

## Lecture 2.4. Gravity field observations. T/M, Ch. 5.

1. Plumb-line direction: Astronomical latitude and longitude (direction of gravity vector).
2. Magnitude of gravity, (BGI, DTU-Space, etc.).
3. Satellite altimetry (RADS, ESA )
4. Acceleration and velocity (vectors) of body in free fall (satellite) (CHAMP)
5. Gravity potentials 2.'orden partial derivatives or first order derivatives of gravity vector (GOCE)
6. Height anomalies (GPS/Levelling)
7. Potential-differences (Precision or hydrostatic levelling), and variations of kinetic energy. (GRACE)
8. Topography/bathymetry

**Astronomical measurements,** sec. 5.3.

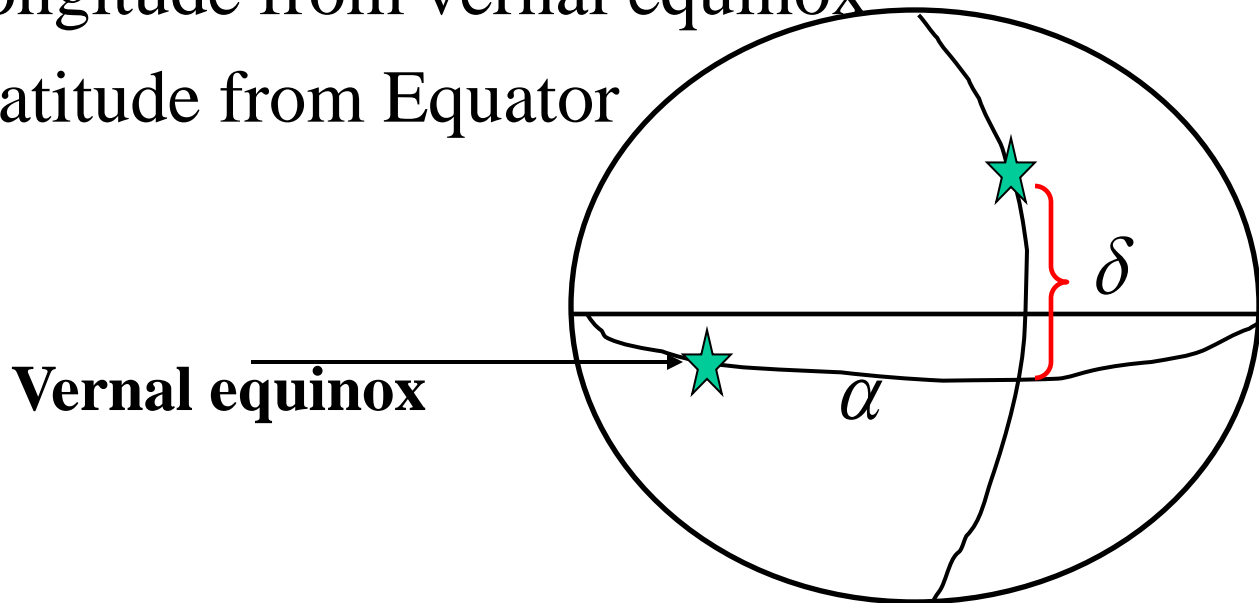
Star-coordinates from star-catalogue:

$(\alpha, \delta, \textit{parallax}, \textit{eigen} - \textit{movement})$

Refer to ekliptika

$\alpha$  longitude from vernal equinox

$\delta$  latitude from Equator

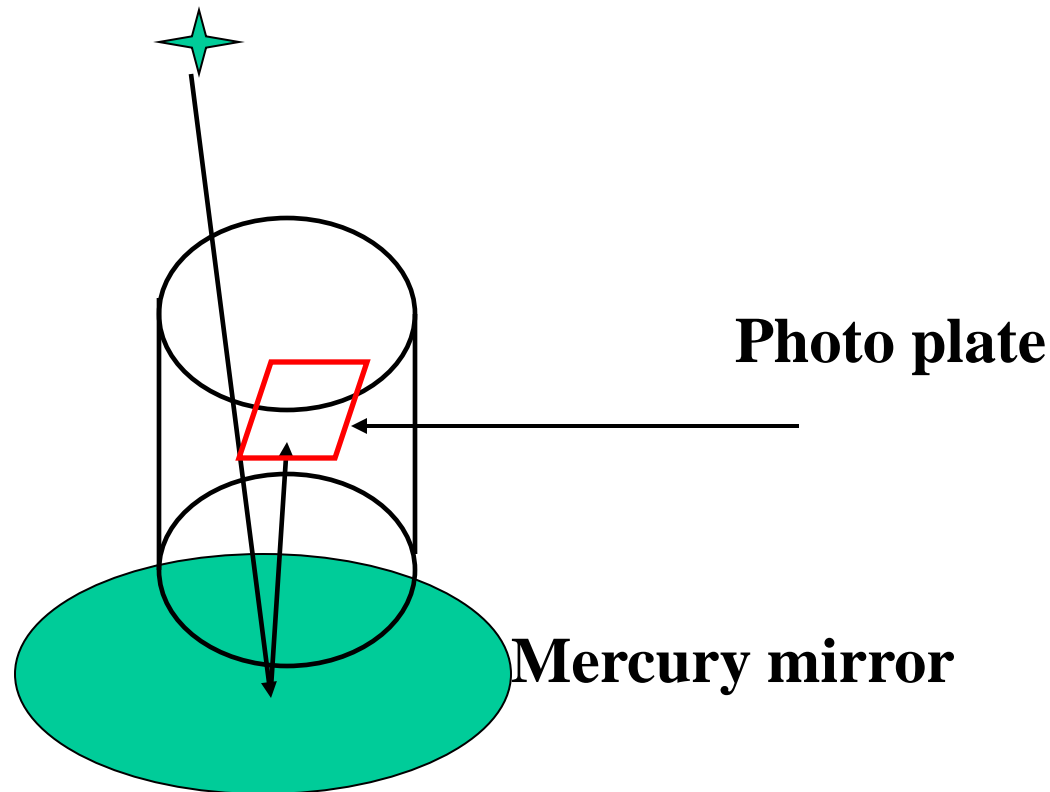


## Zenith-camera.,

p. 165.

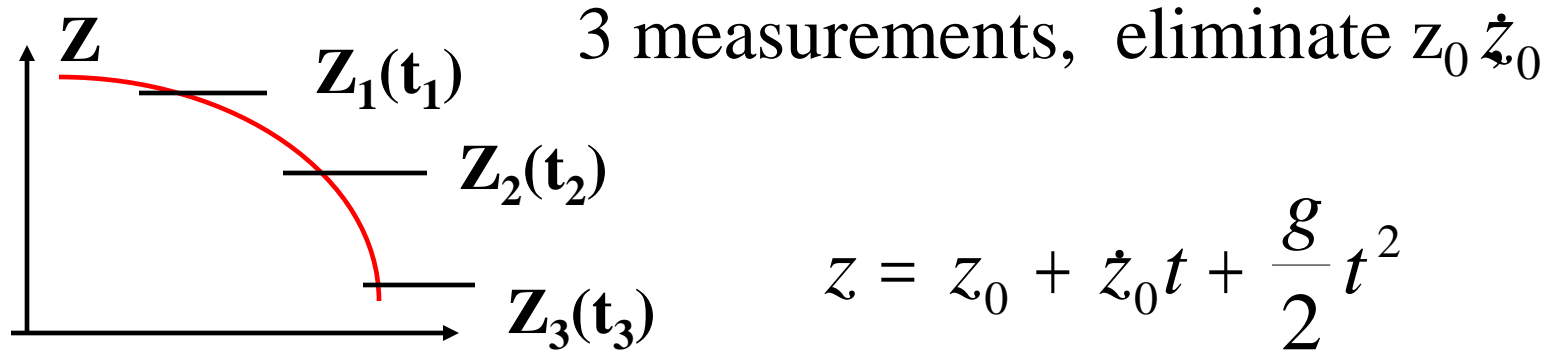
Positioned in level, so refraction is small.

Stars, symmetric about Zenith to be used. Only  $\sim 1$  mgal.



Gravity from Free fall. Vakuüm, Seismic protected., p. 176.

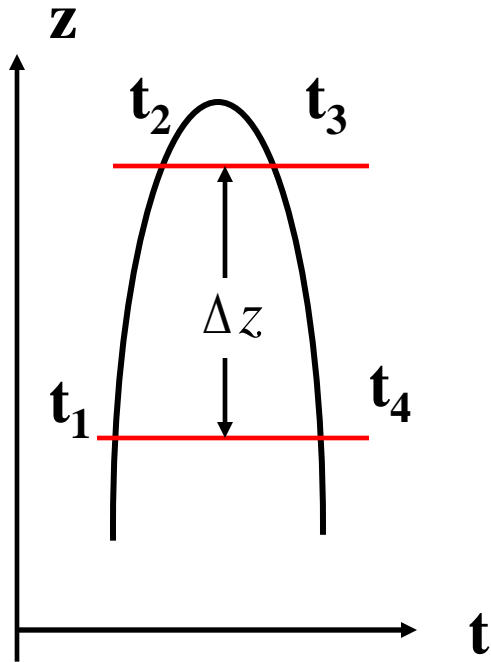
Free fall: **Height measured as a function of time.**



$$g = 2 \frac{(z_3 - z_1)(t_2 - t_1) - (z_2 - z_1)(t_3 - t_1)}{(t_3 - t_1)(t_2 - t_1)(t_3 - t_2)}$$

Gravity measurements, throw, vakuu, seismic protec., p. 176.

60 measurements over 0.5 m gives  $\pm 0.1 \mu\text{m} / \text{s}^2$



$$g = \frac{8\Delta z}{(t_4 - t_1)^2 - (t_3 - t_2)^2}$$

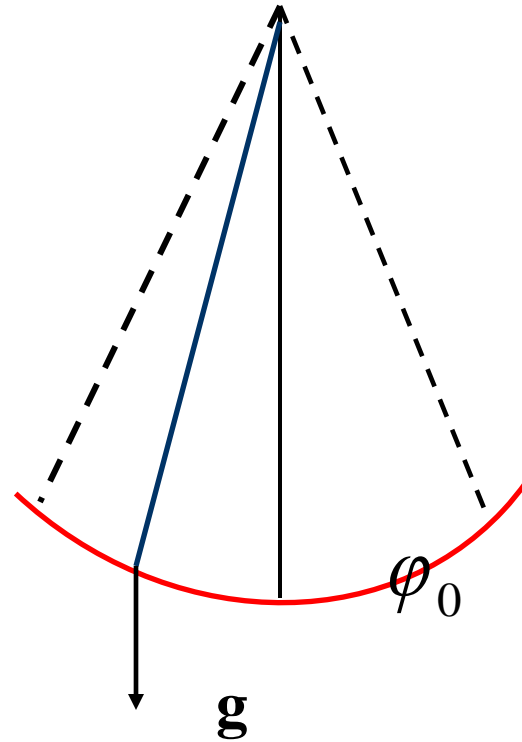
## Gravity: Pendulum.

1. Mathematical Pendulum: point-mass, weightless thread.

$$l\ddot{\varphi} + g \sin \varphi = 0$$

*Period:*

$$T = 2\pi\sqrt{\frac{g}{l}}\left(1 + \frac{\varphi_0^2}{16} + \dots\right), \varphi_0 < 30'$$



## Pendulum at Potsdam, Germany..

Time of oscillation  
depends on gravity.



Lacoste-Romberg gravimeter., p. 185.

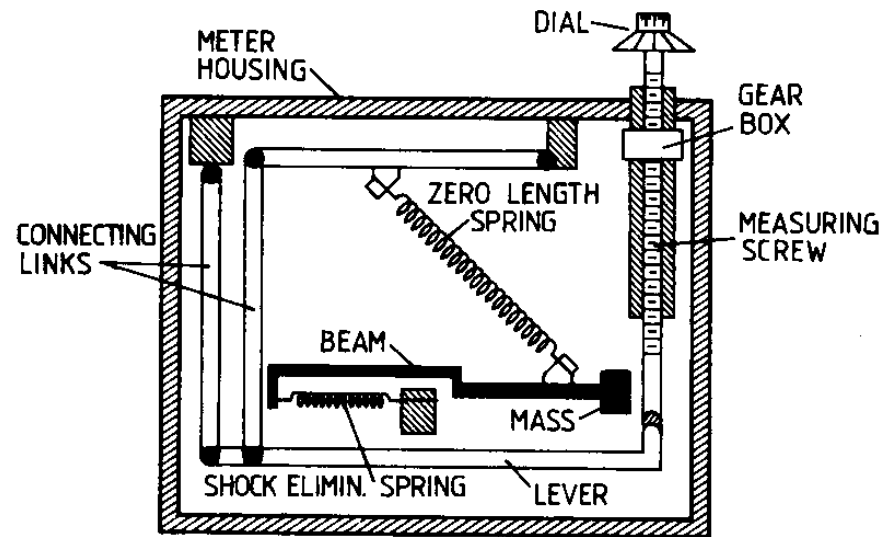
**Astatizing:  $l_0=0$  (0-spring)**

$\delta$  small,  $\alpha \approx 90^\circ$

$a = 0.1 \text{ m}$ ,  $\alpha + \delta = 90^\circ$ ,

$\delta \approx 100''$

*Displacement:  $\pm 2 \mu\text{m}$ .*



**Sensitivity 2000 x larger !!**



Relative gravity measurements at sea or in the air.  
(see Lecture 4.3)

Gyrostabilised board necessary

Spring limited to only move in one plane (direction of movement)

We must take into account the Eötvös effect – which may be determined from position and velocity.

$$g' = \ddot{r}' - R_b^l f^b + (2\omega_{ie}' + \omega_{el}') \times \dot{r}'$$

*Skalar for gyro close to Earth*

$$:\delta g_{Eöt} = 40 \cos \varphi \sin \alpha + 0.012 v^2 \mu m s^{-2}$$

*(v in km / h)*

## Gravity databases.

Globally: Bureau Gravimetrique Internationale

[http://bgi.cnes.fr:8110/bgi\\_f.html](http://bgi.cnes.fr:8110/bgi_f.html)

NGA – USA,

Denmark: DTU-Space. Gravity from Altimetry.

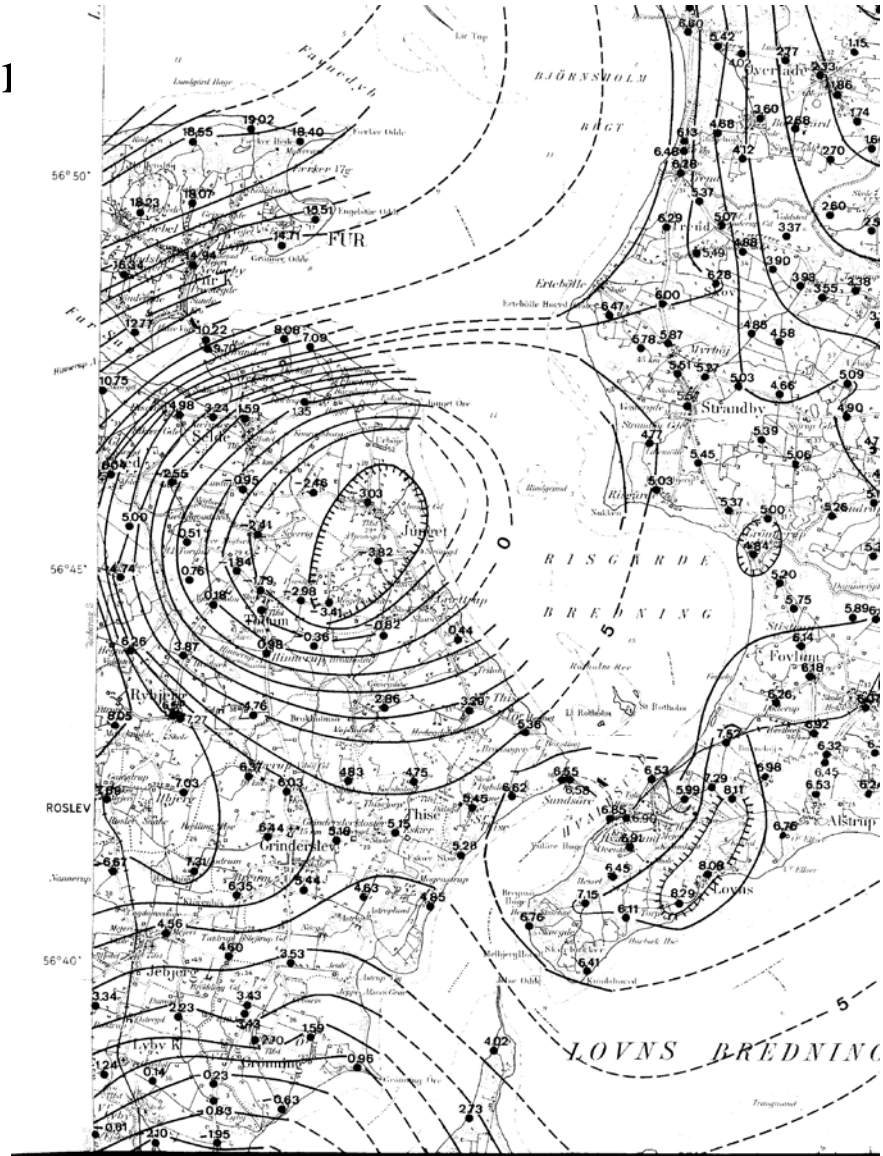
Gravity-data-standard GRAVSOF format:

Latitude, longitude in decimal degrees

height above sea or depth, gravity, gravity anomaly.

Source-code, correction to IGSN71 (if necessary).

# Gravity 1



# Gravity data, example from DK.

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TABLE 9.  
Principal data for detail stations of the Worden gravimeter network in Central Jylland.

Number of Station	Longitude East of Greenwich	Northern Latitude	Height in metres	Normal Gravity in Gals	Observed Gravity in Gals	Bouguer Correction in mGals	Bouguer Anomaly in mGals	Number of Station	Longitude East of Greenwich	Northern Latitude	Height in metres	Normal Gravity in Gals	Observed Gravity in Gals	Bouguer Correction in mGals	Bouguer Anomaly in mGals
	$\lambda$	$\varphi$	$H$	$\gamma_0$	$g$	B.C.	$\Delta g$		$\lambda$	$\varphi$	$H$	$\gamma_0$	$g$	B.C.	$\Delta g$
<b>M 1111</b>								<b>M 1114</b>							
1.....	09°44'18	57°02'21	14.05	981.68527	981.67605	3.16	- 6.06	26.....	09°56'79	57°01'92	38.58	981.68487	981.66975	8.68	- 6.4
2.....	44.77	02.20	6.37	68525	67762	1.43	- 6.20	27.....	58.53	01.81	29.77	68472	67239	6.70	- 5.6
3.....	43.30	02.16	26.05	68520	67383	5.86	- 5.51	<b>M 1114</b>							
4.....	42.73	01.92	19.33	68487	67544	4.35	- 5.08	1.....	10°05'26	57°01'84	2.83	981.68476	981.68255	0.64	- 1.57
5.....	40.86	01.71	2.66	68458	68040	0.60	- 3.58	<b>M 1208</b>							
<b>M 1112</b>								<b>M 1209</b>							
1.....	09°53'44	57°03'10	3.12	981.68649	981.67819	0.70	- 7.60	1.....	09°17'29	56°58'95	3.51	981.68078	981.68177	0.79	+ 1.78
2.....	52.41	02.95	2.51	68629	67804	0.56	- 7.68	2.....	14.95	58.15	1.29	67968	68430	0.29	+ 4.91
3.....	47.63	02.62	1.26	68583	67733	0.28	- 8.22	3.....	17.14	58.10	7.35	67961	67919	1.65	+ 1.23
4.....	49.04	02.60	0.94	68581	67718	0.21	- 8.41	4.....	16.25	58.06	4.19	67955	68136	0.94	+ 2.75
5.....	46.03	02.45	5.02	68560	67726	1.13	- 7.21	5.....	16.57	57.66	8.57	67900	67859	1.93	+ 1.51
6.....	52.55	02.38	14.00	68550	67411	3.15	- 8.24	6.....	14.87	57.60	17.98	67892	67980	4.04	+ 4.92
7.....	51.32	02.32	1.97	68542	67619	0.44	- 8.79	7.....	15.22	57.57	23.85	67888	67772	5.36	+ 4.20
8.....	46.88	02.29	3.82	68538	67686	0.86	- 7.66	8.....	15.85	57.46	28.89	67873	67522	6.50	+ 2.99
9.....	50.63	02.24	1.82	68531	67627	0.41	- 8.63	<b>M 1209</b>							
10.....	48.20	02.08	2.80	68509	67681	0.63	- 7.65	1.....	09°25'94	57°00'65	1.26	981.68312	981.68446	0.28	+ 1.62
11.....	53.59	02.07	29.19	68508	67104	6.56	- 7.47	2.....	25.25	00.50	1.30	68291	68418	0.29	+ 1.56
12.....	48.87	02.03	2.43	68502	67656	0.55	- 7.91	3.....	24.56	00.38	0.94	68275	68442	0.21	+ 1.88
13.....	52.67	01.84	15.74	68476	67282	3.54	- 8.40	4.....	23.07	00.09	1.36	68235	68406	0.31	+ 2.02
14.....	53.82	01.80	55.31	68470	66394	12.44	- 8.33	5.....	21.76	56 59.94	1.73	68214	68323	0.39	+ 1.48
15.....	48.04	01.78	3.77	68468	67689	0.85	- 6.94	6.....	17.86	59.93	4.93	68213	68303	1.11	+ 2.01
<b>M 1113</b>								7.....	20.58	59.81	1.48	68196	68292	0.33	+ 1.29
1.....	10°01'51	57°04'28	1.57	981.68812	981.68461	0.35	- 3.15	8.....	26.07	59.68	5.91	68179	68353	1.33	+ 3.07
2.....	09 58.90	04.08	1.35	68784	68320	0.30	- 4.34	9.....	19.51	59.55	3.31	68161	68206	0.74	+ 1.20
3.....	58.59	03.87	1.87	68755	68249	0.42	- 4.64	10.....	26.43	59.52	15.14	68157	68148	3.40	+ 3.32
4.....	58.04	03.54	2.25	68726	68249	0.42	- 4.64	11.....	25.45	59.47	5.28	68150	68364	1.19	+ 3.33
								12.....	23.32	59.45	1.89	68147	68339	0.43	+ 2.35

## Altimetry databases.

Satellite altimetry:

TU Delft:

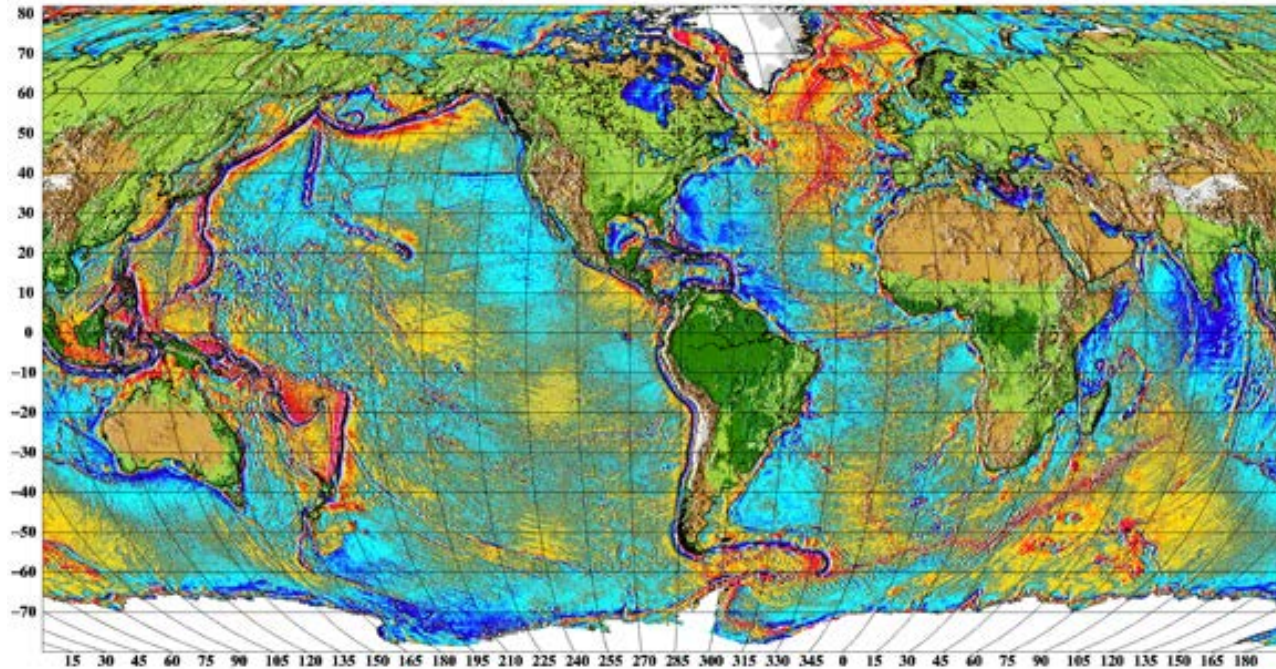
<http://rads.tudelft.nl>

ESA:

<http://earth.esa.int/EOLi/EOLi.html>

# Gravity databases.

**Free Air Gravity Anomalies from Satellite Altimetry**



Source: DTU-Space. Ole Andersen.

## Important databases.

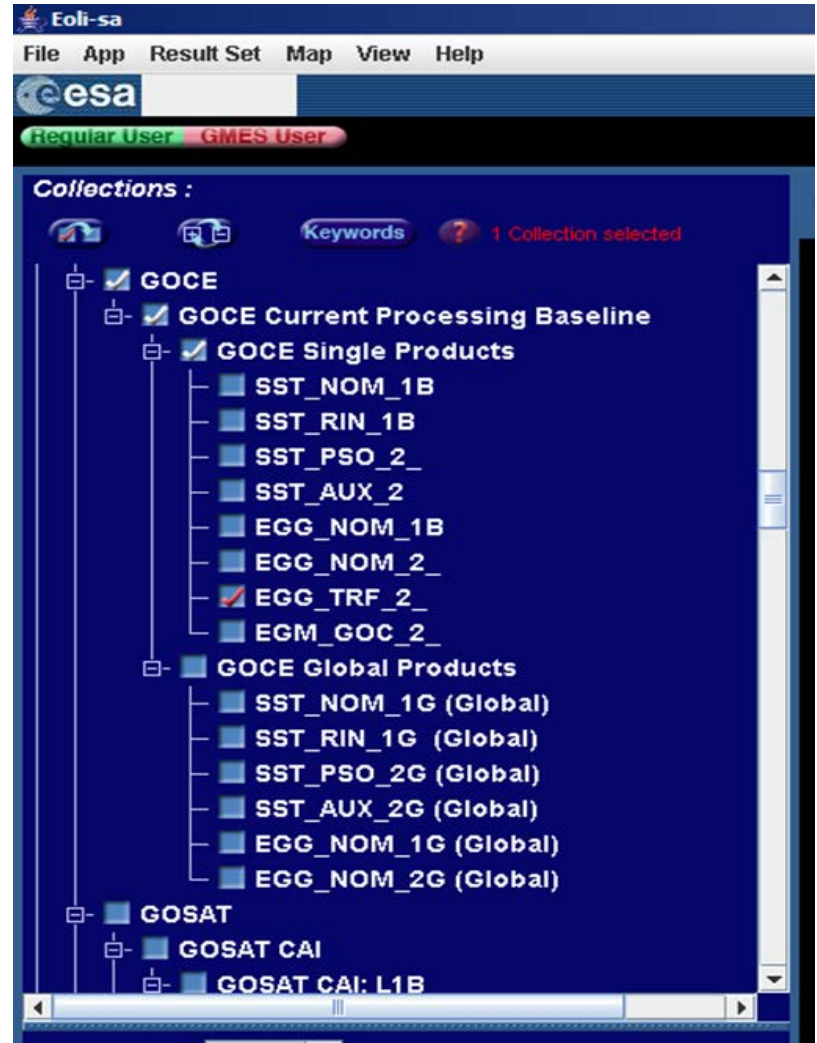
GOCE gradient data:

<http://eo-virtual-archive1.esa.int/Index.html>

<http://earth.esa.int/EOLi/EOLi.html>

<http://earth.esa.int/EOLi/EOLi.html>

<http://earth.esa.int/EOLi/EOLi.html>



# Gravity gradient database.

The screenshot shows the ESA GOCE Virtual Archive website. The page features a navigation menu on the left with categories like 'Home', 'GOCE Level 1b products', 'GOCE Level 2 products', 'GOCE Gravity Models', 'VTGoce Data', 'Thermospheric Data', and 'Changelog'. The main content area is titled 'Available Global GOCE Gravity Models' and contains a table with three rows of data. Below this is another section titled 'Available L1b and L2 GOCE single Products' with a larger table listing various instruments (EGG, SST, STR) and their corresponding products and descriptions. A visitor counter at the bottom left shows 2,353 visitors from Oct 2011 to Oct 2012. A footer note directs users to the GOCE main website for quality reports and software tools.

### Available Global GOCE Gravity Models

Product	Description
EGM_GOC_2	GOCE Gravity solution. Solutions are available up to Third Generation, with three different processing techniques: direct numerical solution, time-wise and space-wise solutions.
EGM_GVC_2	Variance/covariance matrices associated to the Gravity solutions. Available only through the Virtual Online Archive.
EGM_GCF_2	Gravity Coefficients (ICGEM format)

### Available L1b and L2 GOCE single Products

Instrument	Level	Product	Description
EGG	L1b	EGG_NOM_1b	Nominal Gradiometer instrument data
		EGG_NOM_2	Calibrated and corrected gravity gradients in the gradiometer reference frame
	L2	EGG_TRF_2	Calibrated and corrected gravity gradients in the terrestrial reference frame
		EGG_DLK_2i	Gradiometer error Power Spectral Density estimated from Quick-Look gravity solutions
SST	L1b	SST_NOM_1b	Nominal SSTI instrument (GPS) data
		SST_RIN_1b	Nominal SSTI instrument (GPS) data in RINEX format
	L2	SST_PSO_2	Precise Science Orbits
		SST_AUX_2	Time variable gravity field due to non-tidal mass variations
STR	L1b	STR_VC2_1b	Star Tracker Data-Virtual Channel #2
		STR_VC3_1b	Star Tracker Data-Virtual Channel #3

For all data published on this site, quality reports, software tools and other relevant information, please see the GOCE main website: <http://earth.esa.int/GOCE/>



## GRACE database.

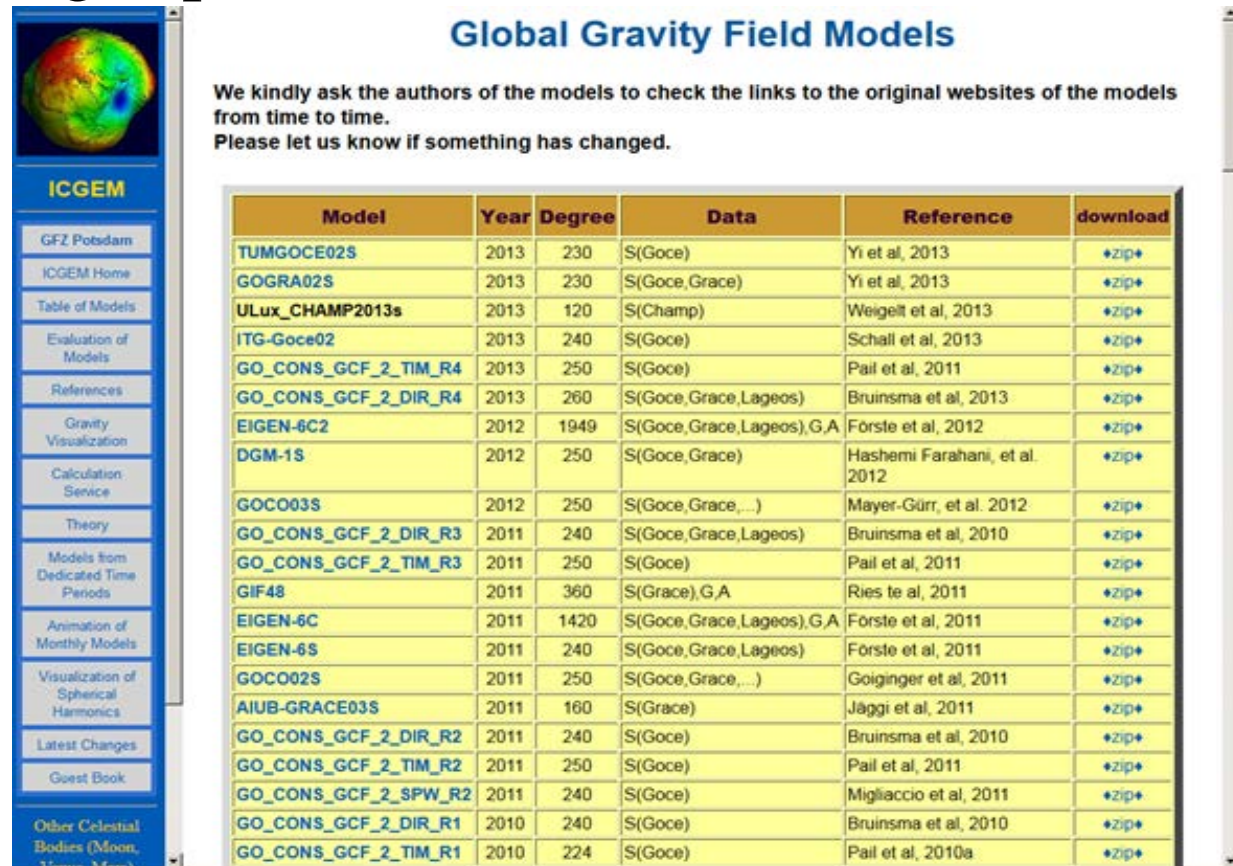
GRACE L1b data.

<http://podaac.jpl.nasa.gov/gravity/grace-documentation>

## Gravity model database.

Spherical harmonic coefficients:

<http://icgem.gfz-potsdam.de/ICGEM/>



**Global Gravity Field Models**

We kindly ask the authors of the models to check the links to the original websites of the models from time to time.  
Please let us know if something has changed.

Model	Year	Degree	Data	Reference	download
TUMGOCE02S	2013	230	S(Goce)	Yi et al, 2013	+zip+
GOGRA02S	2013	230	S(Goce,Grace)	Yi et al, 2013	+zip+
ULux_CHAMP2013s	2013	120	S(Champ)	Weigelt et al, 2013	+zip+
ITG-Goce02	2013	240	S(Goce)	Schall et al, 2013	+zip+
GO_CONS_GCF_2_TIM_R4	2013	250	S(Goce)	Pail et al, 2011	+zip+
GO_CONS_GCF_2_DIR_R4	2013	260	S(Goce,Grace,Lageos)	Bruinsma et al, 2013	+zip+
EIGEN-6C2	2012	1949	S(Goce,Grace,Lageos),G,A	Förste et al, 2012	+zip+
DGM-1S	2012	250	S(Goce,Grace)	Hashemi Farahani, et al. 2012	+zip+
GOCO03S	2012	250	S(Goce,Grace,...)	Mayer-Gürr, et al. 2012	+zip+
GO_CONS_GCF_2_DIR_R3	2011	240	S(Goce,Grace,Lageos)	Bruinsma et al, 2010	+zip+
GO_CONS_GCF_2_TIM_R3	2011	250	S(Goce)	Pail et al, 2011	+zip+
GIF48	2011	360	S(Grace),G,A	Ries et al, 2011	+zip+
EIGEN-6C	2011	1420	S(Goce,Grace,Lageos),G,A	Förste et al, 2011	+zip+
EIGEN-6S	2011	240	S(Goce,Grace,Lageos)	Förste et al, 2011	+zip+
GOCO02S	2011	250	S(Goce,Grace,...)	Goiginger et al, 2011	+zip+
AIUB-GRACE03S	2011	160	S(Grace)	Jäggi et al, 2011	+zip+
GO_CONS_GCF_2_DIR_R2	2011	240	S(Goce)	Bruinsma et al, 2010	+zip+
GO_CONS_GCF_2_TIM_R2	2011	250	S(Goce)	Pail et al, 2011	+zip+
GO_CONS_GCF_2_SPW_R2	2011	240	S(Goce)	Migliaccio et al, 2011	+zip+
GO_CONS_GCF_2_DIR_R1	2010	240	S(Goce)	Bruinsma et al, 2010	+zip+
GO_CONS_GCF_2_TIM_R1	2010	224	S(Goce)	Pail et al, 2010a	+zip+

## Topography databases.

<http://www2.jpl.nasa.gov/srtm/>

Only topography !

[http://topex.ucsd.edu/WWW\\_html/srtm30\\_plus.html](http://topex.ucsd.edu/WWW_html/srtm30_plus.html)

Topography and bathymetry.