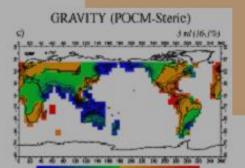
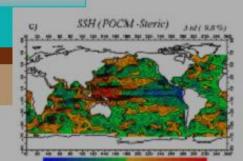


第11回森羅万象学校 「リモートセンシングは地球をどこまで斬ったか」 休暇村支笏湖·2011年2月13-14日

地上および衛星重力測定による 変動モニタリング(2)

地球惑星科学真攻 福田洋





内容2(14日午前)

✓地上での重力測定

- ・ 重力計の原理
- 超伝導重力計の応用
- 野外重力測定

✓ 衛星高度計

- 衛星高度計の原理
- ・ 海域の重力場
- 海面形状とGOCE
- 海水準変動

✓展望

- 精密測位による地球環境監視
- 将来ミッション

重力計測定の分類

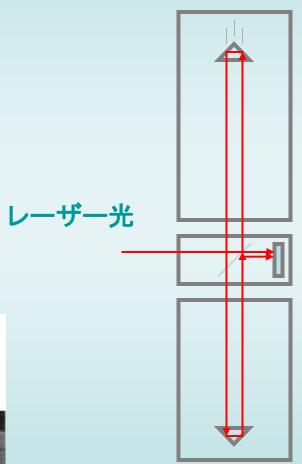
- 絶対測定 自由落下、投げ上げ 原子干渉
- 一定点(連続観測)超伝導、バネ

相対測定バネ、弦、加速度センサー 超伝導 - 可搬型 屋内、野外、海底

- 動体上 潜水艦、船上、航空機

絶対重力計

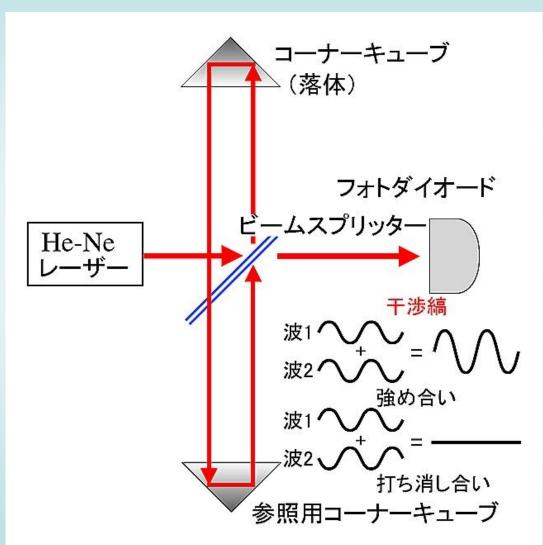


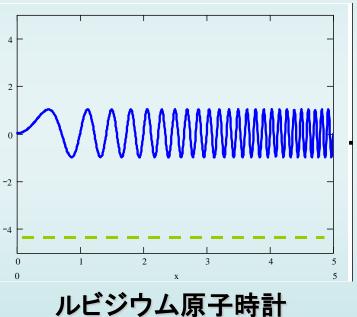




絶対重力計

マイケルソン干渉計





絶対重力計

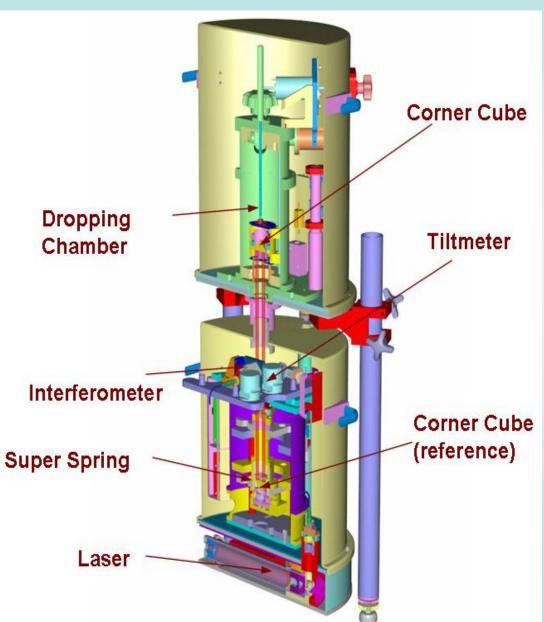




FG-5

A-10

A10野外用絶対重力計

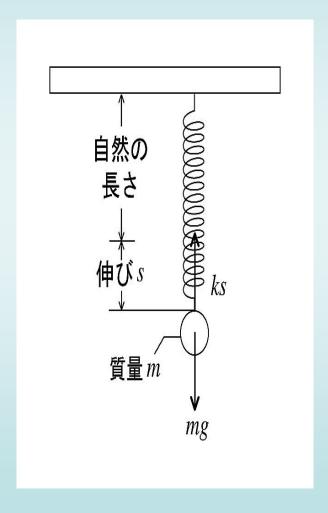




A-10

相対重力測定

重力差 時間変化



ラコスト重力計



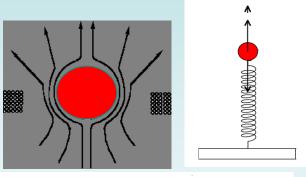
超伝導重力計

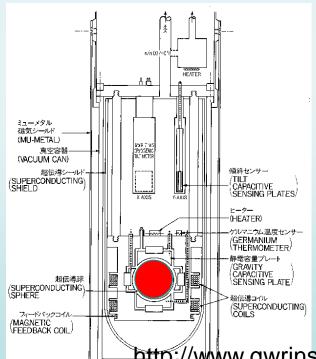
Superconducting Gravimeter



~1ngal

≒ 3μ





http://www.gwrinstruments.com/photos/osg/obsspecs.pdf

超伝導重力計の変遷



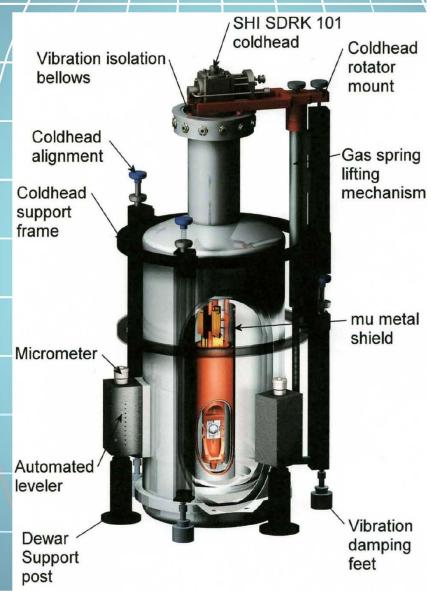








新超伝導重力計





INTRODUCING THE NEW



SIMPLIFIED SUPERCONDUCTING GRAVIMETER FOR PORTABLE OPERATION



iGray™ FEATURES

Superconducting persistent currents (i) produce the most stable relative gravity meter in existence.

• Super stable: Drift less than 0.5 μGal/month

Scale factor constant to better than 1 part in 10⁴ for years!

Super precise: 1 nanoGal (10⁻³ µGal) in frequency domain

0.05 µGal in the time domain for 1 minute averaging

Super low noise: 0.3 μGal/(Hz)^{1/2}

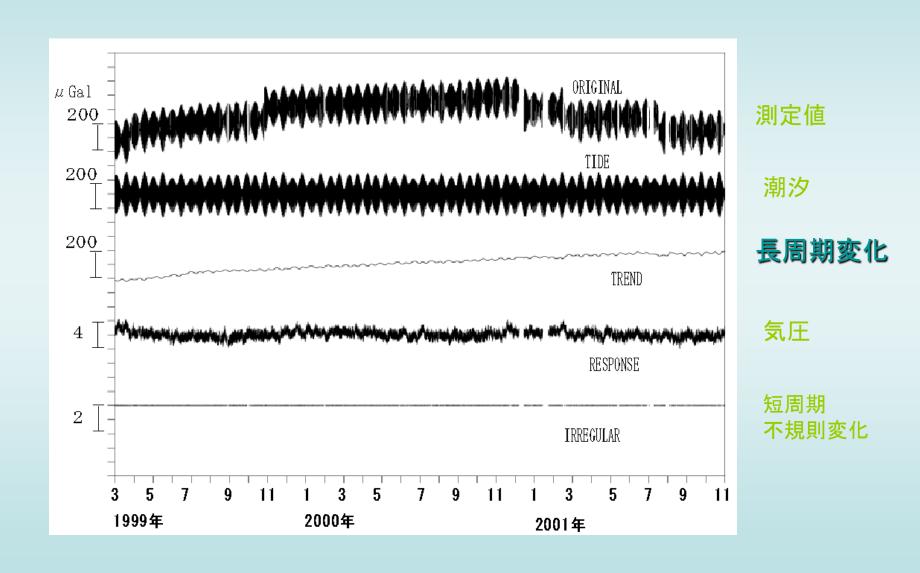
重力時間の原因

- 超短周期 < 1 時間: 地震, 地球の固有振動, 大気, 陸水
- 短周期,1 時間 1日: 潮汐,海洋荷重変化,内核の並進運動,コアモード, 自由コア衝動,大気,陸水
- 中間周期, 1日-1年: 潮汐, 海洋荷重変化, 海洋ダイナミクス,大気, 陸水
- 長周期 > 1 年: 海洋荷重変化,極運動,海水準変動,テクトニクス, 大気,陸水

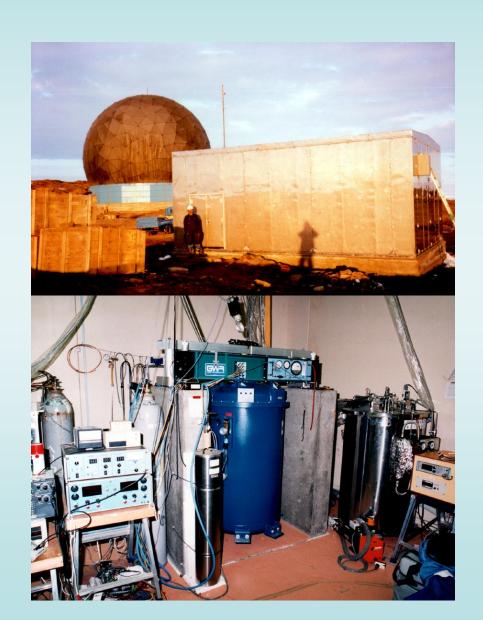
超伝導重力計の応用

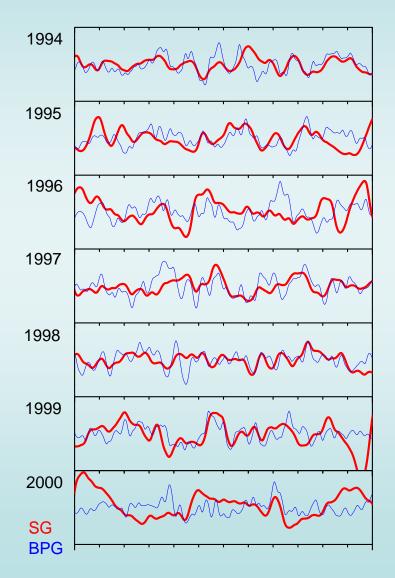
海洋荷重変動 GRACEとの比較

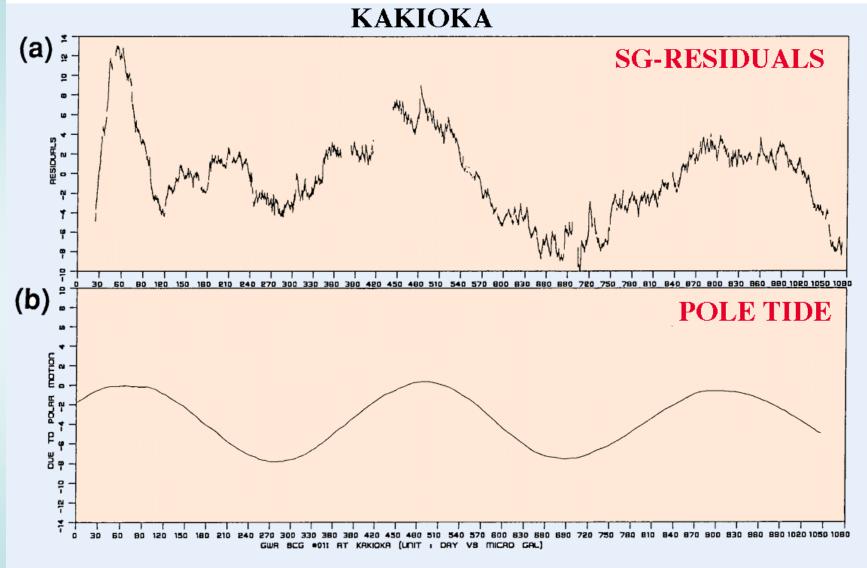
超伝導重力計観測データの例



南極昭和基地での超伝導重力観測

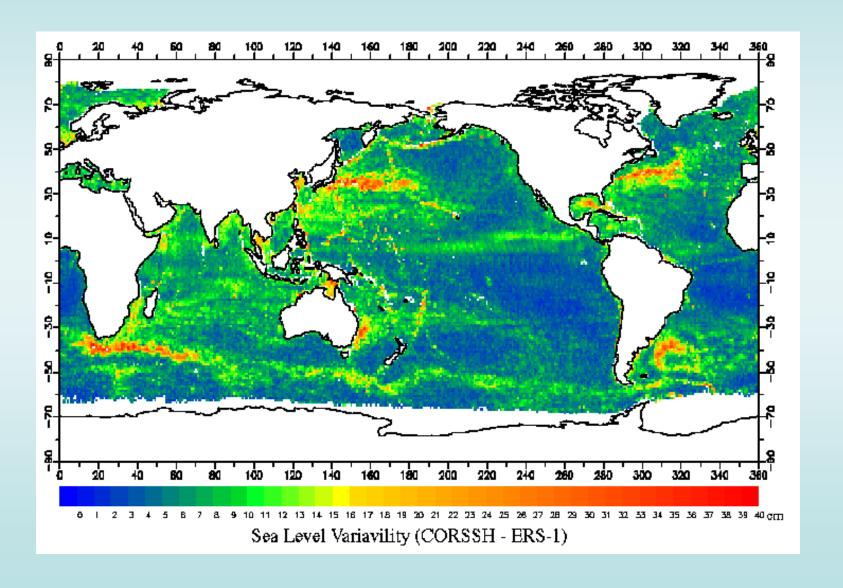


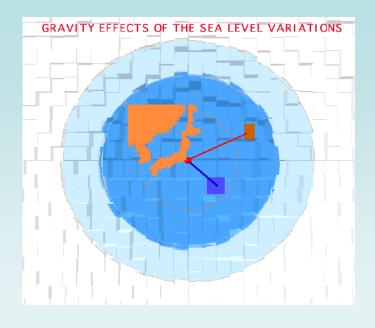


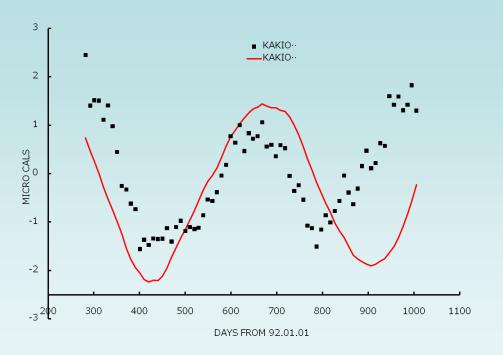


 $\sigma = 1.35 \pm 0.20$ (after Seama et al., 1993)

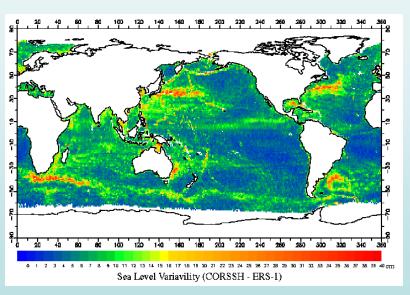
海面高度計による海面高の変化

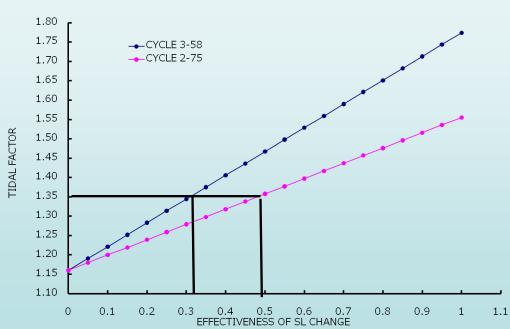


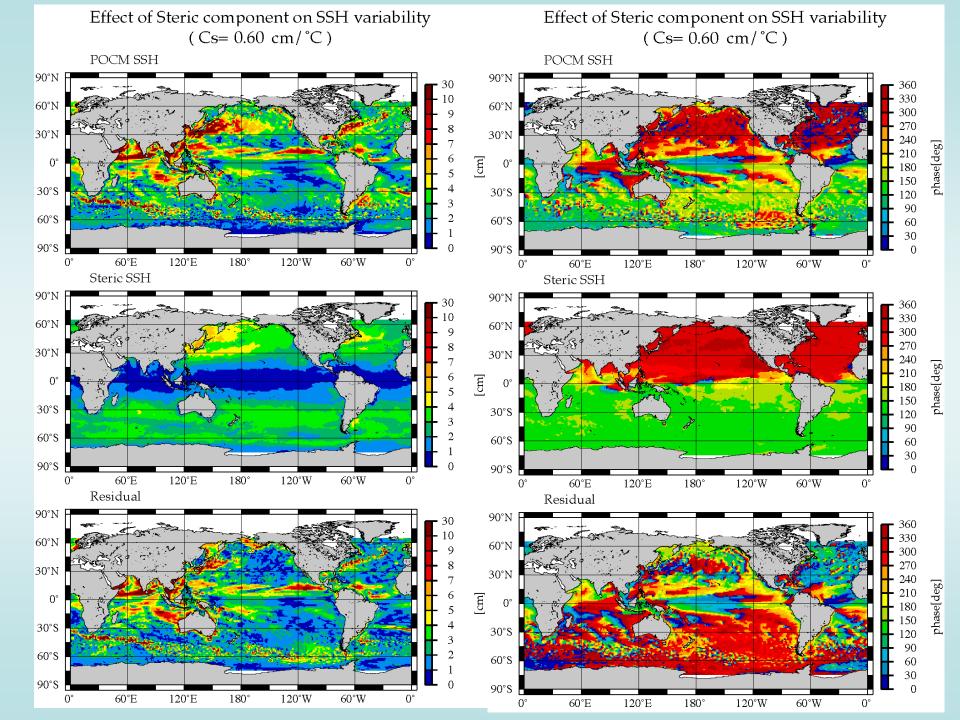




EFFECTS OF SL CHANGES ON POLE TIDE AT KAKIOKA







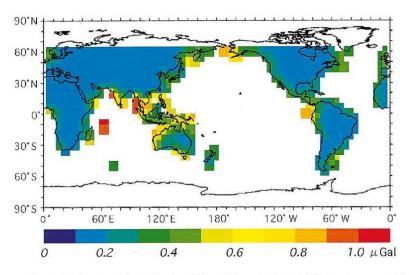


Fig. 4. Variability of the annual gravity changes induced by the SSH variations. This variability was computed based on the POCM SSH data which were corrected for the steric effect using the coefficient of 0.60×10^{-2} m/°C.

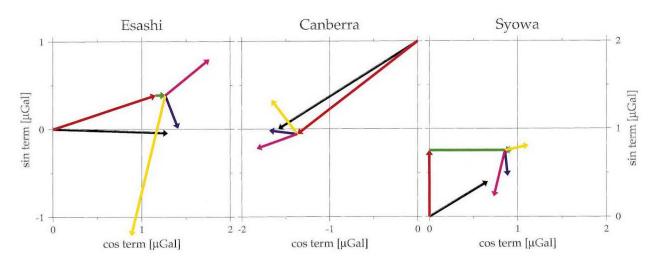
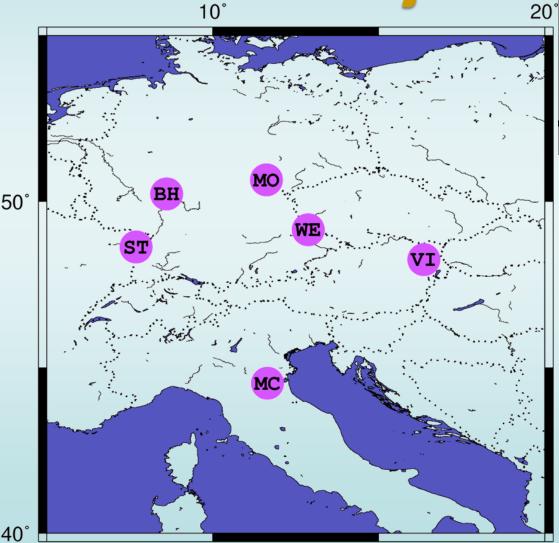


Fig. 5. Phasor plots of the observed annual components and predicted ones. The horizontal and vertical axes correspond to the cosine and sine terms, respectively. The phase angle of each vector is referred to an analysis epoch of $00.00\,h$ UTC, 1 January 2000, and the angle is measured from the cosine axis, counter clockwise for a lag. From the left, the results for Esashi, Canberra and Syowa are displayed, respectively. The three vectors of black, red and green show the observation, the polar motion effect and the effect of solid tide, respectively. The effects of the Sa ocean wave are very small to display with the scale of this plot. Its effect is only displayed in the plot for Syowa as the small vector picked with white seeing at the top of the solid tide vector. The three vectors of yellow, blue and pink show the effect of SSH variations evaluated using the steric coefficients of 0.0×10^{-2} , 0.60×10^{-2} and $1.0 \times 10^{-2}\,\text{m/°C}$, respectively.

GGP Satellite Project





50°

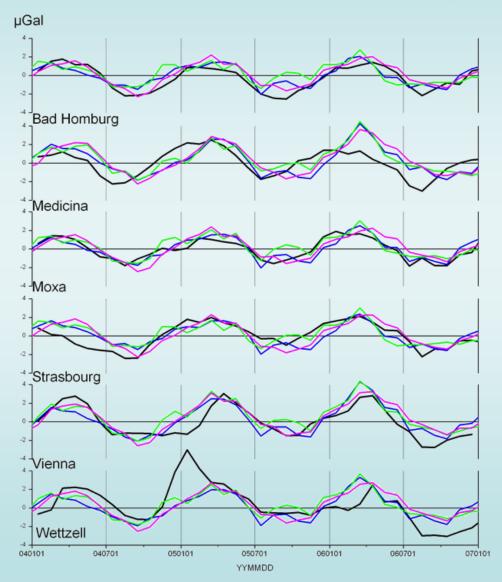
ローカルな影響を除いたSGデータで GRACEデータの検証を行う

40°

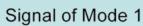
SG残差時系列との比較

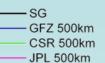
SG — SFZ 500 km — CSR 500 km — JPL 500 km

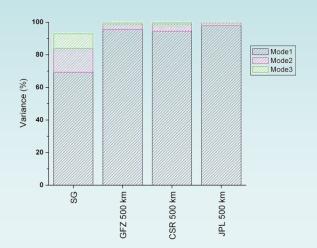
EX.
GRACE solutions:
GFZ
JPL
CNES/GRGS

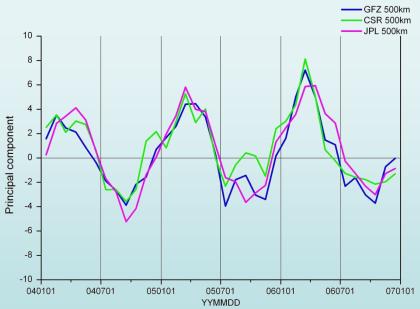


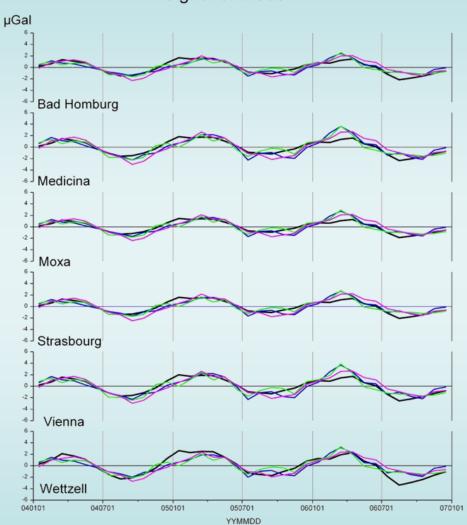
EOF Mode 1





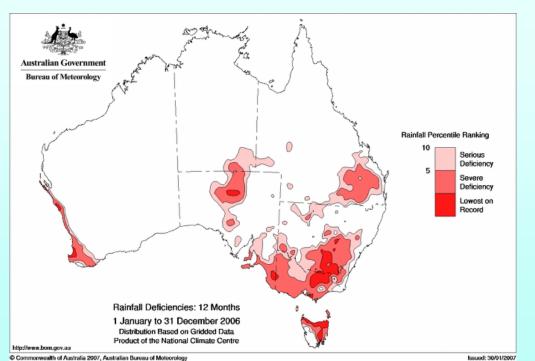






2006年オーストラリアの大干ばつ

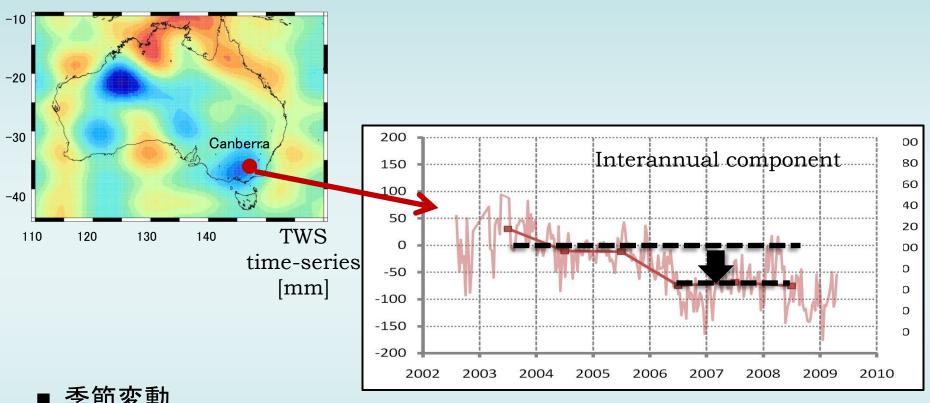
- Australia suffered historic drought due to rainfall deficiency in 2006
- BoM (Australian Government Bureau of Meteorology) reported that, in the historical record dating from 1900,
 - the driest August to November period averaged across south Australia,
 - the second driest averaged over the Murray Darling Basin, and
 - the third driest across Australia and the fourth driest for Victoria.





Rainfall Percentile Ranking (2006 – I2 months) BoM drought Statement, (2006 Dec.)

GRACEによるキャンベラのTWS変化



- 季節変動
 - → 降雨と良く合う
- 経年変化
 - → 2006年の干ばつによるTWS減少が回復しない



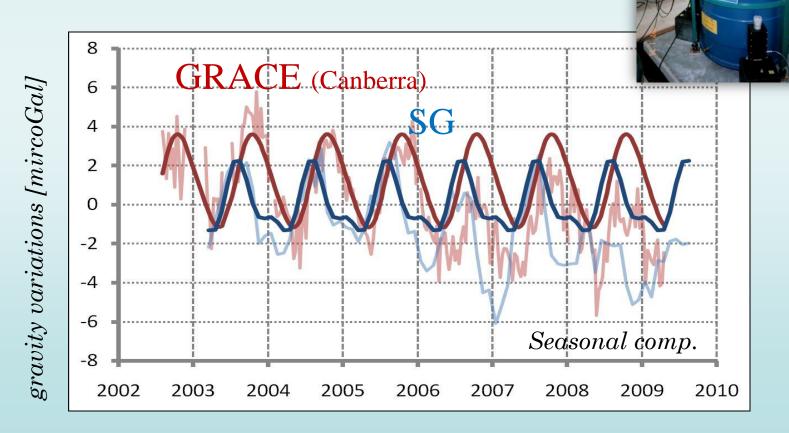
GRACEとSGの比較

SG data Correction Atmosphere

Tide (Solid earth, Ocean, Pole)

Height changes

Mechanical drift



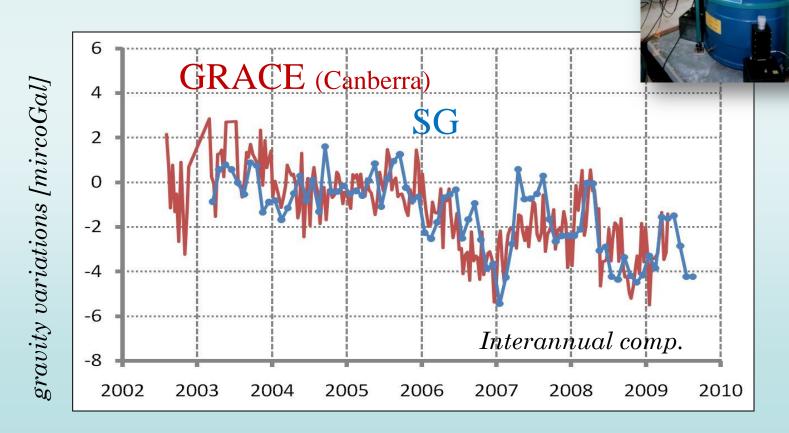
GRACEとSGの比較

SG data Correction Atmosphere

Tide (Solid earth, Ocean, Pole)

Height changes

Mechanical drift



野外重力測定 地下水変動と地盤沈下

地下水変動と重力変化

 $\Delta g \text{ (mgal)} = (-0.3086 + 2\pi G \delta \rho) \delta h \text{ (meter)} + 2\pi G P_e \delta_{qwl} \text{ (meter)}$

300μgal (10nm/s²) / meter 40μgal (10nm/s²) / meter

δh :高さ変化 δρ : 密度差

: 地下水位変化 :有効空隙率

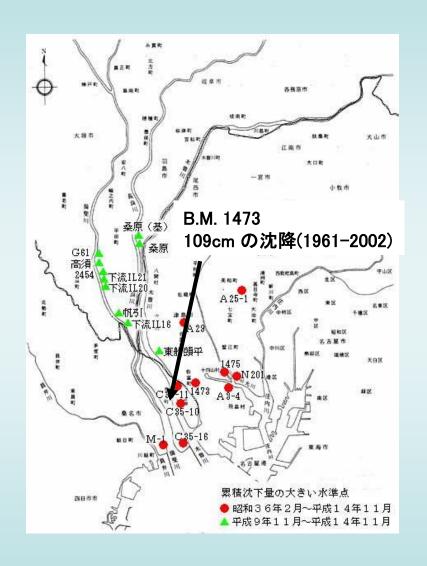
:万有引力定数

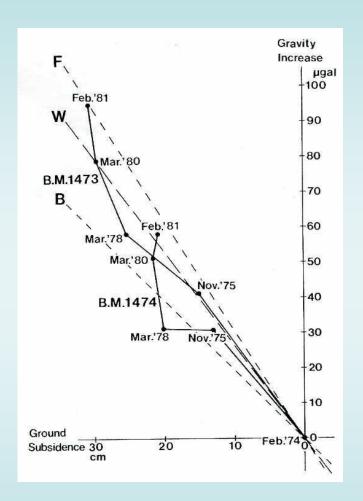


Attraction increases

Ground Water

地下水くみ上げによる地盤沈下と重力変化

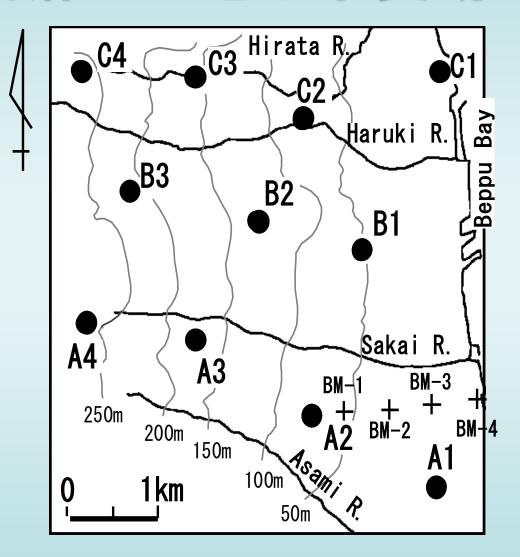




愛知県十四山(じゅうしやま)村(現:弥富市)での地下水くみ上げによる地盤沈下に伴う重力変化の例(Satomura, 1985)

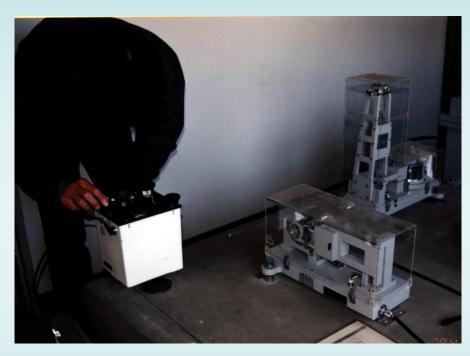
国土交通省中部地方整備局

別府での地下水変動と重力変化





(相対)重力測定





大分気象台 一等重力点

地球熱学研究施設

地下水位変化と重力変化

ref

C4

C3

C2

C1

B3

B2

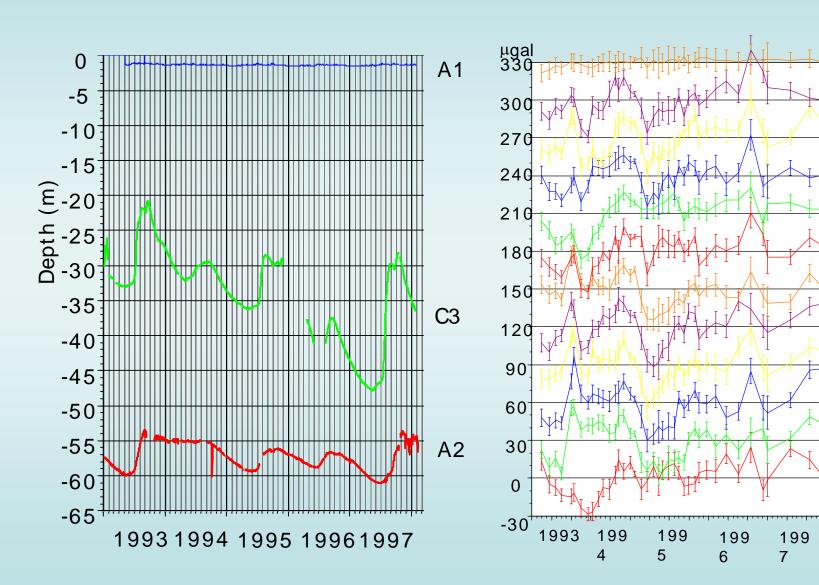
B1

A4

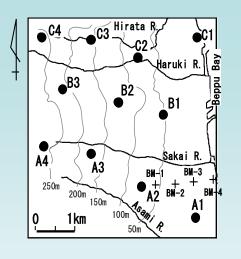
А3

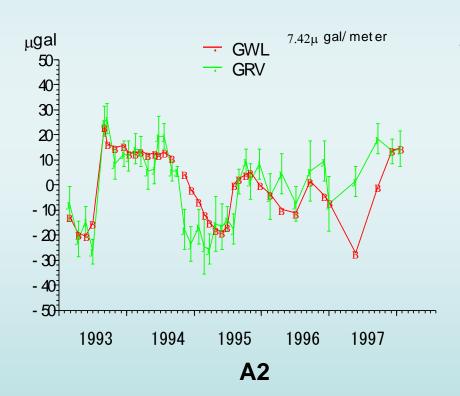
A2

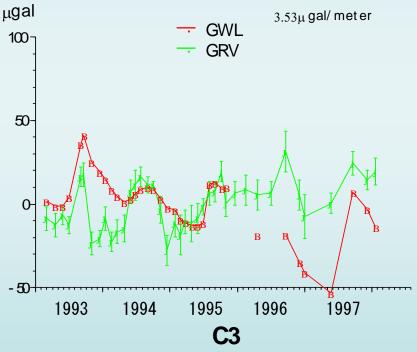
A1



重力変化と水位変化







A10 絶対重力計

- A10特徵
 - バッテリー駆動による屋外での測定
 - 取り扱いが簡単
 - 短い測定時間(1drop/1秒、100drop/1set, 10set)
 - 精度は10 µGal

. . . .

• 課題

- ノイズの大きな都市での測定
- 柔らかな堆積層
- 高温・多湿な環境



野外測定

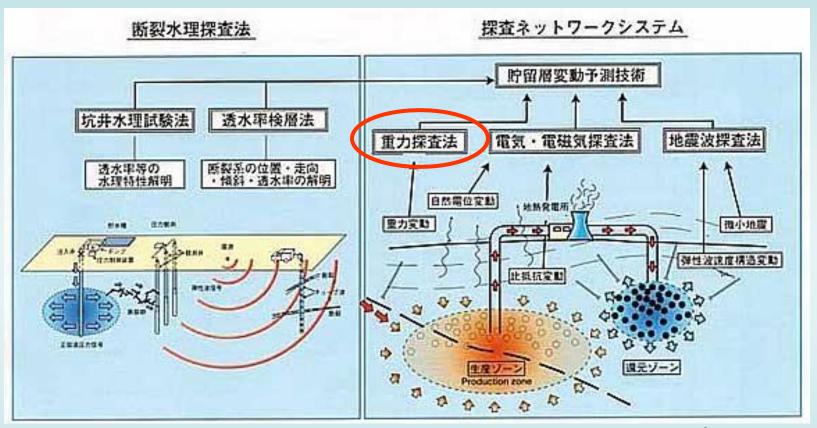








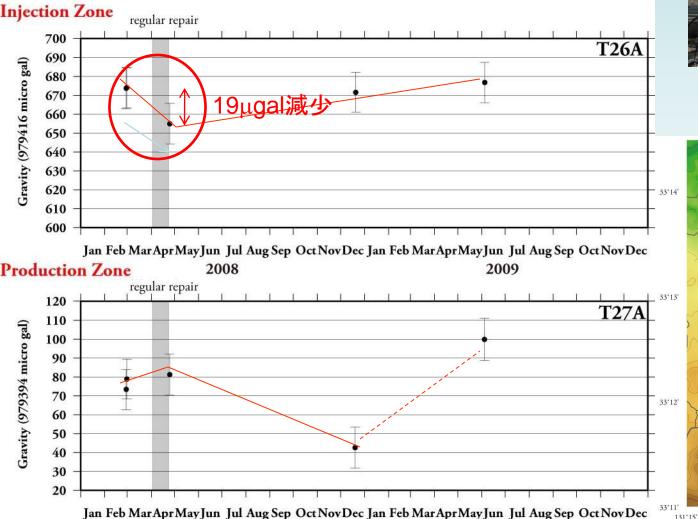
貯留層変動探査法開発



NEDO h9-13プロジェクト

http://www.nedo.go.jp/enetai/chinetsu/monitor/index.htm

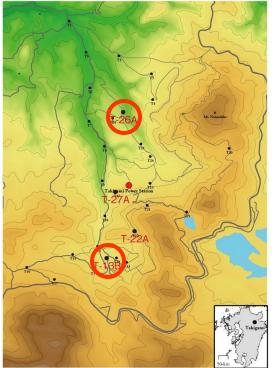
滝上地熱発電所周辺での測定



2009

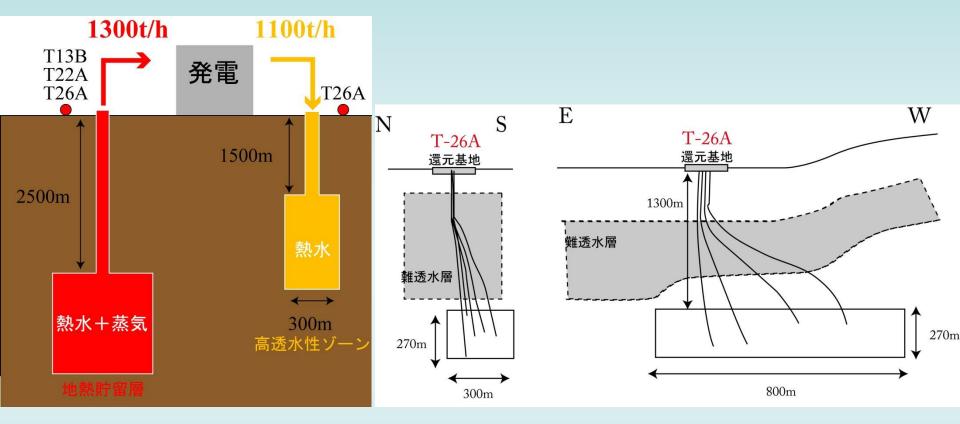
2008





131°17'

還元井での質量バランス



メンテナンス前後の重力変化量: -19μgal

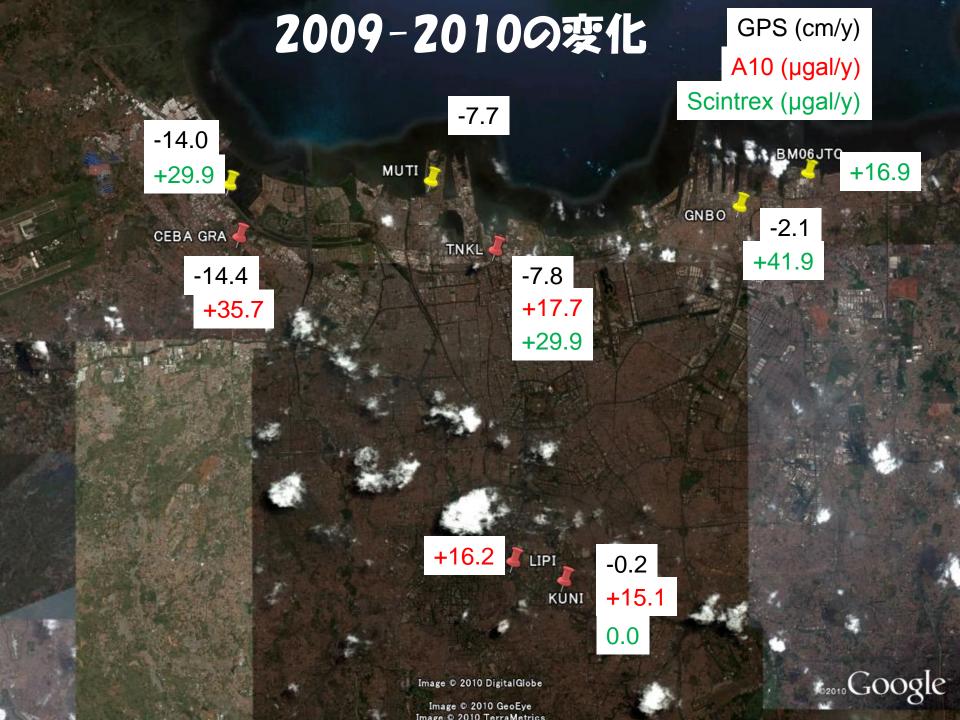
メンテナンス期間中(約20日間)の流出: 0.6Mt

1時間あたりに換算すると1260t

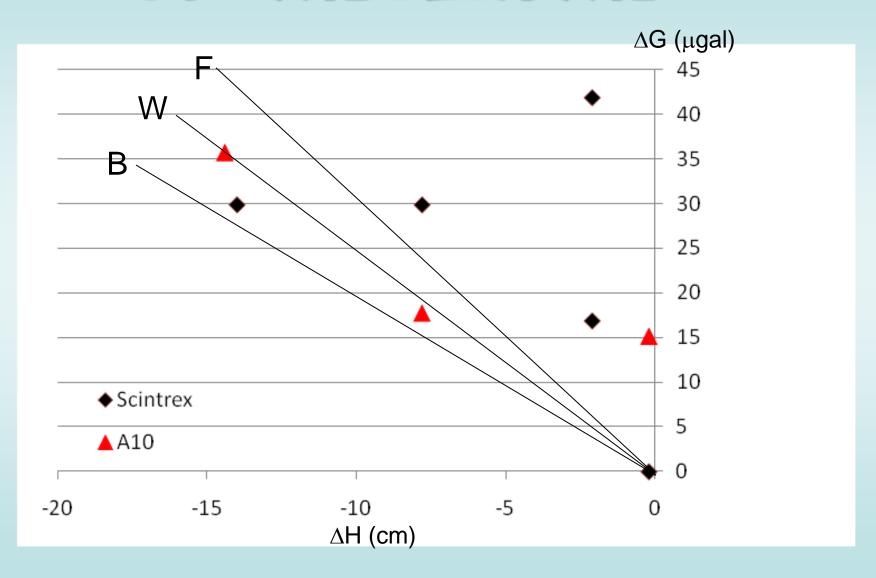
実際に還元している量(1100t/h)とほぼ同量







高さ変化と重力変化



内容2(14日午前)

✓地上での重力測定

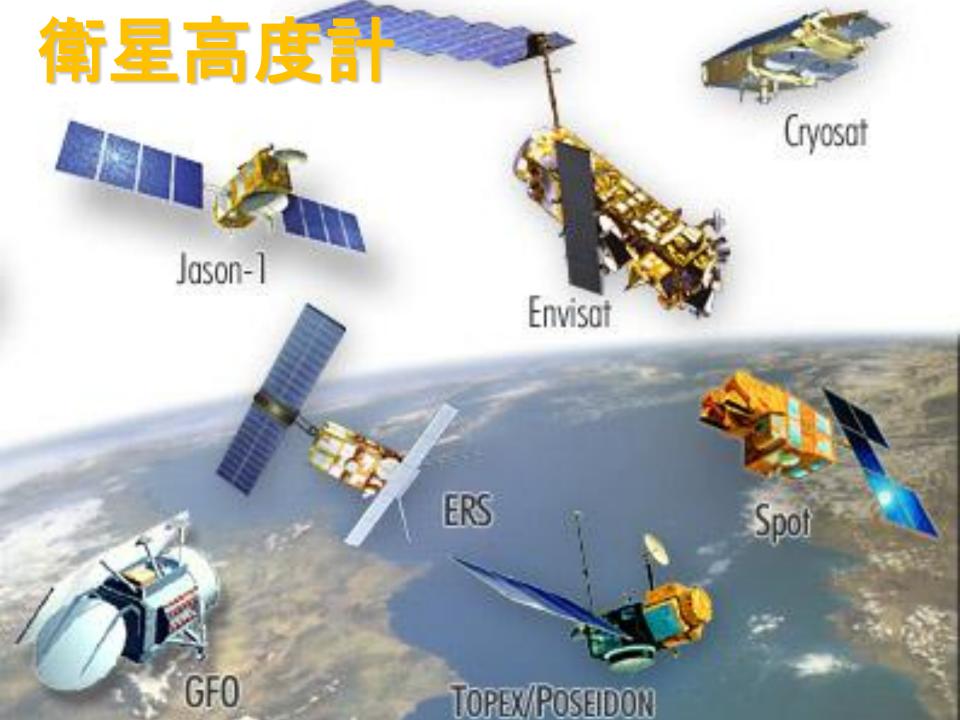
- ・ 重力計の原理
- 超伝導重力計の応用
- 野外重力測定

✓ 衛星高度計

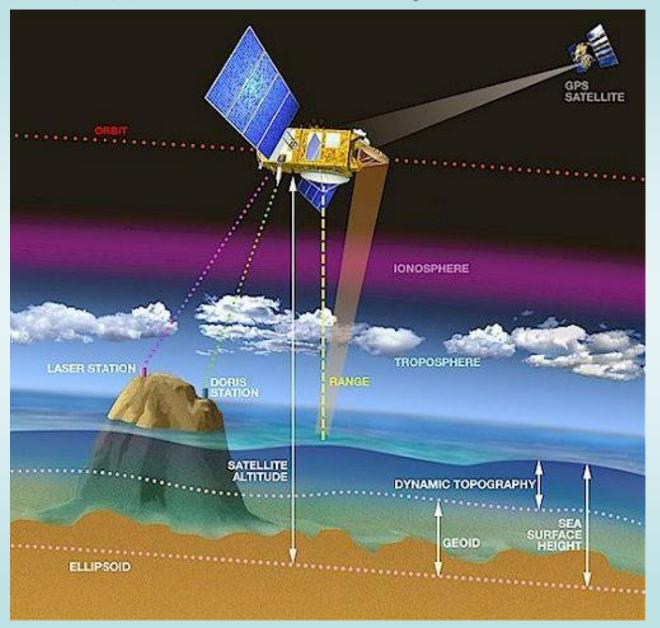
- 衛星高度計の原理
- ・ 海域の重力場
- 海面形状とGOCE
- 海水準変動

✓展望

- 精密測位による地球環境監視
- 将来ミッション

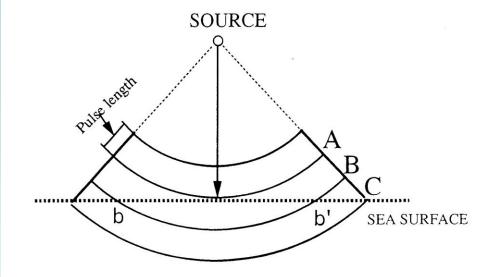


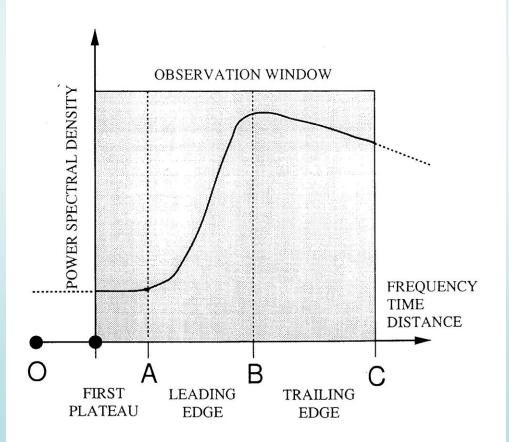
衛星高度計(Satellite Altimetry)



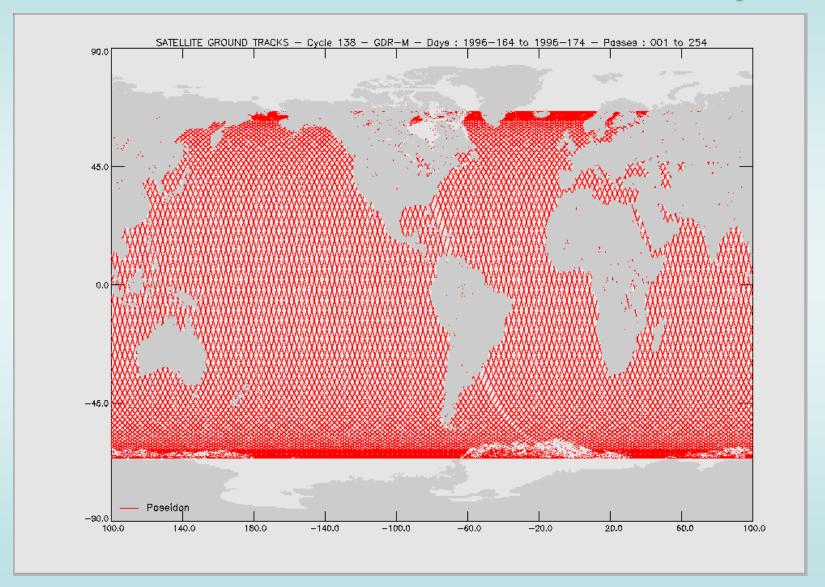
http://www.aviso.oceanobs.com/en/altimetry/principle/basic-principle/index.html

マイクロ波 レーダー による測距



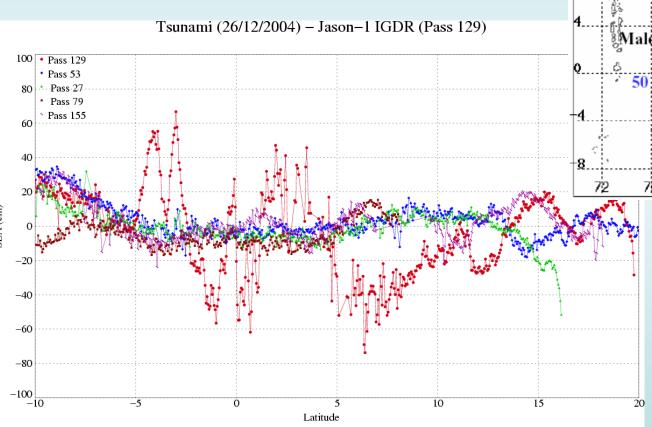


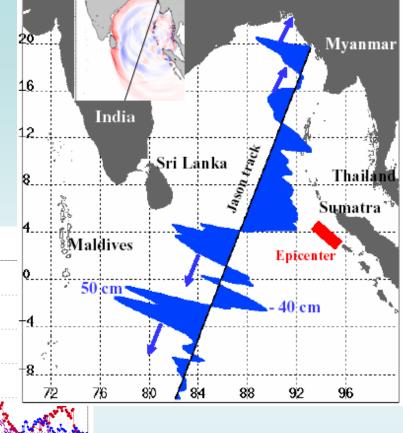
衛星の軌跡(T/P,Jason-1)



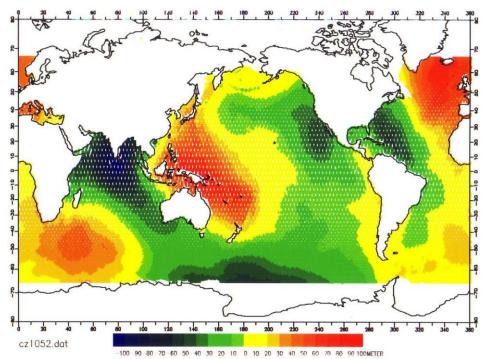
http://www.jason.oceanobs.com/html/actualites/applis/welcome_uk.html

26 Dec. 2004 Tsunami measured by Jason-1



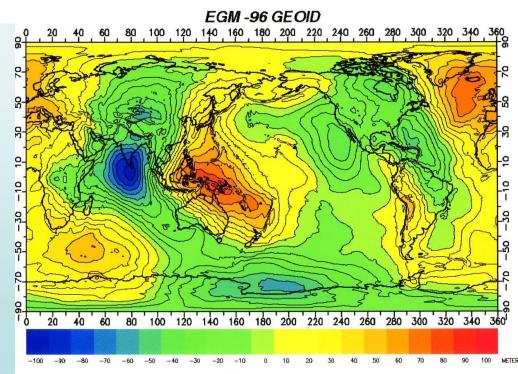




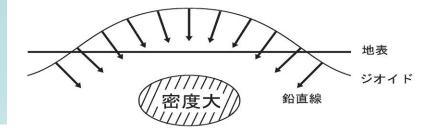


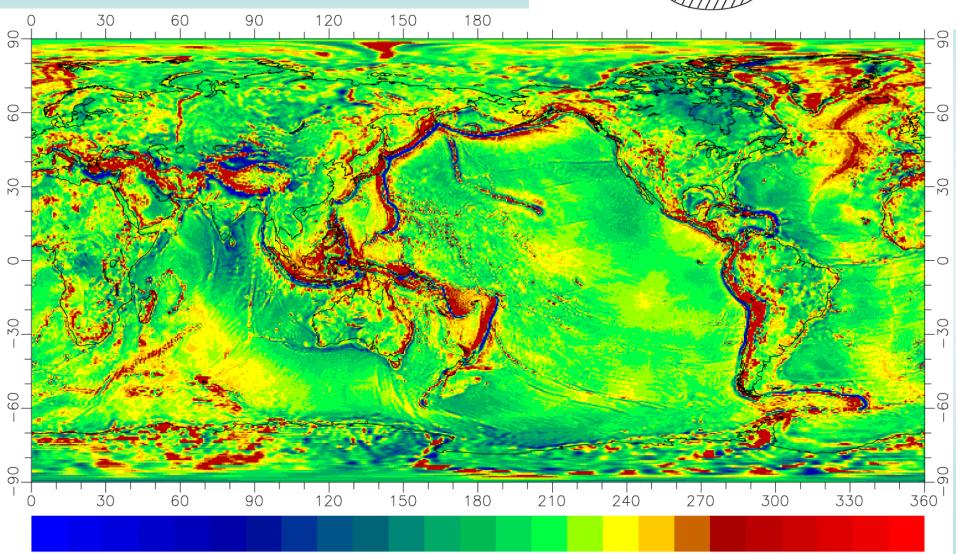
T/P Sea Surface Heiht (h)

EGM-96 GEOID



ジオイドと重力異常

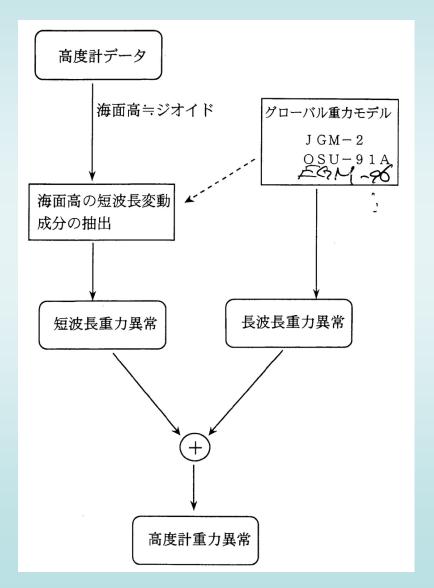




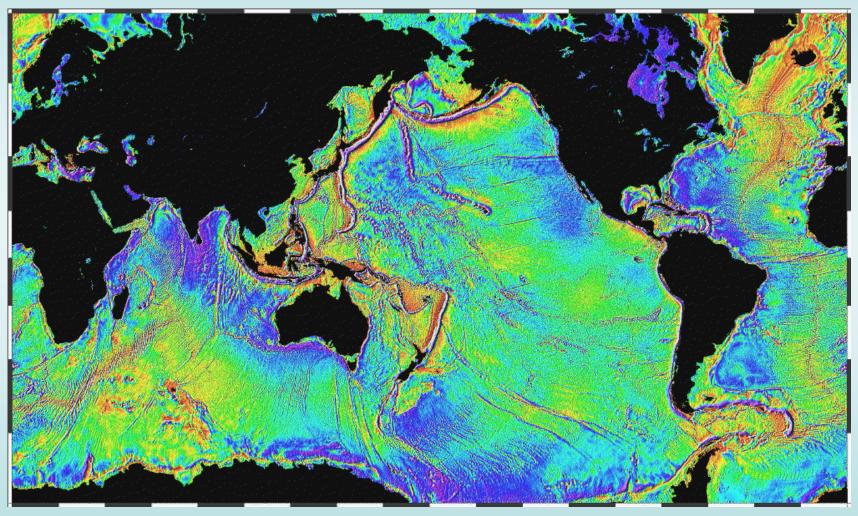
-300mgal

+300

高度計データによる重力異常

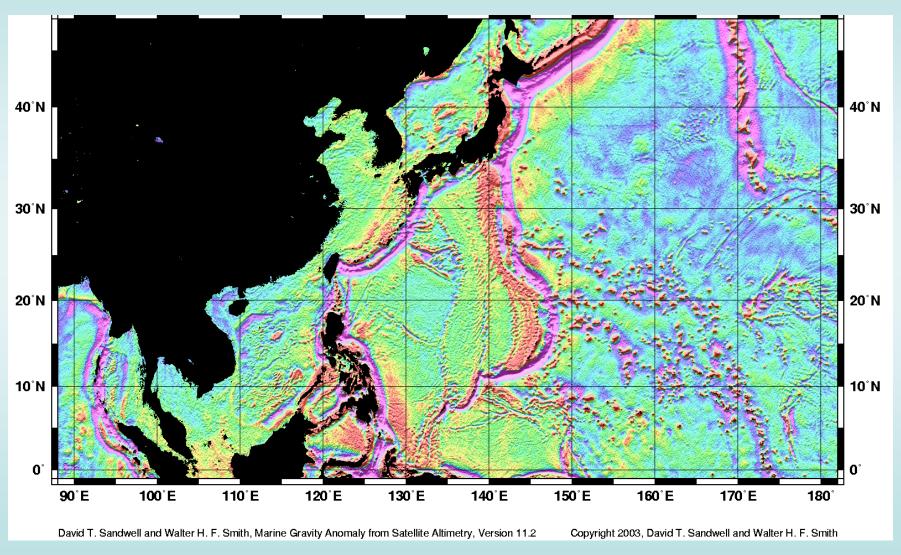


海洋の重力異常

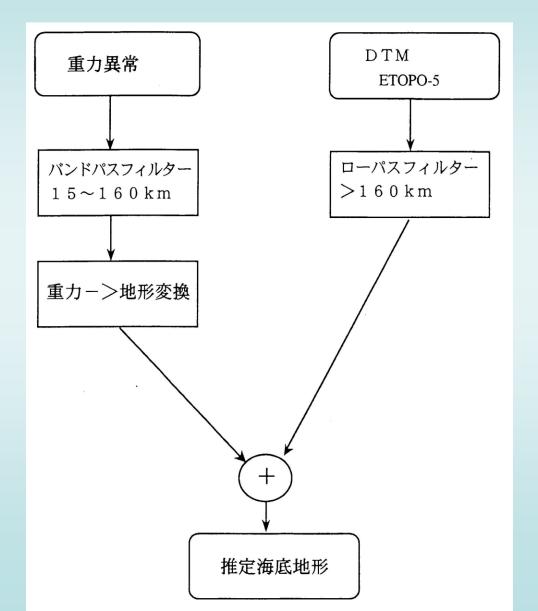


http://topex.ucsd.edu/marine_grav/mar_grav.html

日本近海の重力異常

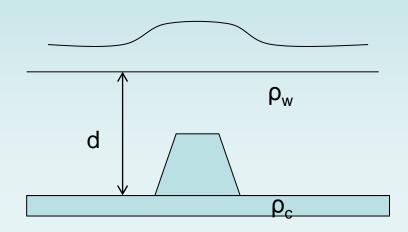


重力異常からの海底地形の推定

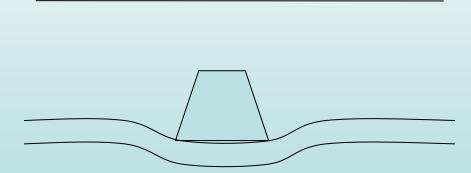


海底地形の推定

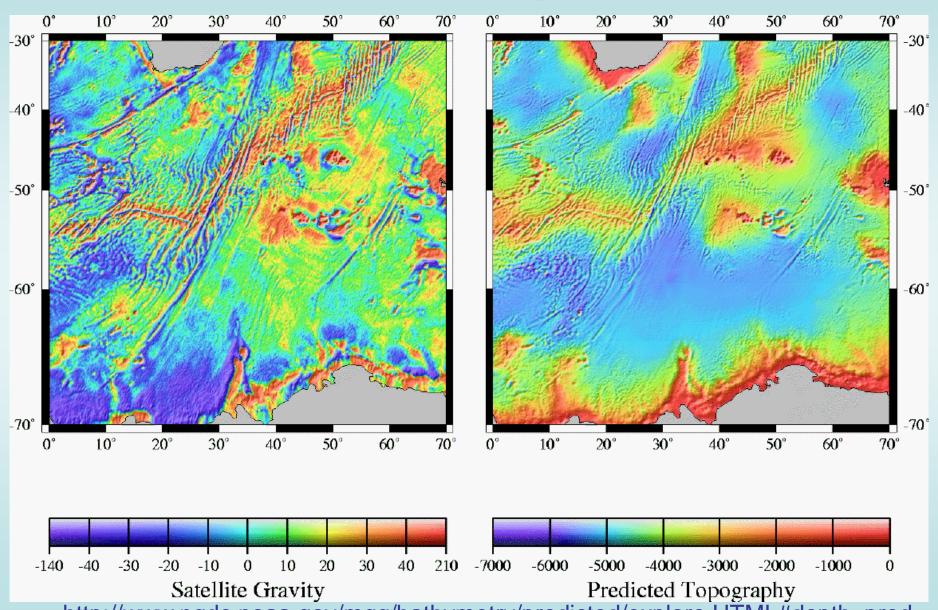
簡単な場合:



一般の場合:

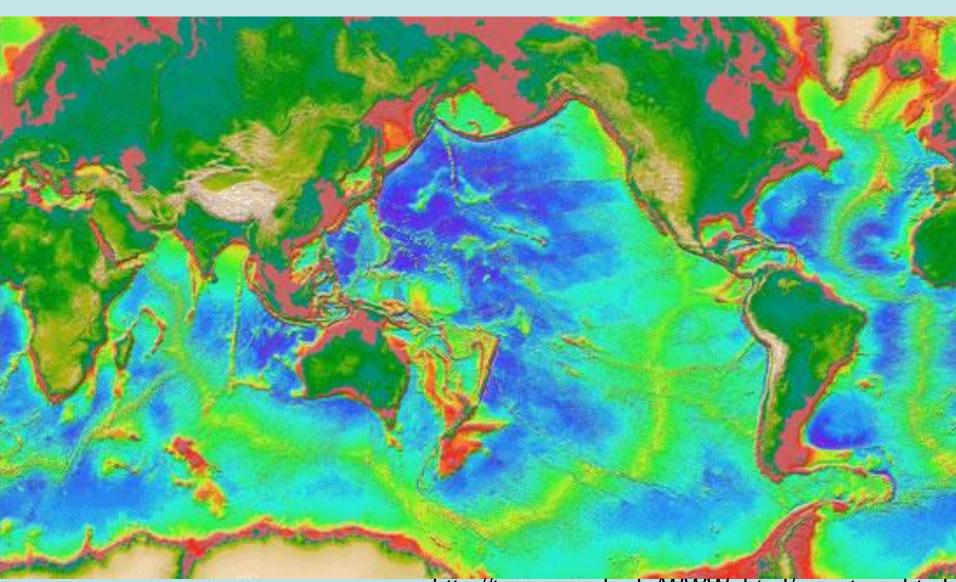


重力異常と海底地形



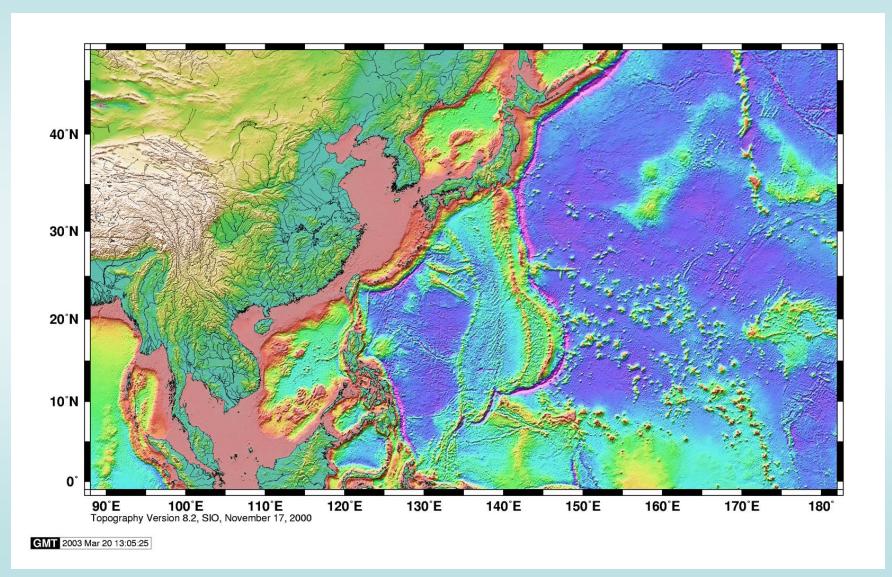
http://www.ngdc.noaa.gov/mgg/bathymetry/predicted/explore.HTML#depth_pred

グローバルな海底地形

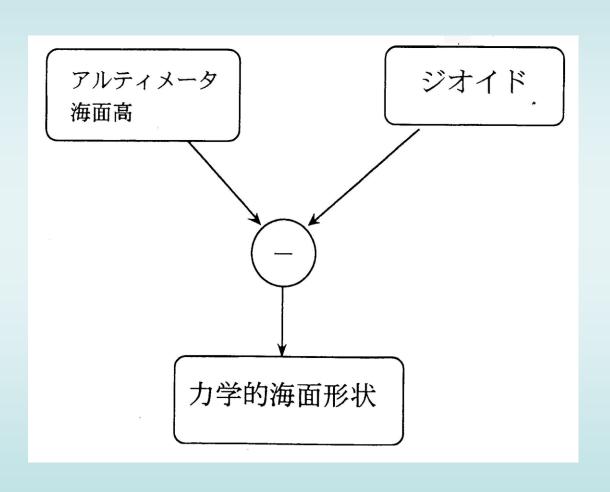


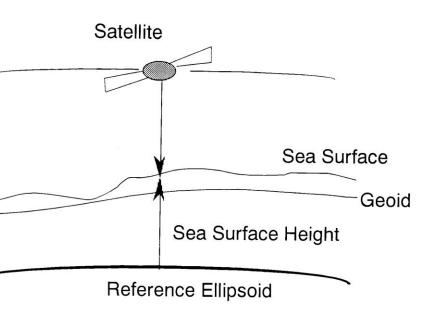
http://topex.ucsd.edu/WWW_html/mar_topo.html

日本近海の海底地形



アルティメーターと海面形状





海面形状と海流

Fig. 1. A schematic view of the satellite altimetry.

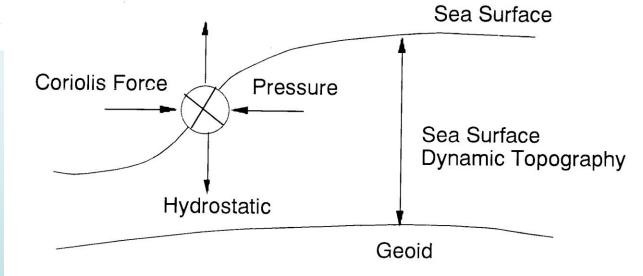


Fig. 2. A schematic view of the sea surface dynamic topography which is caused by geostrophic balance between ocean current and the slope of the sea surface.

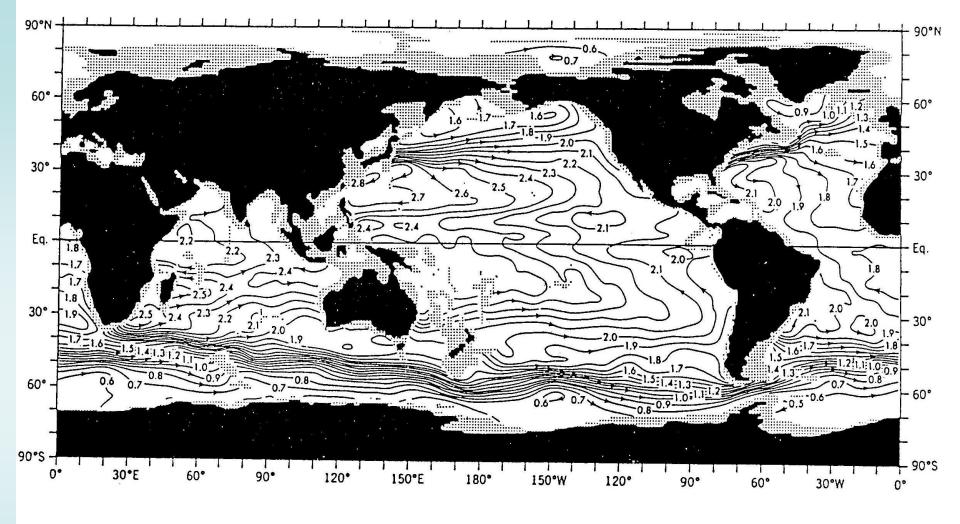
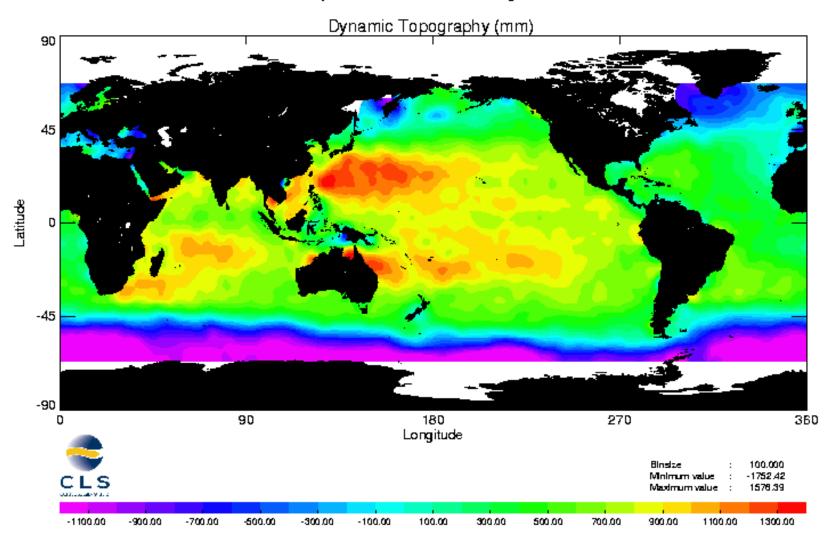
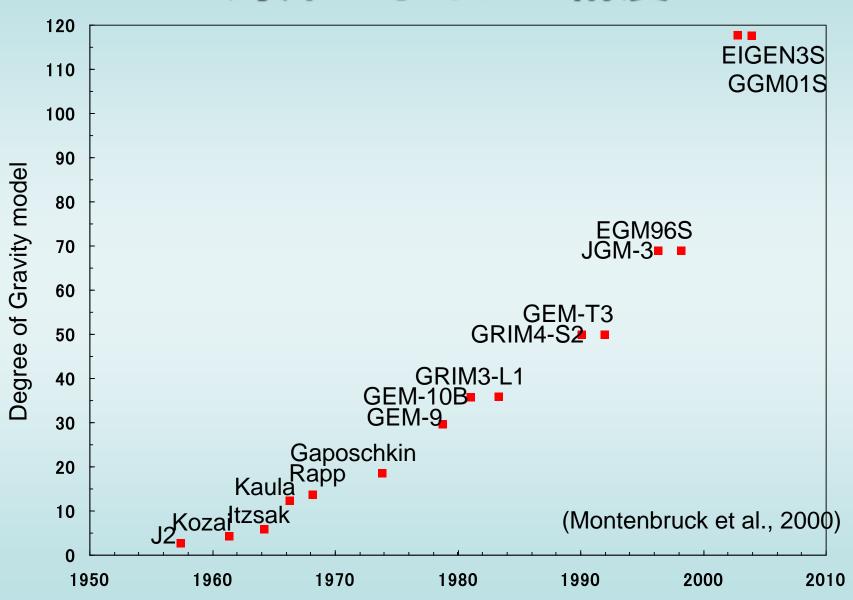


Figure 2-6. Global dynamic height relative to 2,000 dbar determined from historical hydrographic data [from Levitus, 1982]. Contours in geopotential meters, m²/sec², show the major surface circulation patterns [after Cheney et al., 1983].

Topex/Poseidon cycle 200

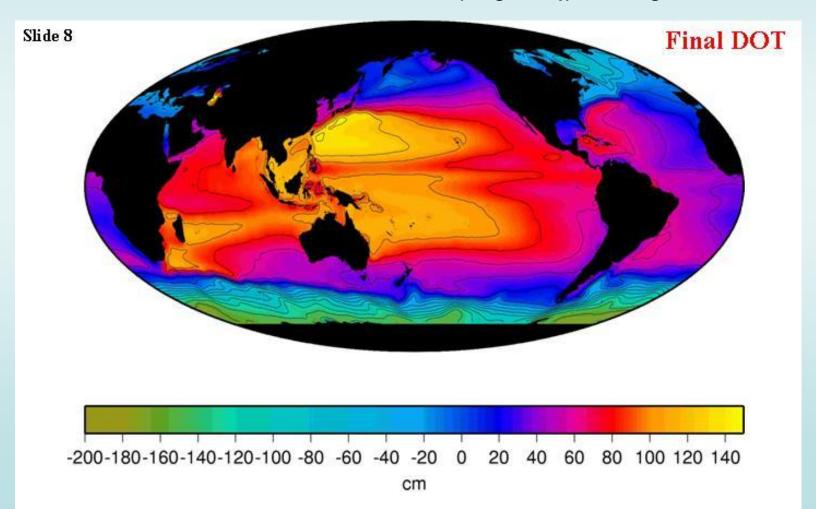


海洋ジオイドの精度



GRACEによるジオイドを基準とした 海面形状

http://grace.jpl.nasa.gov/dot.html



GOCE (2009.03.17, ESA)

Electrostatic Gravity Gradiometer (EGG):

- 3 pairs of 3-axis, servo-controlled, capacitive accelerometers

Satellite to Satellite Tracking Instrument (SSTI):

- 12 channel, dual-frequency satellite-to-satellite tracking rece

Drag-free Attitude-Control System (DFACS) comprising:

- Ion Thruster Assembly (Xenon propellant) and magnetotorquite
- Sensors Star trackers, a 3-axis magnetometer, a digital sun sensor,

and a coarse Earth and Sun sensor

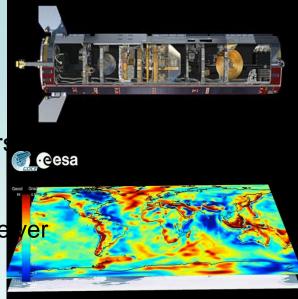
-Cold-gas thrusters for gradiometer calibration only

Sun-synchronous, dusk/dawn or dawn/dusk circular orbit

- 250 km mean altitude
- 96.5° inclination

Nominal mission duration of 20 months including:

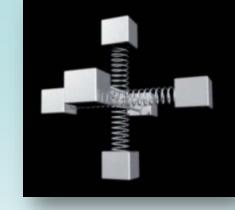
- 3-month commissioning and calibration
- two nominal 6-month measurement phases separated by longeclipse hibernation period



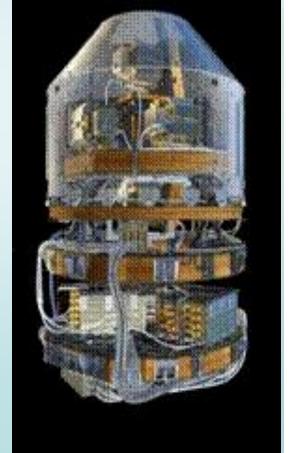
http://www.esa.int/ SPECIALS/GOCE/i ndex.html

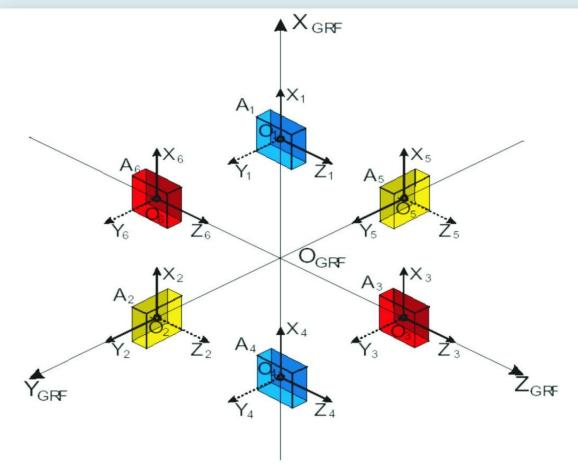
EGG

$$\begin{bmatrix} W_{ij} \end{bmatrix} = \operatorname{grad} \mathbf{g} = \operatorname{grad} (\operatorname{grad} W) = \begin{pmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & W_{zz} \end{pmatrix}$$
 www.esa.int/SPECIALS/

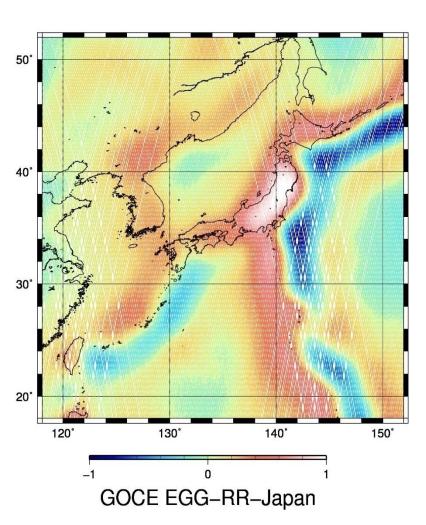


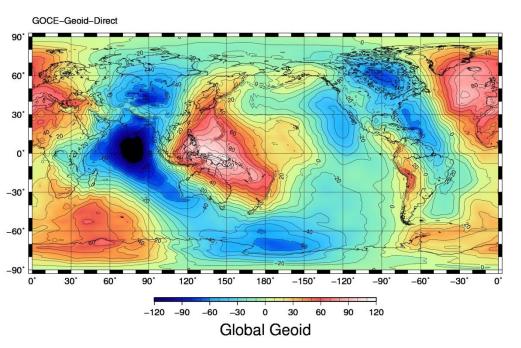
http://www.esa.int/SPECIALS/GOCE/index.html

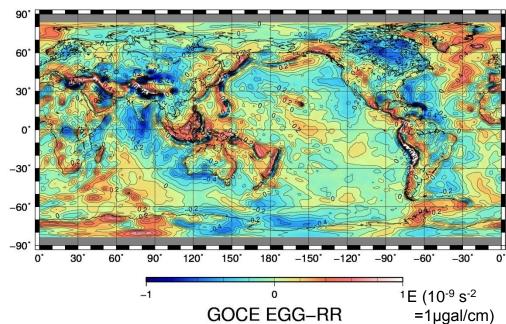




GOCE Level 2 Data





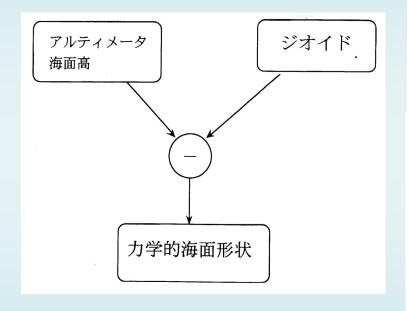


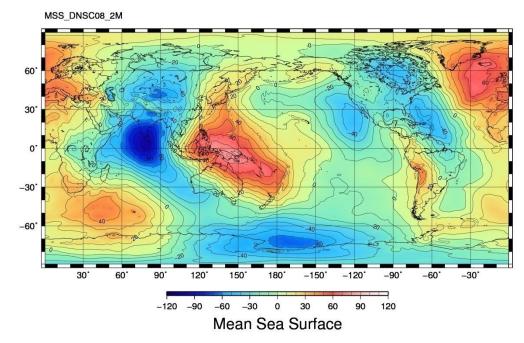
地球物理学的応用

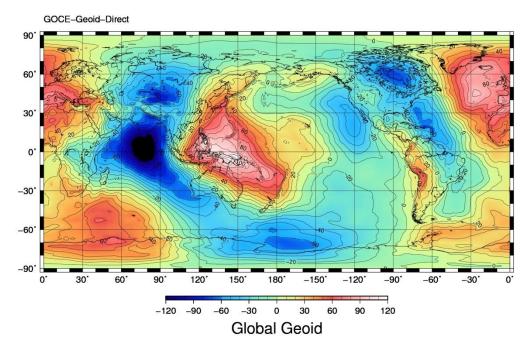
Table 3-1: Static gravity field, scientific requirements in preparation for GOCE, from: Rummel (2005).

Static gravity fie	ld, scientific requirements	in reparation for GC	DCE		
Application			Accuracy		Spatial resolution
			Geoid	Gravity	Half wavelength
gramma, kapa samang sasas sam	ran recommenda e samena erg se es se recom annom a sun exceptions e		[cm]	[mGal]	D [km]
Solid Earth	Lithosphere/upper mantle density			1-2	100
	Continental lithosphere	Sedimentary		1-2	50-100
		Basins rifts		1-2	20-100
		Tectonic motions		1-2	100-500
	Seismic hazards			1	100
	Ocean lithosphere/asthenosphere			0.5	100-200
Oceanography	Short scale		1-2		100
			0.2		200
	Basin scale		~0.1		1000
ice sheets	Rock basement			1 - 5:	50-100
	lce vertical movements		2		100-1000
Geodesy	Levelling by GPS		1		100-1000
	Unified height system		·1		100-20000
	INS			≈1-5	100-1000
	Orbits			~1-3	100-1000
Sea level			Many of the above applications, with		
change			their specific requirements, are relevant		
				to studies of sea level change.	

海面形状



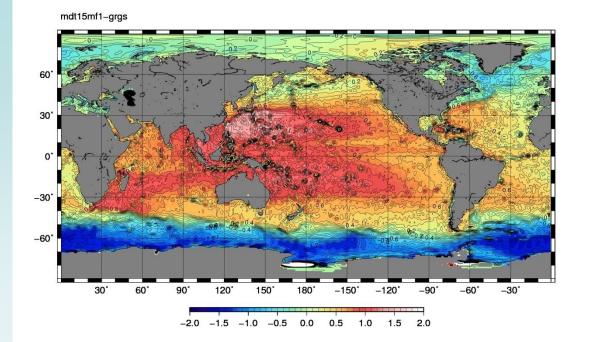


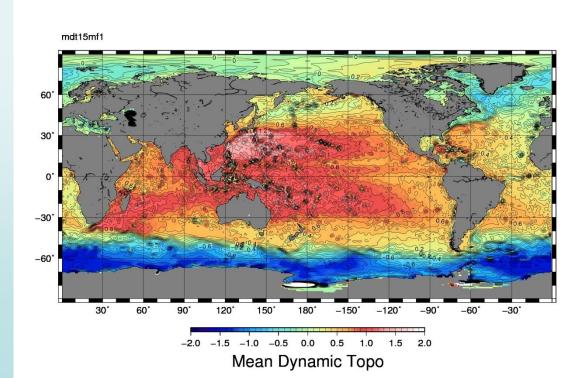


海面形状

GRACE



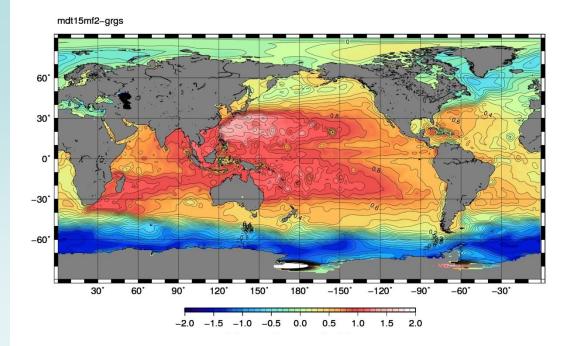


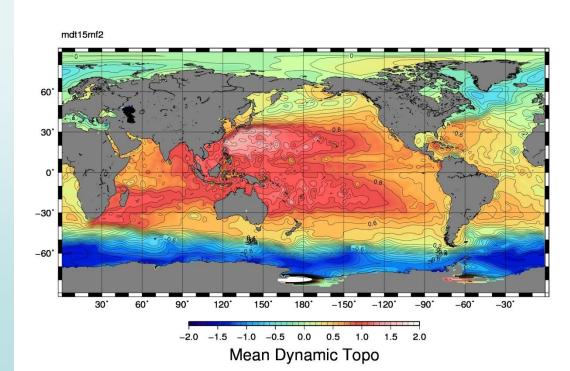


海面形状

GRACE

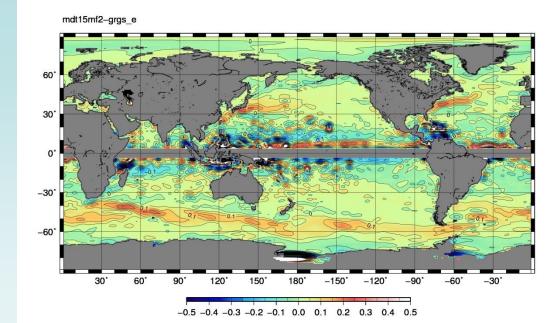


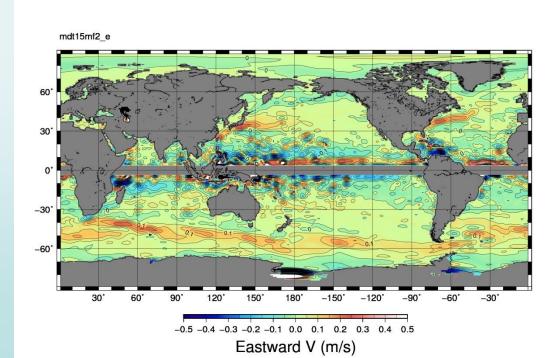






GRACE

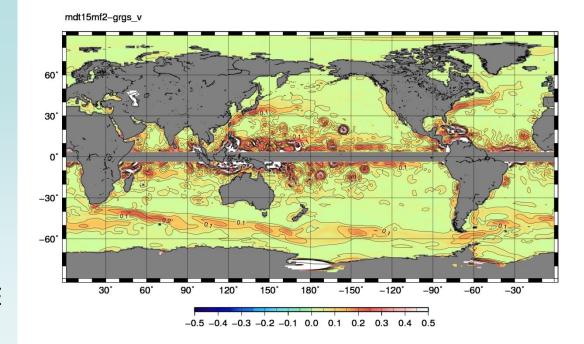


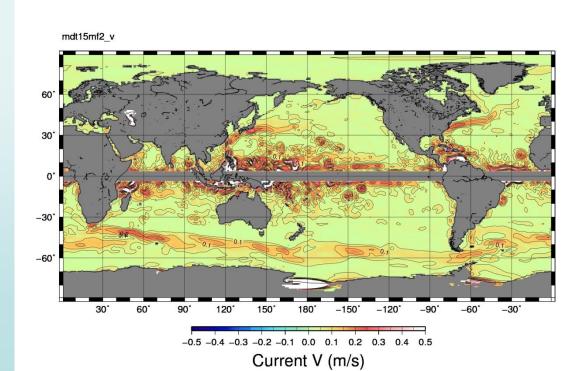


GOCE



GRACE

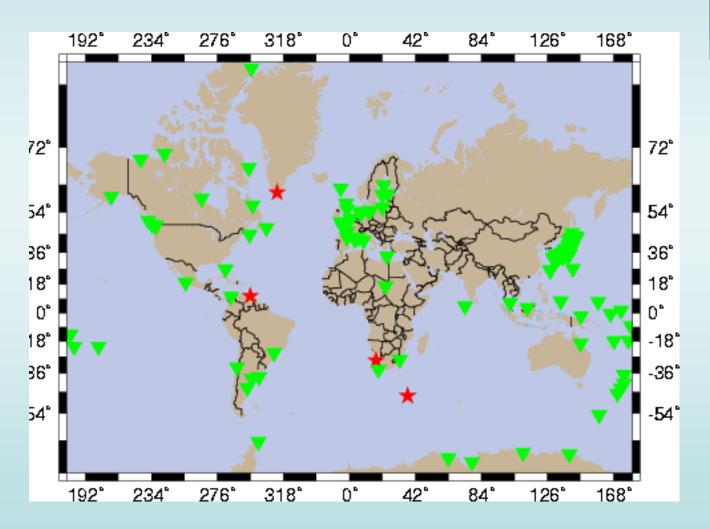


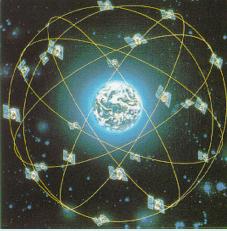


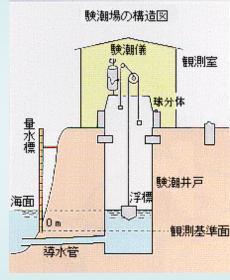
GOCE

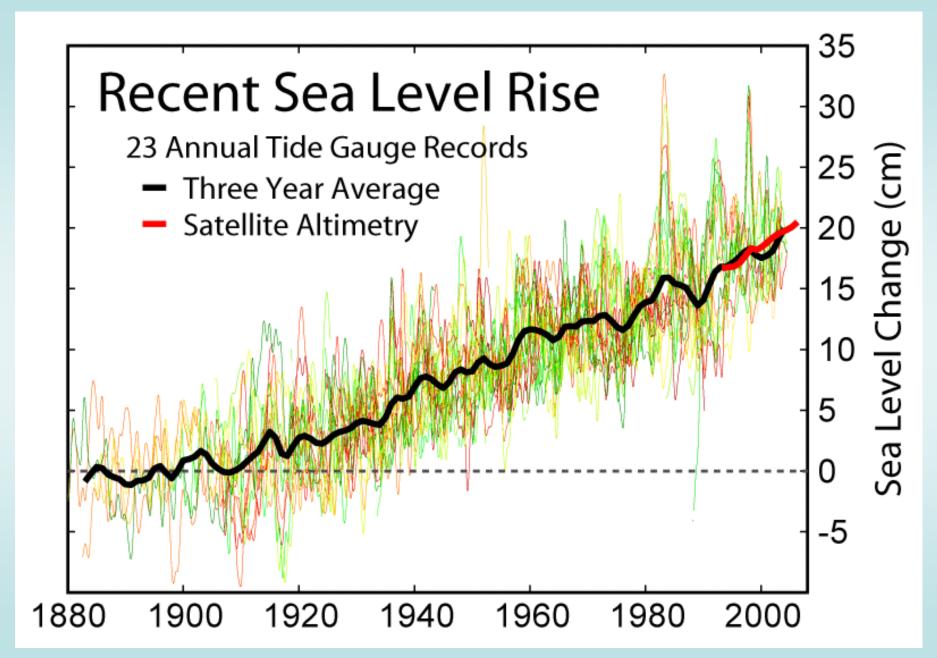
海水準変動

International GPS Service GPS Tide Gauge Benchmark Monitoring - Pilot Project

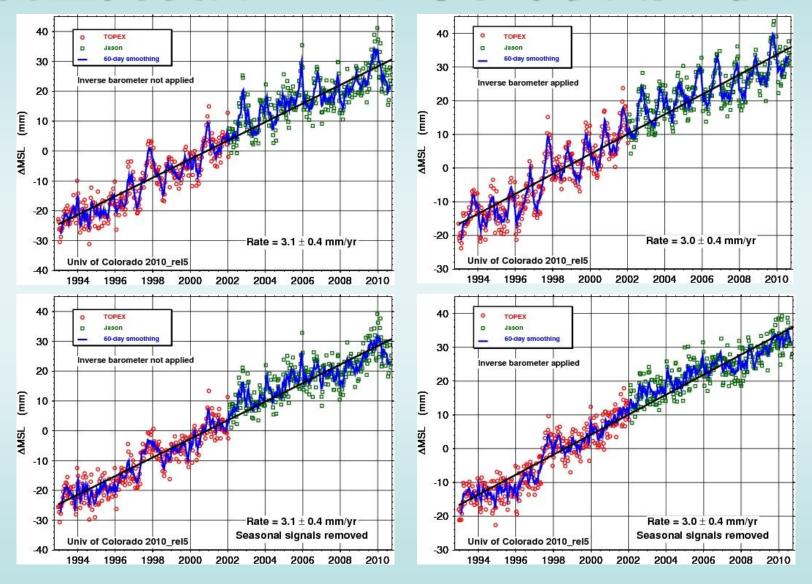




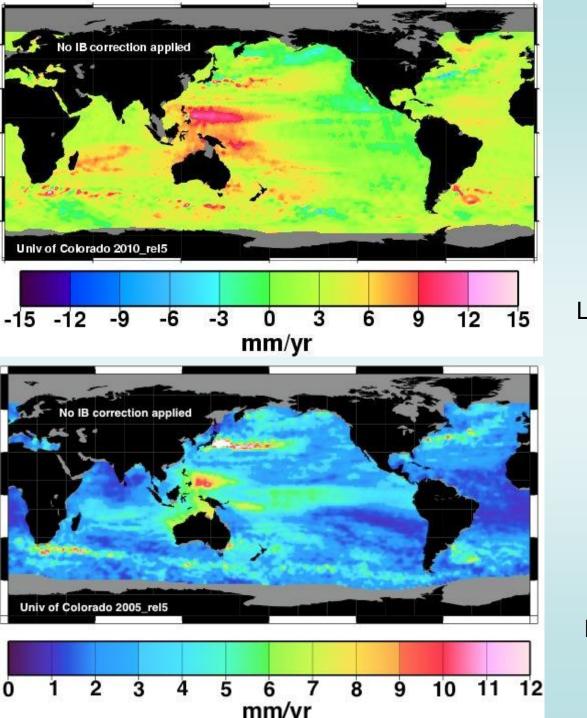




衛星高度計による海水準変動の検出



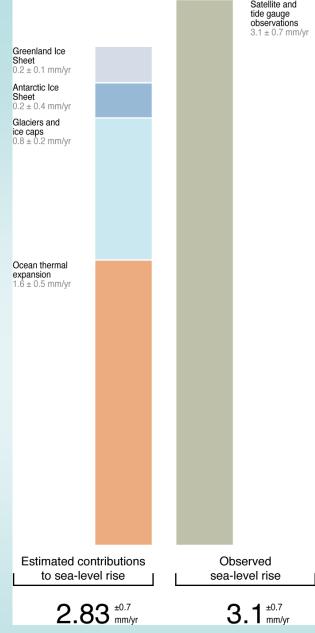
http://sealevel.colorado.edu/results.php



Local Trend of SL

Formal Error

http://sealevel.colorado.edu/



Estimated contributions to sea-level rise (1993-2003) http://maps.grida.no/go/graphic/ estimated-contributions-to-sea-level-rise-1993-2003

Current estimates of sea-level trends from geophysical sources Geophysical sources Sea-level contributions (mm/yr) Thermosteric 0.4 (1950 - 2003)(Levitus et al., 2005; Ishii et al., 2006) Glaciers and ice caps 0.51 to 0.8 (1961 - 2004)(Arendt et al., 2002; Dyurgerov and Meier, 2005; Kaser et al., 2006). Summary: $0.66 \pm 0.15 \text{ mm/yr}$ Greenland ice sheet -0.03 to 0.57(1992 - 2005)(Abdalati et al., 2001; Rignot and Thomas, 2002; Krabill et al., 2004; Zwally et al., 2005; Johannessen et al., 2005; Rignot & Kanagaratnam, 2006); 0.3 to 0.63 (Ramillien et al., 2006; Luthcke et al., 2006; Chen et al., 2006a). Summary: $0.30 \pm 0.33 \text{ mm/vr}$ Antarctic ice sheet -0.12 to 0.17(1992 - 2006)(Thomas et al., 2004; Davis et al., 2005; Wingham et al., 2006; Zwally et al., 2005); 0.14 to 0.52 (Ramillien et al., 2006; Chen et al., 2006b; Velicogna and Wahr, 2006a,b; this study). Summary: 0.20 ± 0.32 mm/yr Hydrologic 0.0 to 0.12 (Milly et al., 2003; Ngo-Duc et al., 2005). Summary: 0.06 ± 0.06 mm/yr Anthropogenic 0.05 (Sahagian et al., 1994) 1.11 to 3.01 mm/yr, or 2.10 ± 0.99 mm/yr Total

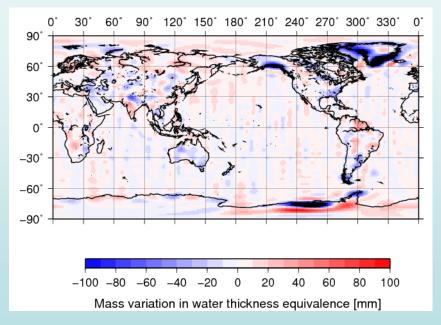
Table 1

C.K. Shum et al., Polar Science, 2008

海水準変動の収支は?

Reference	Steric sea level change with rms errors (mm/year)	Period	Depth range (meters)	Data
Antonov et al. (2005)	0.40 ± 0.05	1955–1998	0-3000	Levitus et al. (2005b)
Antonov et al. (2005)	0.34 ± 0.04	1955–2003	0–700	Levitus et al. (2005b)
Ishii et al. (2005)	0.38 ± 0.04	1955–2003	0–700	Ishii et al. (2005)
Antonov et al. (2005)	1.23 ± 0.2	1993–2003	0–700	Levitus et al. (2005b)
Ishii <i>et al</i> . (2005)	1.8 ± 0.2	1993–2003	0–700	Ishii et al. (2005)
Willis et al. (2005)	1.6 ± 0.3	1993–2003	0–750	Willis et al. (2005)

Recent estimates for steric sea level trends from different studies



海洋のトレンド: 391 Gt (≒1.1mm/yr)

南極以外の陸のトレンド: -207 Gt 南極の氷床トレンド: -185 Gt?

内容2(14日午前)

✓地上での重力測定

- ・ 重力計の原理
- 超伝導重力計の応用
- 野外重力測定

✓ 衛星高度計

- 衛星高度計の原理
- ・ 海域の重力場
- 海面形状とGOCE
- 海水準変動

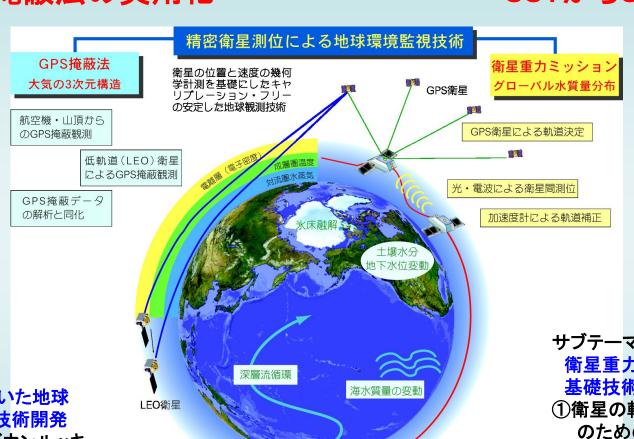
✓ 展望

- 精密測位による地球環境監視
- 将来ミッション

精密衛星測位による地球環境技術 (H14-16年度科振費)

GPS掩蔽法の実用化

SSTからSSIへ



成層圏の寒冷化

サブテーマ1

GPS掩蔽法を用いた地球 大気圏モニター技術開発

- ①航空機からのダウンルッキ ングGPS掩蔽観測技術の開発
- ②LEO衛星によるGPS掩蔽観測 の国際共同研究の推進
- ③GPS掩蔽観測データの解析 とデータ同化システムの開発

サブテーマ2

衛星重力ミッションの

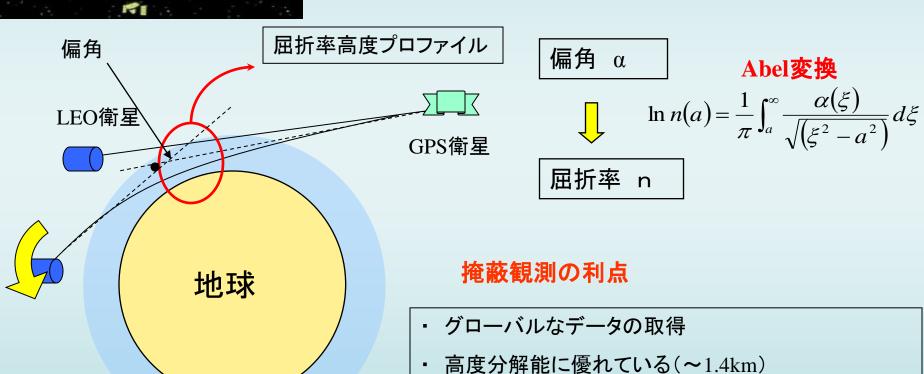
基礎技術開発

- ①衛星の軌道決定精度向上 のための基礎技術開発
- ②衛星間測位の高精度化に 関する基礎技術開発
- ③衛星搭載型高感度加速度計 の開発
- 4 将来の衛星観測ミッション に関する技術評価と物理設計



GPS掩蔽観測

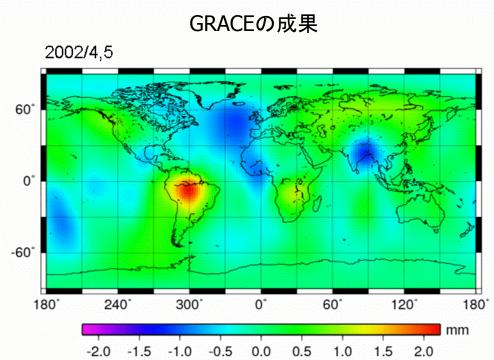
$$\alpha = \int \frac{1}{n} (\vec{T} \times \nabla n) ds$$



高精度(温度:~0.5K)

測器の個体差に影響されない(幾何学的計測)

SSTからSSIへ

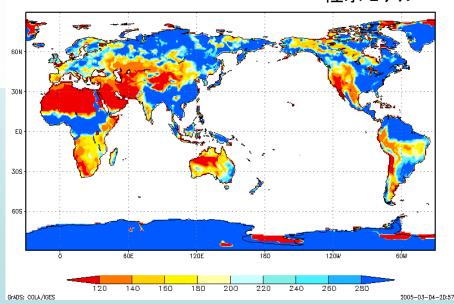


SSI データ利用 シミュレーション

陸水・土壌水分モニターを目的とした L-L SSIの利用シミュレーションを実施する。 GRACEはマイクロ波レーダーを用いた L-L SST(Low-Low Satellite to Satellite Tracking)を採用し、世界の主要な河川域で の陸水変化が検出できるようになった。

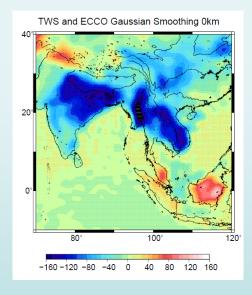
将来、レーザー干渉技術を用いた L-L SSI (Low-Low Satellite to Satellite Interferometry)が実現するとさらに高感度 な観測が可能になると期待される。

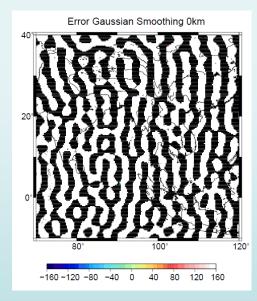
陸水モデル



SSIデータのシミュレーション

=(陸水、海洋モデル) + (GRACEの係数誤差) /10 /100

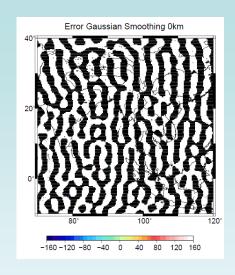


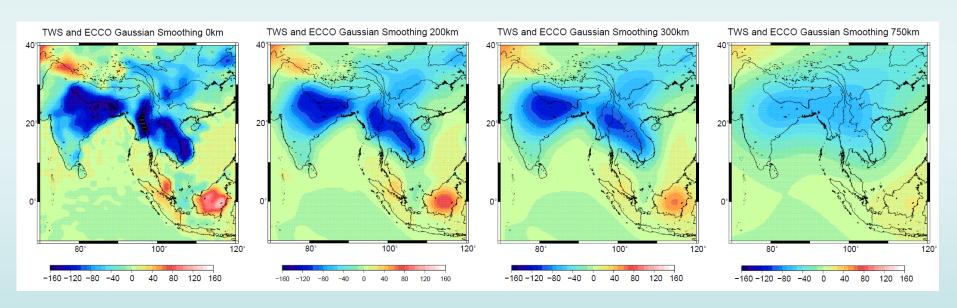


/1

/1000

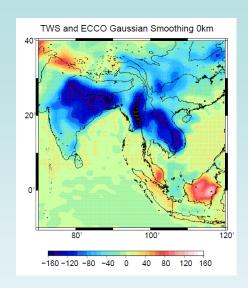
シミュレートした信号のフィルター出力

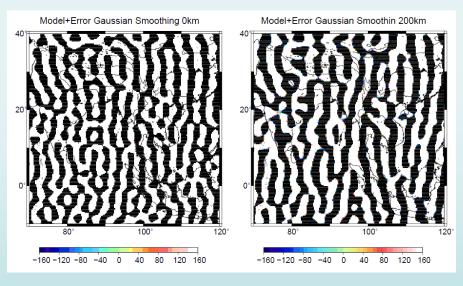


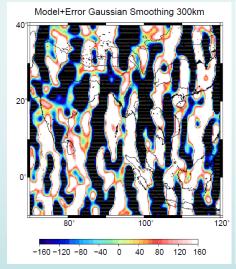


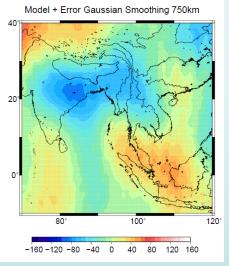
0km 200km 300km 750km

GRACEと同等の精度







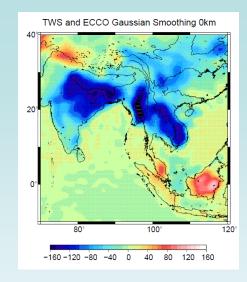


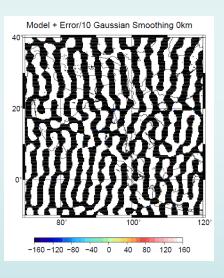
0km

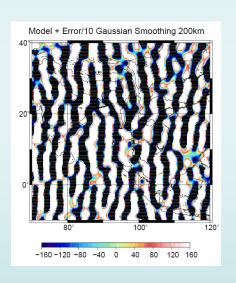
200km

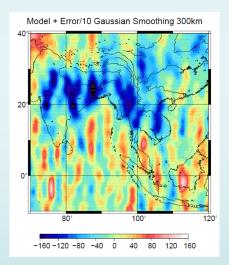
300km

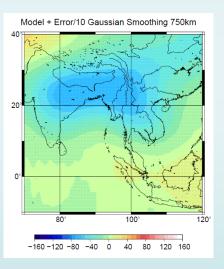
GRACEの10倍精度









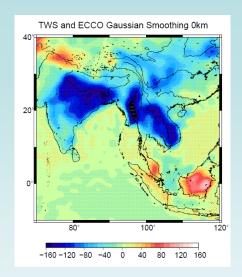


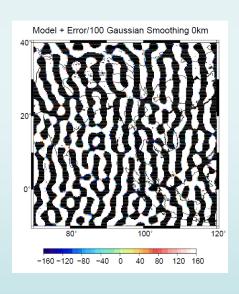
0km

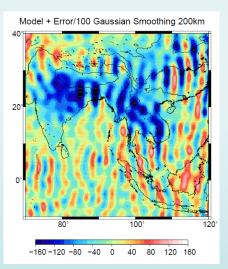
200km

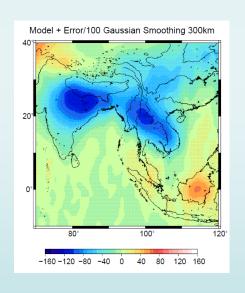
300km

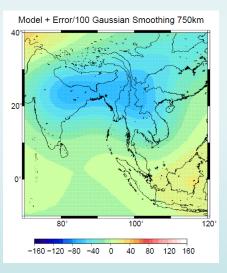
GRACEの100倍精度









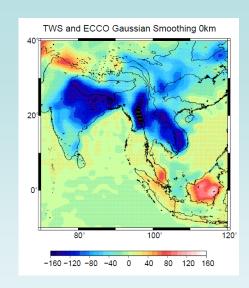


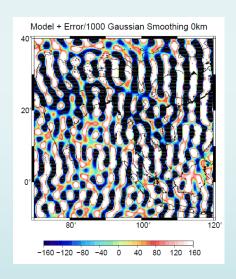
0km

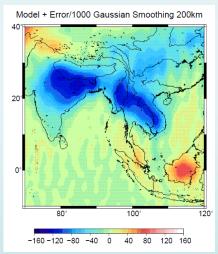
200km

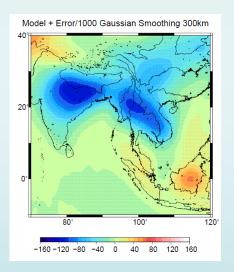
300km

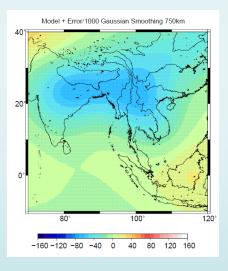
GRACEの1000倍精度









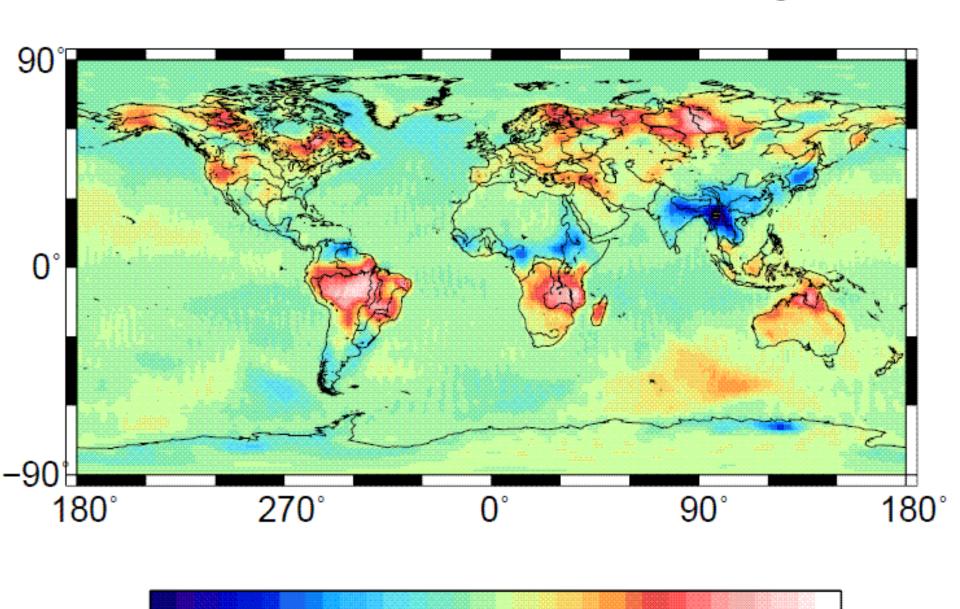


0km

200km

300km

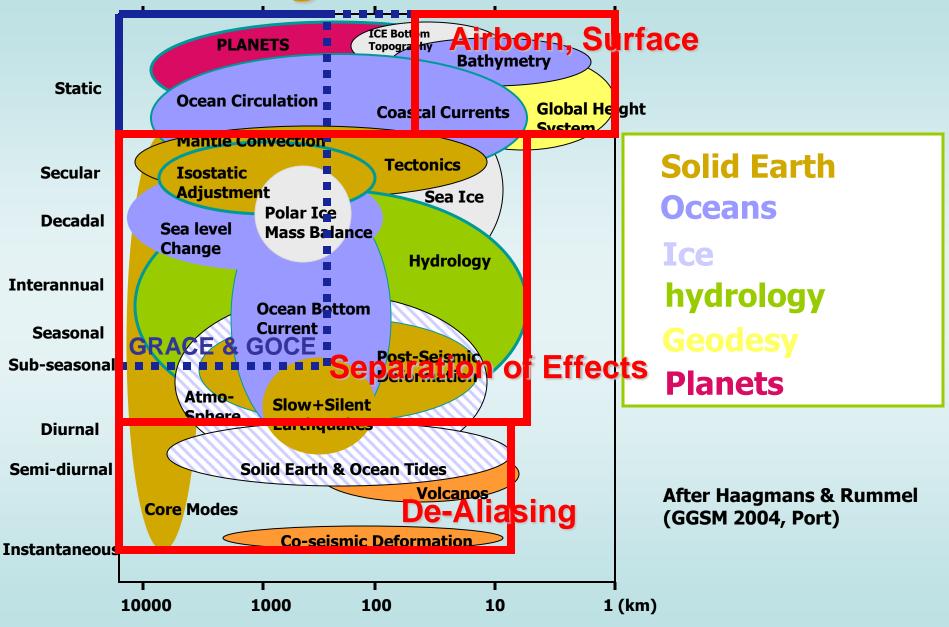
Model + Error/1000 Gaussian Smoothing 200km



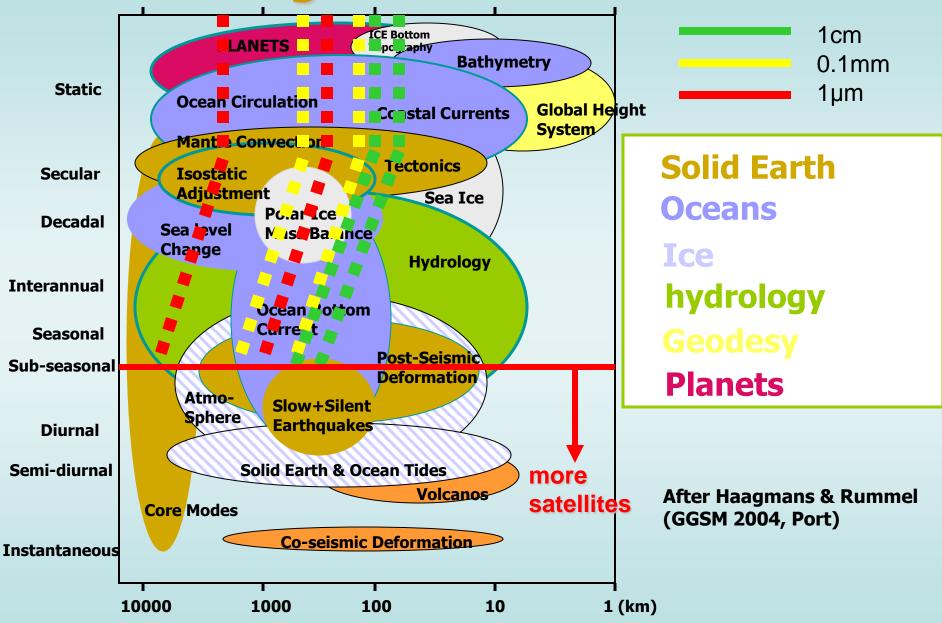
将来ミッション

- ✓ 観測向上の余地は?
 - · 空間分解能、時間分解能
- ✓ 新たな科学目標?
 - 深部地球ダイナミクス、大気…
- ✓ ミッションシナリオ
 - ・ 衛星高度、編隊飛行、データの連続性 …
- ✓ 補完ミッション、モデル
 - ・ 高度計、潮汐モデル
 - GRACE Gap Filler Mission
 - 小型衛星ミッション
 - DPF

Challenges for Future Missions



Challenges for Future Missions



地球内部から超高層にいたる多彩な地球観測

加速度計 GPS受信機

High-Low Satellite to Satellite Tracking

GPSによる連続的な衛星の軌道追跡から加速度計による非重力場加速度成分を補正することにより地球重力場を測定

GPS伝播遅延

天頂方向からのGPS電波伝搬 遅延・シンチレーション特性 の解明による大気圏・電離圏 観測への応用

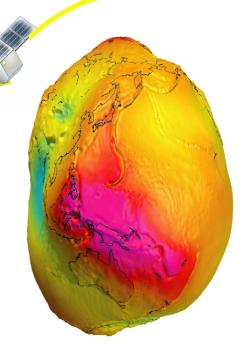


加速度計とGPS測位を併用した軌道擾乱観測による 超高層(100km以上)の中性大気密度分布の観測



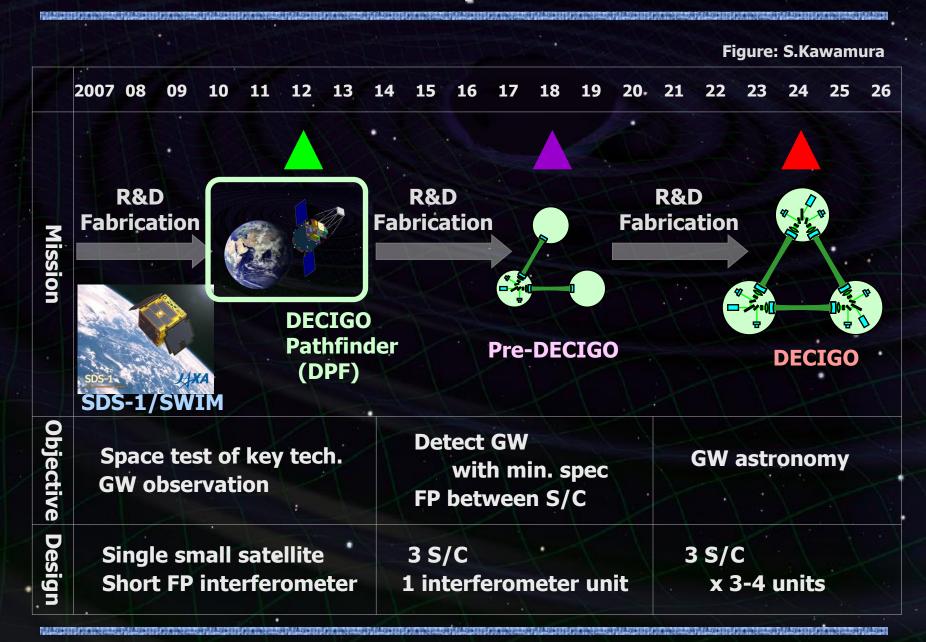
海面反射

海面、氷面からのGPS電波の反射波計測による海上風(海上波浪)、海面・氷床高度測定



GPS掩蔽

GPS衛星の掩蔽時における地平線からのGPS電波屈折角の連続観測による電離層電子密度、大気圏温度・湿度の鉛直構造の観測



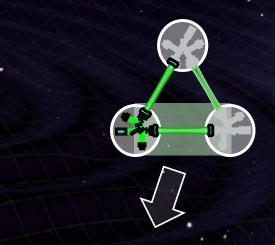
DECIGO-PF

DECIGO Pathfinder (DPF)

First milestone mission for DECIGO

Shrink arm cavity

DECIGO 1000km → DPF 30cm



Single satellite

(Payload ~1m³, 350kg)

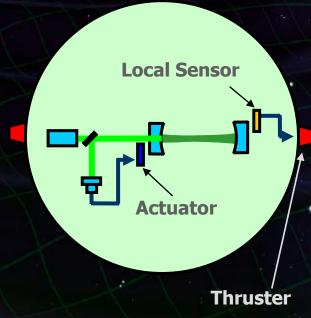
Low-earth orbit

(Altitude 500km, sun synchronous)

30cm FP cavity with 2 test masses

Stabilized laser source

Drag-free control

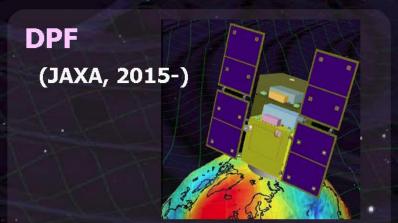


GOCE and DPF



Satellite Gravity Gradiometry





Earth observation by gravity gradiometer Drag-free control of satellite

Altitude 295km, 3-axis GG

Sens. $5x10^{-12}$ m/s²/Hz^{1/2}

Baseline 0.5m

Weight 1,200 kg

Altitude 500km, 1-axis GG

Sens. $1x10^{-15} \text{ m/s}^2/\text{Hz}^{1/2}$

Baseline 0.3m

Weight 350 kg

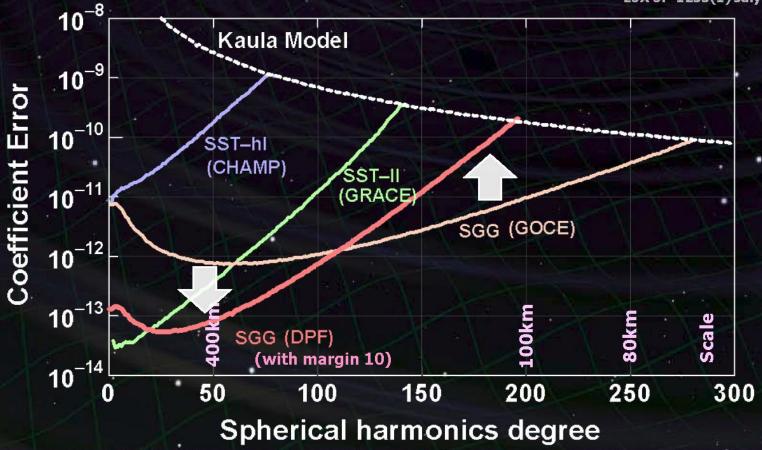
DPF sensitivity



Comparison of sensitivities

Better in low orders (large scale) ← Sensors
Worse in high orders (small scale) ← Altitude

Report for Mission Selection Gravity Field and Steady-State Ocean Circulation Mission ESA SP-1233(1) July 1999.



月・惑星 ミッション SELENE

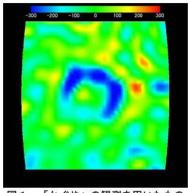


図1 「かぐや」の観測を用いたもの

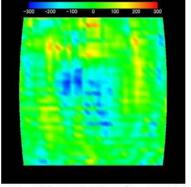


図2 従来の月重力場モデル (LP165P)



アポロ盆地 (南緯36度, 西経150度, 直径500km)

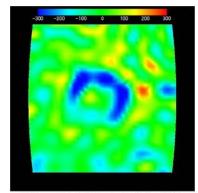


図3 月の裏側にあるアポロ盆地 (南緯36度,西経150度,直径500km)

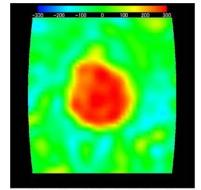
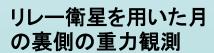
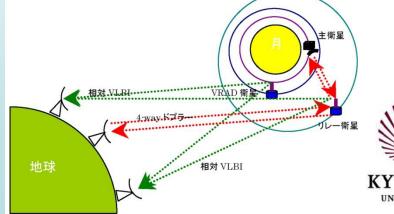


図4 月の表側にある晴れの海 (北緯26度, 東経19度, 直径880km)



左の晴れの海の盆地では、地表面の 玄武岩溶岩と、地下のマントルの隆 起によって正の重力異常(赤色)が 見られます。

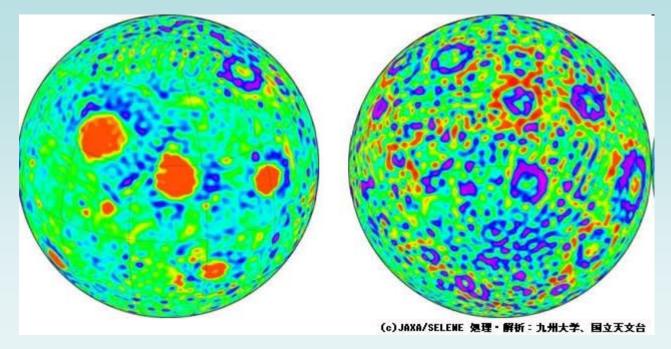






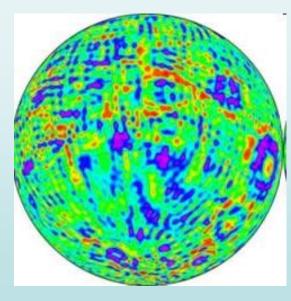






4ウェイドップラ観測から得られた月の裏側の重力場

http://www.kaguya.jaxa.jp/ja/science/RSAT/Farside_Gravity_Field_j.htm



SELENE 以前

まとめ

???

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