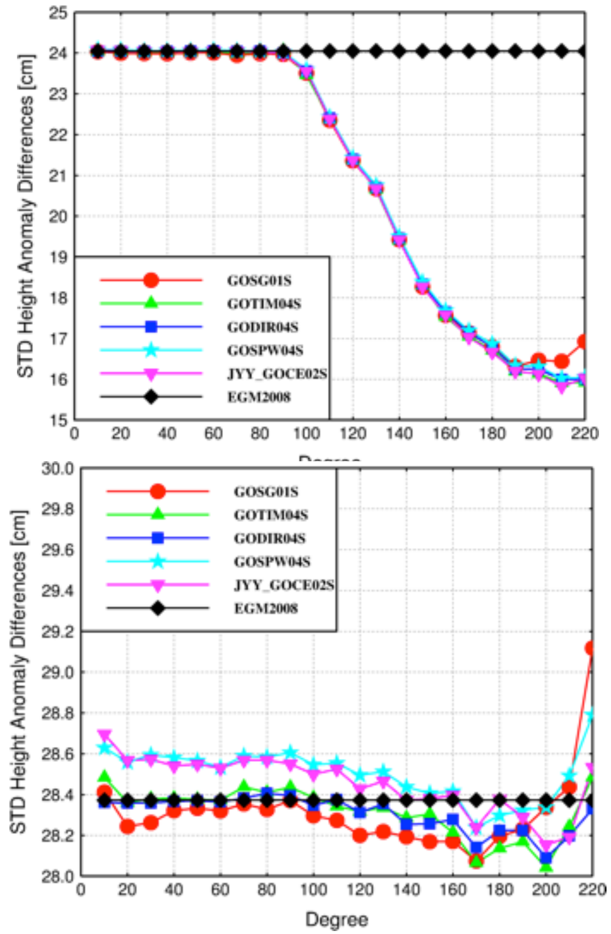

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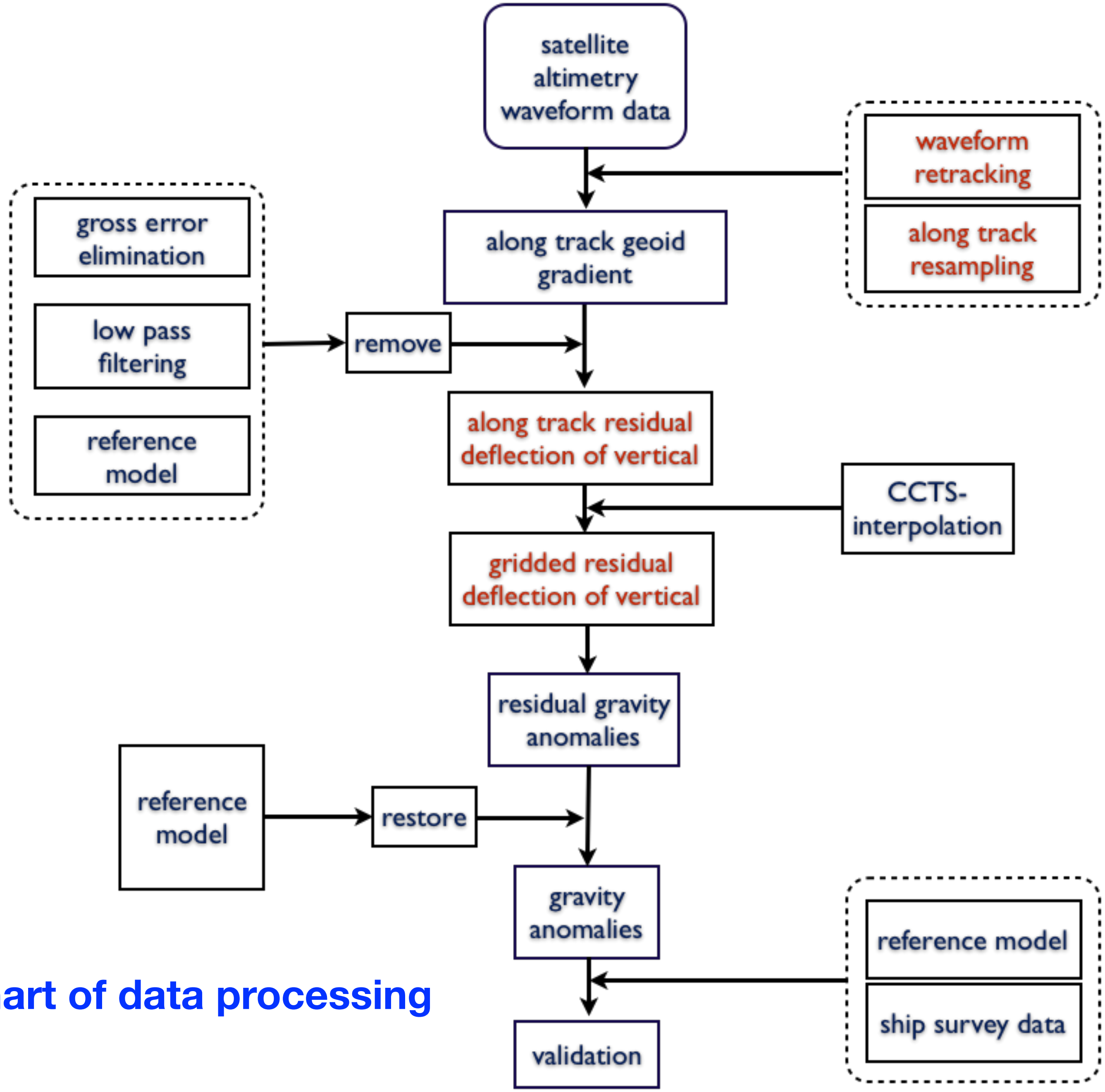
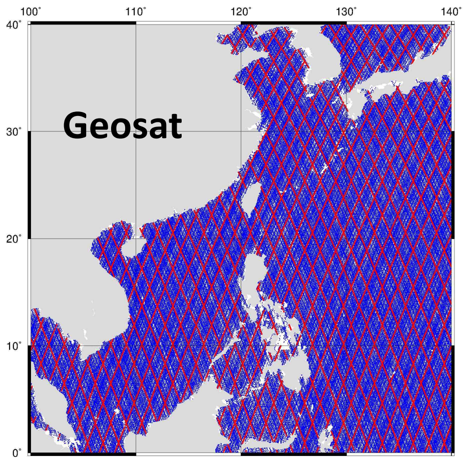
Global marine gravity anomalies determination

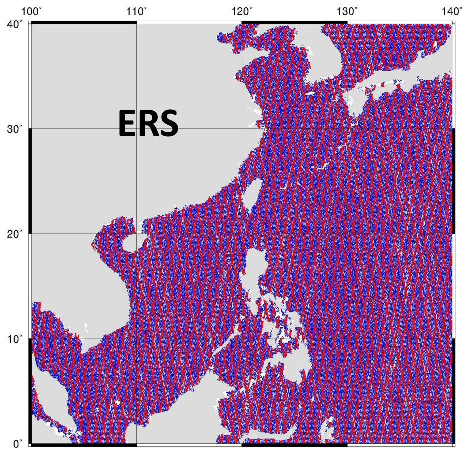


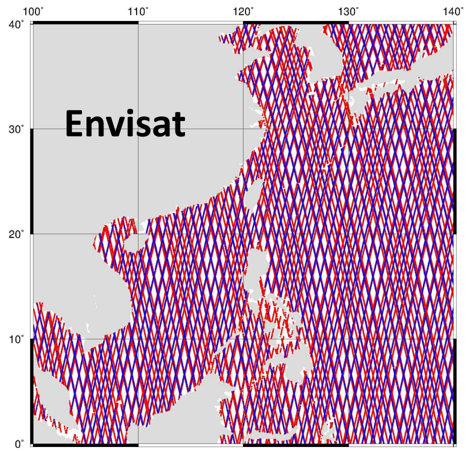
Flow chart of data processing

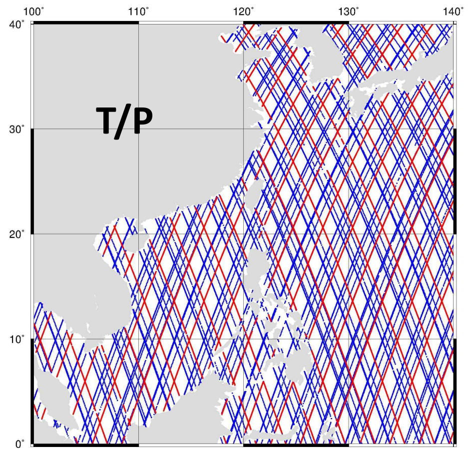
Global marine gravity anomalies determination

❖ Data description: for example in China Sea

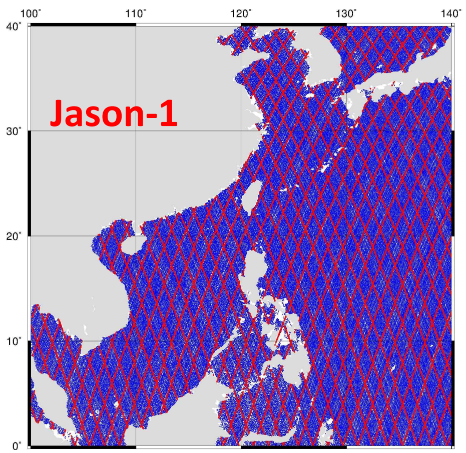


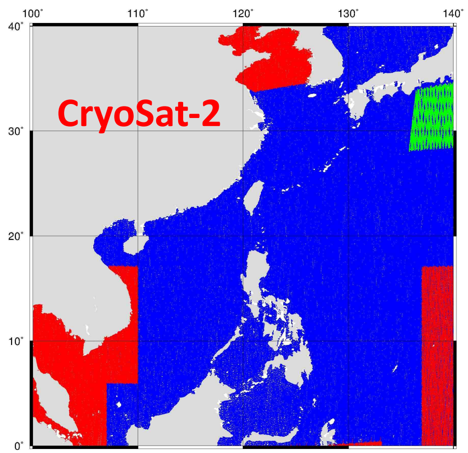


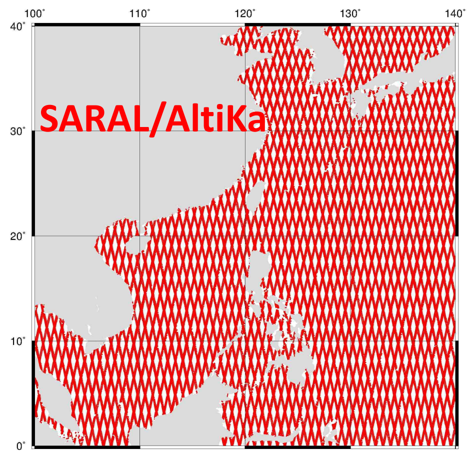




New data comparing with EGM2008

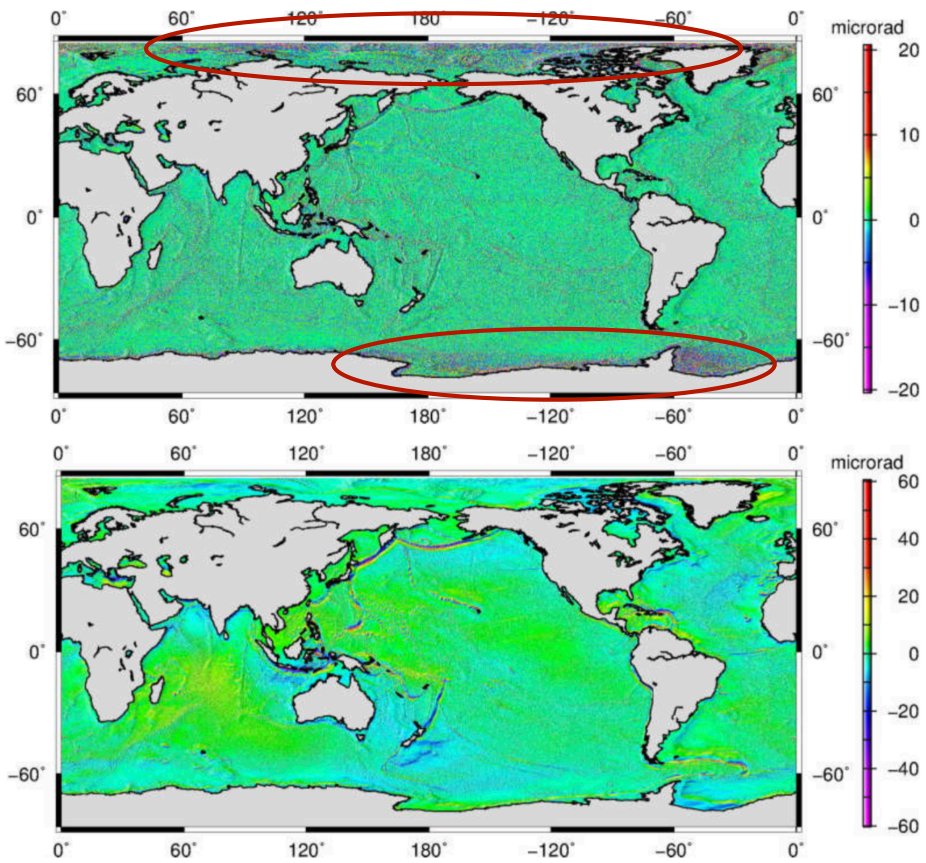




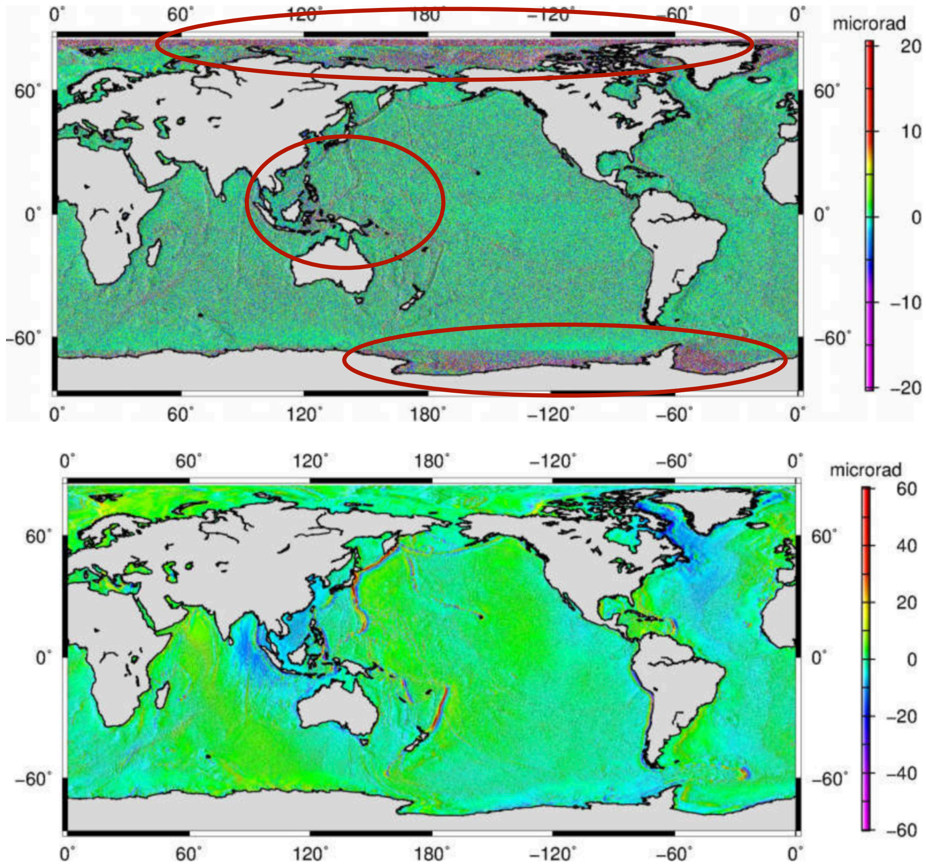


Global marine gravity anomalies determination

- ❖ Gridded global marine residual deflections of the vertical from altimetry data
  - ✦ Resolution: 1′×1′
  - ✦ Reference model: EGM2008

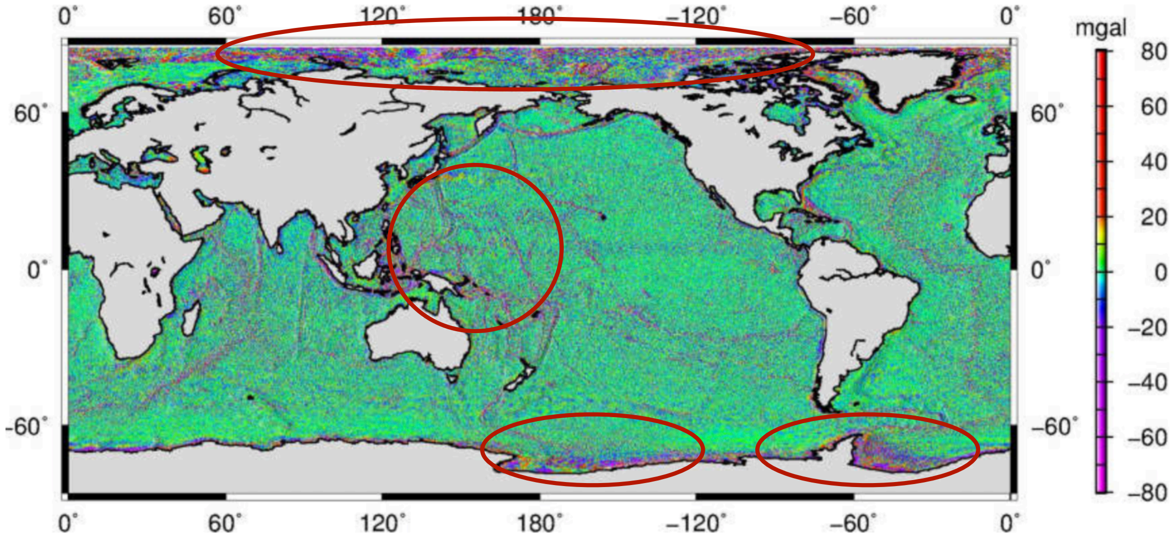


North-south component

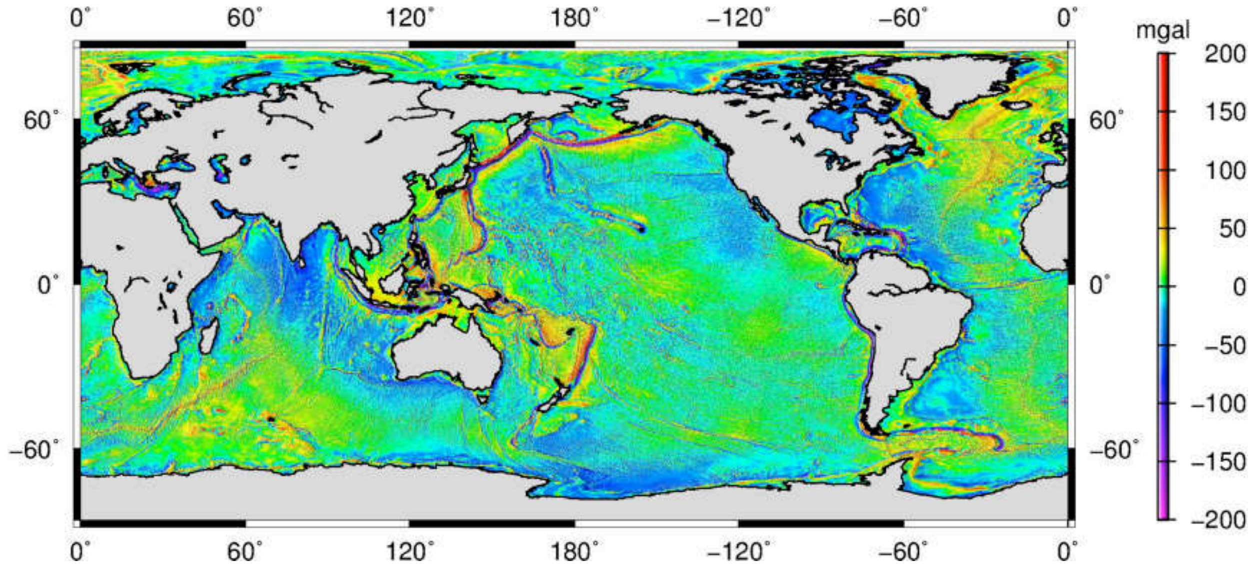


West-east component

Global marine gravity anomalies determination



Gridded global marine gravity anomaly residuals



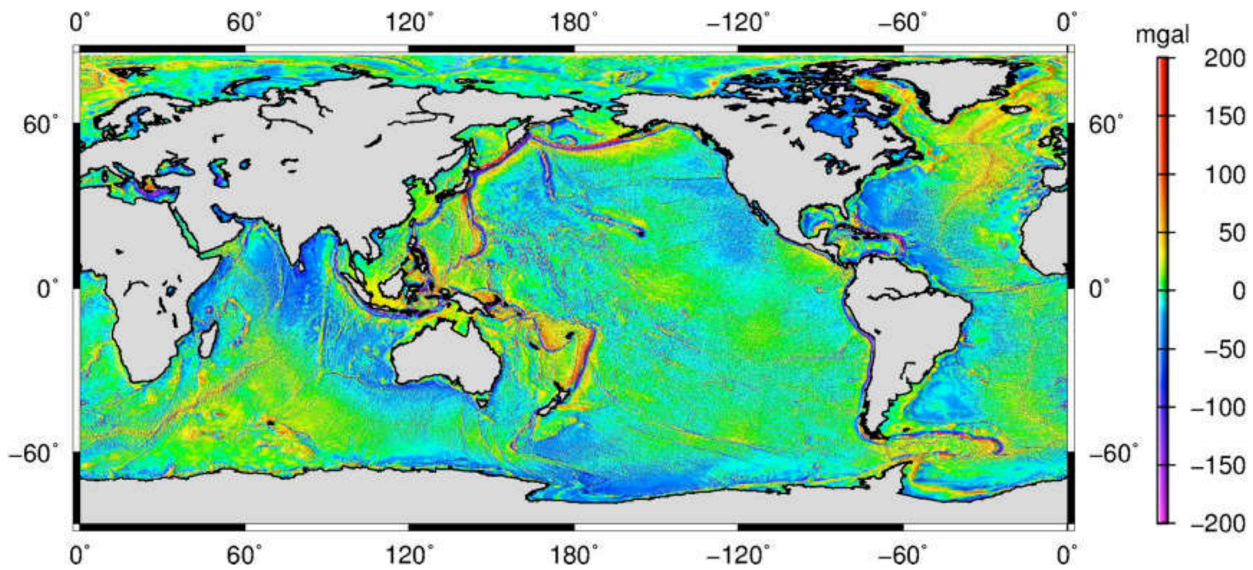
Global marine gravity anomalies

Global marine gravity anomalies determination

❖ Comparing with DTU13 and V23.1 globally

unit: mGal

Model	Min	Max	Average	STD
WHU VS DTU13	-113.623	108.358	-0.029	3.553
WHU VS V23.1	-147.000	252.399	-0.044	1.869
V23.1 VS DTU13	-186.643	127.894	0.023	3.811

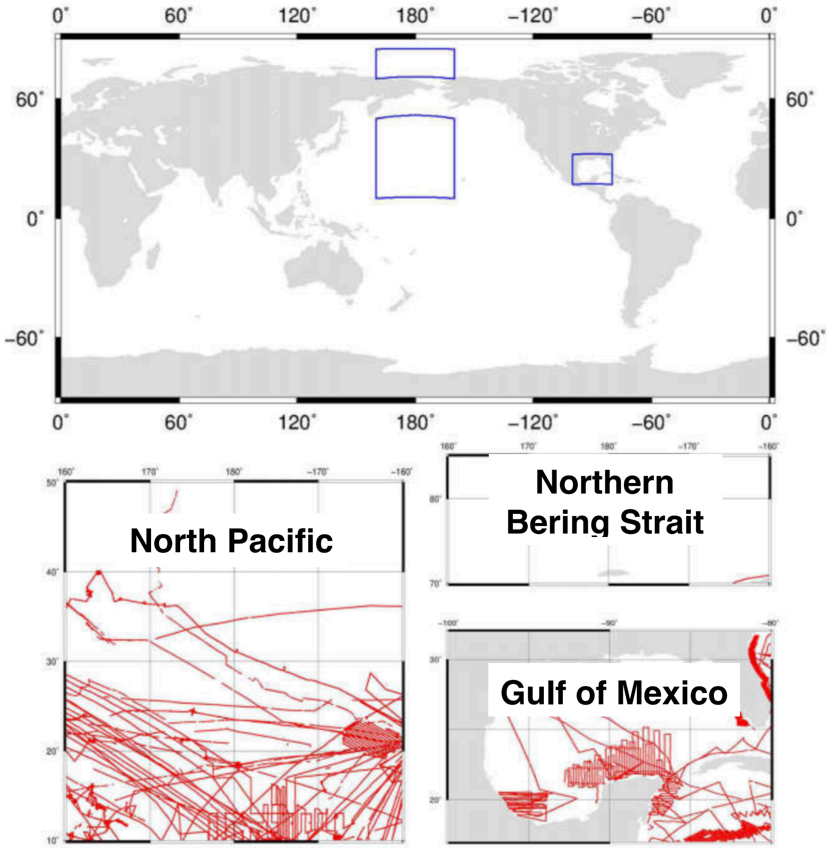


Global marine gravity anomalies

Global marine gravity anomalies determination

❖ Comparing with shipborne gravity data in regions

Selected regions



Results statistics (STD) unit: mGal

Model	Area		
	North Pacific	Gulf of Mexico	Northern Bering Strait
WHU VS Shipborne data	4.259	4.394	3.907
EGM2008 VS Shipborne data	4.925	4.881	4.814
WHU VS EGM2008	1.889	2.753	3.899
WHU VS DTU13	1.788	2.573	3.572
WHU VS V23.1	1.756	2.016	2.248
EGM2008 VS DTU13	1.898	1.207	2.952
EGM2008 VS V23.1	1.802	2.936	3.711

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- ❖ Introduction
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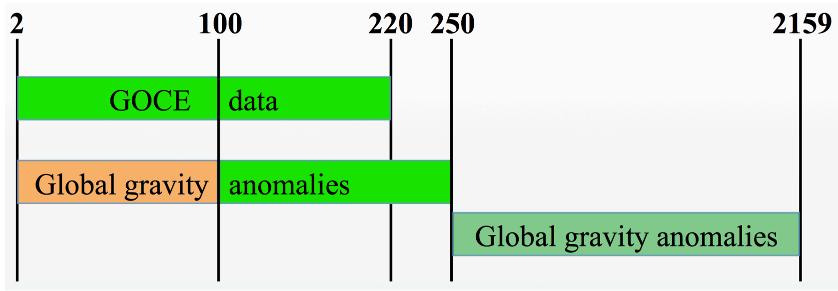
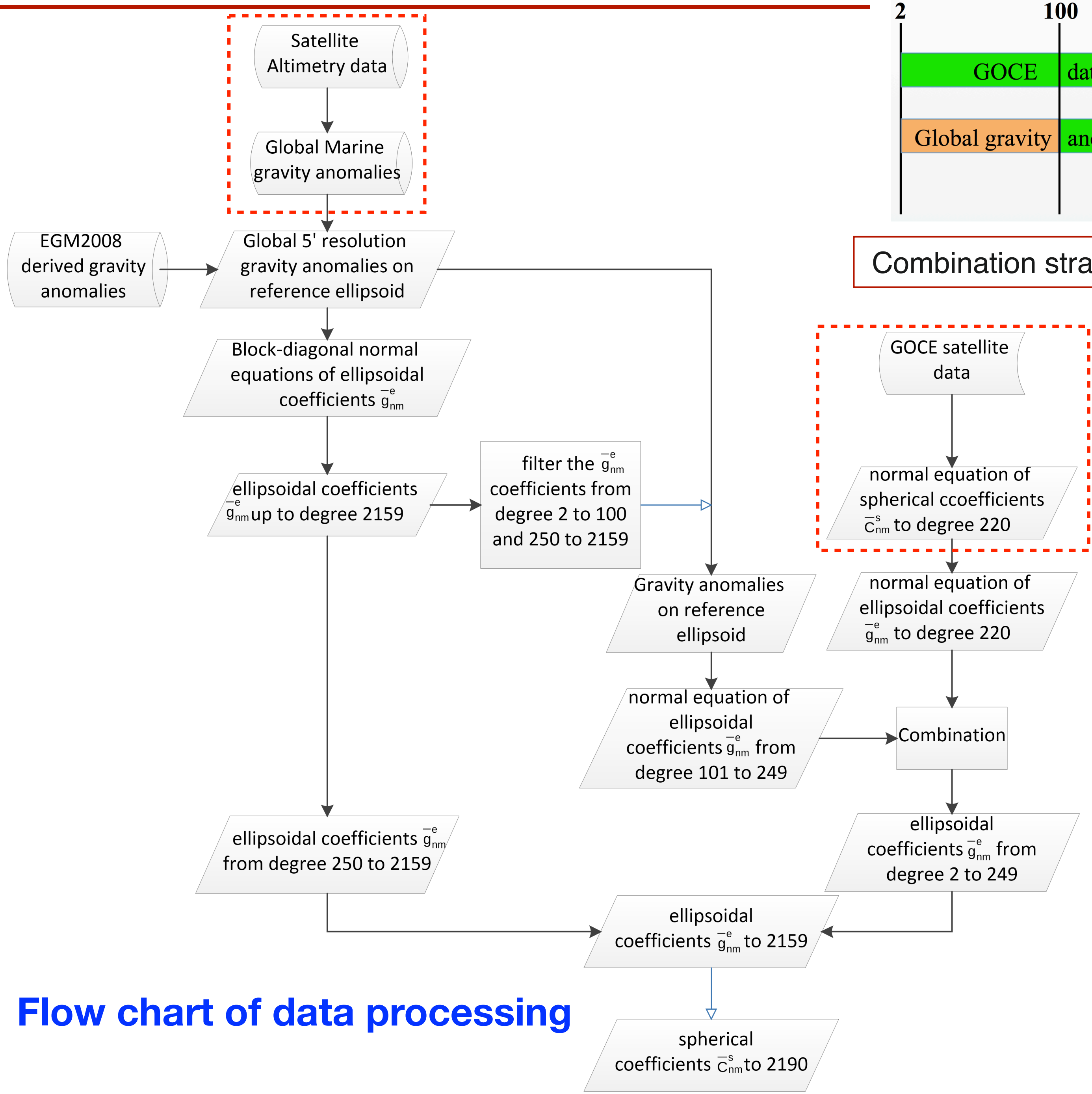
- ❖ High resolution model determination and evaluation
- ❖ Prospects: future work

High resolution model determination and evaluation



Combination strategies with the least squares method



Flow chart of data processing

High resolution model determination and evaluation

❖ Theory for high resolution model determination

✦ The relationship between gravity anomalies and disturbing potential coefficients in spherical harmonics

SGG-UGM-1

$$T = \frac{GM}{r}\sum_{n=2}^{\infty}\left(\frac{R}{r}\right)^n \sum_{m=0}^{n} \bar{C}_{nm}^{S} \bar{Y}_{nm}(\theta,\lambda)$$

$$\Delta g = -\frac{\partial T}{\partial r} - \frac{2}{r}T$$

$$\longrightarrow \quad \Delta g = \frac{GM}{r^2}\sum_{n=2}^{\infty}(n-1)\left(\frac{R}{r}\right)^n \sum_{m=0}^{n} \bar{C}_{nm}^{S} \bar{Y}_{nm}(\theta,\lambda)$$

✦ The relationship between gravity anomalies and ellipsoidal coefficients in ellipsoidal harmonics on the reference ellipsoid

$$(r\Delta g)$$

$$r\Delta g = a\sum_{n=2}^{\infty}\sum_{m=0}^{n} \bar{g}_{nm}^{e} \bar{Y}_{nm}(\theta,\lambda)$$

$$r\Delta g = a\sum_{n=2}^{\infty}\left(\frac{R}{r}\right)^{n+1} \sum_{m=0}^{n} \bar{g}_{nm}^{s} \bar{Y}_{nm}(\theta,\lambda)$$

$$\longrightarrow \quad \boxed{\bar{g}_{nm}^{e} \quad \bar{g}_{nm}^{s}} \quad \xrightarrow{?} \quad \bar{\boldsymbol{C}}_{nm}^{s}$$

High resolution model determination and evaluation

❖ Theory for high resolution model determination

✦ Transformations from ellipsoidal harmonic coefficients to spherical harmonic coefficients

◉ From $\bar{g}^{e}_{nm}$ to $\bar{g}^{s}_{nm}$ based on the Jekeli's transformation

$$\bar{v}^{s}_{nm} = \sum_{k=0}^{w} L_{nmk} \frac{1}{\bar{S}_{n-2k,|m|}(\frac{b}{E})} \bar{v}^{e}_{n-2k,m}, w = [\frac{n-|m|}{2}]$$

$$\bar{v}^{e}_{nm} = \bar{S}_{n|m|}(\frac{b}{E}) \sum_{k=0}^{w} \lambda_{nmk} \bar{v}^{s}_{n-2k,m}, w = \left[\frac{n-|m|}{2}\right]$$

◉ Linear relationship between $\bar{g}^{s}_{nm}$ and $\bar{C}^{s}_{nm}$

$$\Delta g = \frac{GM}{r^2} \sum_{n=2}^{\infty} (n-1)(\frac{R}{r})^n \sum_{m=0}^{n} \bar{C}^{s}_{nm} \bar{Y}_{nm}(\theta,\lambda)$$

$$r\Delta g = a \sum_{n=2}^{\infty} (\frac{R}{r})^{n+1} \sum_{m=0}^{n} \bar{g}^{s}_{nm} \bar{Y}_{nm}(\theta,\lambda)$$

$$\Rightarrow \quad \bar{C}^{s}_{nm} = \frac{a^2}{GM(n-1)} \bar{g}^{s}_{nm}$$

High resolution model determination and evaluation

❖ Theory for high resolution model determination

✦ The determination of gravity field model from gravity anomalies on the ellipsoid

SGG-UGM-2

$$r\Delta g = a\sum_{n=2}^{\infty}\sum_{m=0}^{n}\bar{g}_{nm}^{e}\bar{Y}_{nm}(\theta,\lambda)$$

$$\bar{g}_{nm}^{s} \xrightarrow{\bar{C}_{nm}^{s}=\frac{a^2}{GM(n-1)}\bar{g}_{nm}^{s}} \bar{C}_{nm}^{s}$$

$$\uparrow \text{Jekeli's}$$

$$(r\Delta g)^{E} \xrightarrow[\text{NQ or LS}]{} \bar{g}_{nm}^{e}$$

High resolution model determination and evaluation

❖ The evaluation with GPS/Leveling data in China and USA (unit: m)

China (649 points)

Model	Max	Min	Mean	STD
EGM2008	1.729	-1.535	0.239	0.240
SGG-UGM-2	0.774	-0.603	0.246	0.164
SGG-UGM-1	0.744	-0.618	0.246	0.162
EIGEN-6C4	0.729	-0.698	0.243	0.157
GECO	1.165	-0.847	0.244	0.180

USA (6169 points)

Model	Max	Min	Mean	STD
EGM2008	0.360	-1.396	-0.511	0.284
SGG-UGM-2	0.386	-1.394	-0.511	0.282
SGG-UGM-1	0.317	-1.407	-0.511	0.280
EIGEN-6C4	0.397	-1.392	-0.512	0.282
GECO	0.313	-1.391	-0.513	0.281

Qingdao (152 points)

Model	Max	Min	Mean	STD
EGM2008	0.510	-0.090	0.196	0.100
SGG-UGM-2	0.415	-0.067	0.180	0.093
SGG-UGM-1	0.362	-0.075	0.168	0.102
EIGEN-6C4	0.373	-0.054	0.179	0.089
GECO	0.411	-0.137	0.174	0.116

Taiwan (88 points)

Model	Max	Min	Mean	STD
EGM2008	0.918	0.437	0.676	0.086
SGG-UGM-2	0.733	0.272	0.563	0.088
SGG-UGM-1	0.720	0.248	0.569	0.091
EIGEN-6C4	0.715	0.267	0.557	0.091
GECO	0.729	0.204	0.564	0.106

High resolution model determination and evaluation

- The evaluation with GPS/Leveling data in China and USA (unit: m)

China (649 points)

Model	Max	Min	Mean	STD
EGM2008	1.729	-1.535	0.239	0.240
SGG-UGM-2	0.774	-0.603	0.246	0.164
SGG-UGM-1	0.744	-0.618	0.246	0.162
EIGEN-6C4	0.729	-0.698	0.243	0.157
GECO	1.165	-0.847	0.244	0.180

USA (6169 points)

Model	Max	Min	Mean	STD
EGM2008	0.360	-1.396	-0.511	0.284
SGG-UGM-2	0.386	-1.394	-0.511	0.282
SGG-UGM-1	0.317	-1.407	-0.511	0.280
EIGEN-6C4	0.397	-1.392	-0.512	0.282
GECO	0.313	-1.391	-0.513	0.281

Nr	Model	Nmax	Australia (201 points)	Brazil (1112 points)	Canada (2691 points)	Europe (1047 points)	Japan (816 points)	USA (6169 points)	All (12036 points)
167	**SGG-UGM-1**	2,159	0.217 m	0.446 m	0.13 m	0.121 m	0.076 m	0.245 m	0.2353 m
166	**GOSG01S**	220	0.359 m	0.518 m	0.373 m	0.426 m	0.526 m	0.442 m	0.4392 m
165	**IGGT_R1**	240	0.317 m	0.513 m	0.348 m	0.387 m	0.483 m	0.412 m	0.4111 m
164	**IfE_GOCE05s**	250	0.337 m	0.512 m	0.329 m	0.385 m	0.48 m	0.414 m	0.4081 m
163	**GO_CONS_GCF_2_SPW_R5**	330	0.33 m	0.511 m	0.299 m	0.346 m	0.442 m	0.396 m	0.3873 m
162	**GAO2012**	360	0.293 m	0.531 m	0.309 m	0.453 m	0.759 m	0.366 m	0.4177 m
161	**XGM2016**	719	0.218 m	0.44 m	0.151 m	0.14 m	0.125 m	0.263 m	0.2489 m
152	**GECO**	2,190	0.216 m	0.451 m	0.131 m	0.123 m	0.08 m	0.246 m	0.2371 m
151	**GGM05G (upto210)**	210	0.357 m	0.521 m	0.374 m	0.454 m	0.543 m	0.448 m	0.4461 m
151	**GGM05G**	240	0.326 m	0.502 m	0.342 m	0.384 m	0.487 m	0.407 m	0.4065 m
150	**GOCO05s**	280	0.335 m	0.505 m	0.308 m	0.344 m	0.45 m	0.399 m	0.3904 m
149	**GO_CONS_GCF_2_SPW_R4**	280	0.322 m	0.508 m	0.33 m	0.375 m	0.473 m	0.406 m	0.4023 m
148	**EIGEN-6C4**	2,190	0.212 m	0.446 m	0.126 m	0.121 m	0.079 m	0.247 m	0.2361 m
105	**EIGEN-5C**	360	0.244 m	0.524 m	0.278 m	0.266 m	0.339 m	0.341 m	0.3422 m
104	**EGM2008**	2,190	0.217 m	0.46 m	0.128 m	0.125 m	0.083 m	0.248 m	0.2397 m
103	**ITG-Grace03**	180	0.603 m	0.686 m	0.636 m	0.67 m	0.752 m	0.633 m	0.6502 m

Outline

- Introduction
- GOCE satellite gravity field model determination
- Global gravity anomalies formation and process
- High resolution model determination and evaluation
- Conclusions and prospects

Conclusions and prospects

❖ Conclusions

- ✦ A high-resolution gravity field model SGG-UGM-2 was modeled from the GOCE data, altimetry data and EGM2008 derived gravity anomalies
- ✦ SGG-UGM-2 model has nearly same accuracy with the model EIGEN-6C4, better than GECO and EGM2008
- ✦ Comparing with SGG-UGM-1 model, the accuracy of SGG-UGM-2 model is improved near/in the ocean

❖ Prospects: future work

- ✦ To involve terrestrial gravity observation data in China
- ✦ Starting from the data processing of the original ground gravity data, airborne-gravity data (eg. Grav-D)
- ✦ Combining with new derived satellite gravity model

Thanks for your attentions!