Simultaneous observation of gravity tide in Juneau, Southeast Alaska with gPhone #032 and L&R G578 gravimeters

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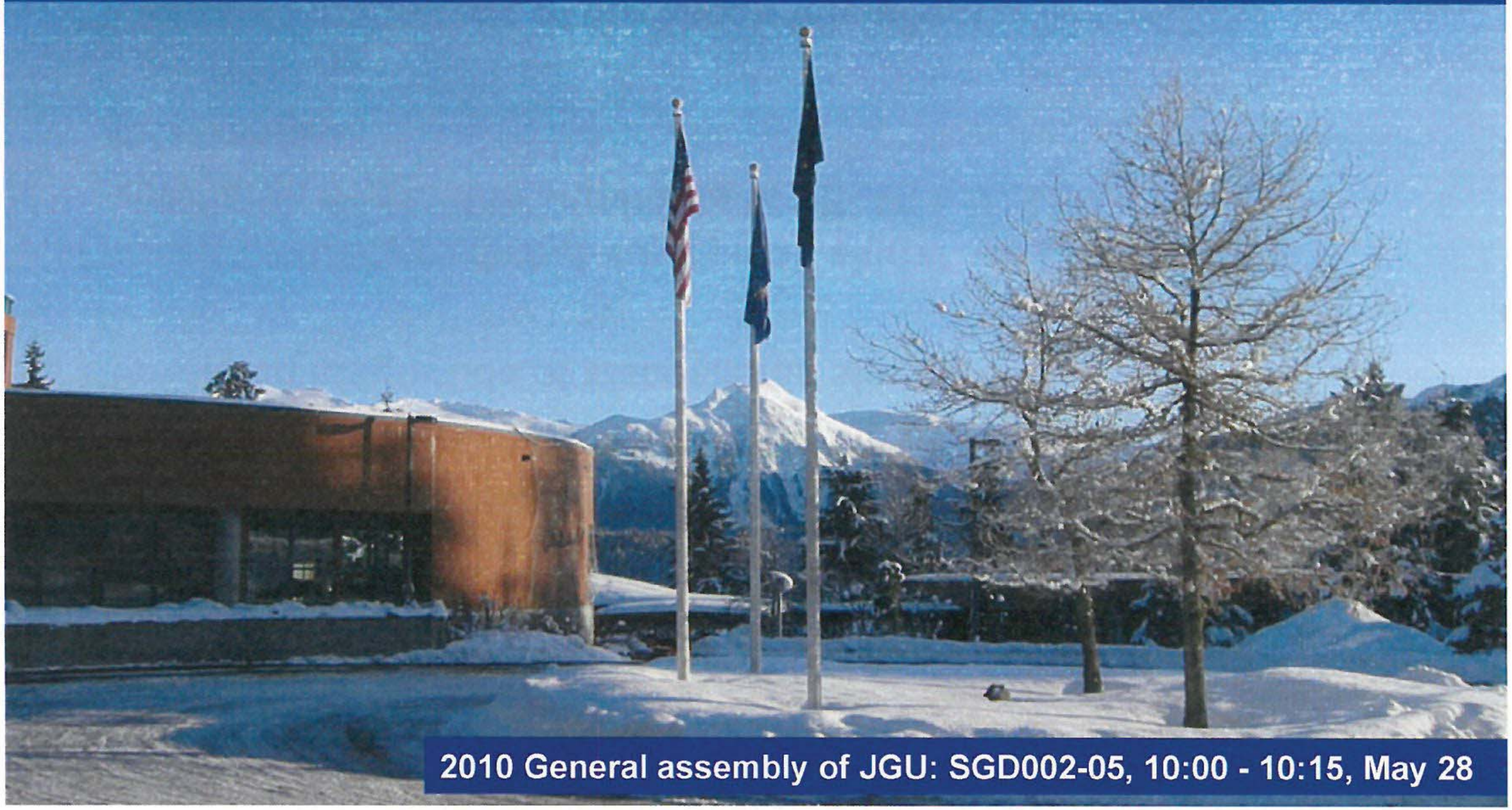


2010 General assembly of JGU: SGD002-05, 10:00 - 10:15, May 28

Purpose of this observation

To obtain a data to study the viscoelastic response in the short-period tidal band.

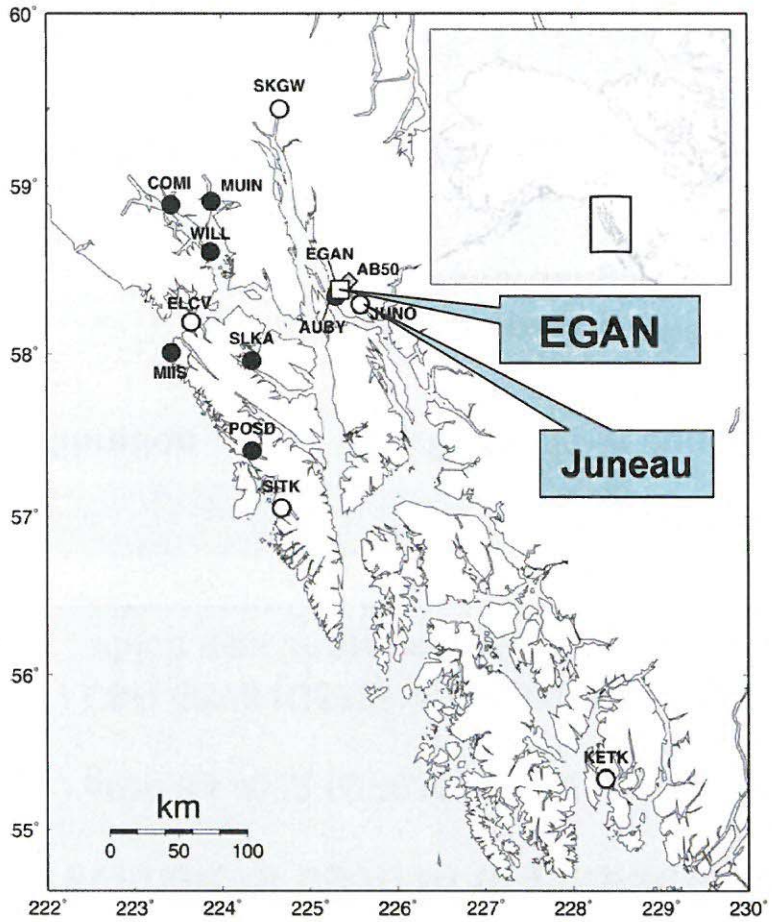
**Predicted magnitude of viscoelastic signal < 0.1 μGal

/ As a possibility to detect such small signal, we can expect to very large ocean tide amplitude in SE-AK exceeding 8 m in total range.

**Predicted magnitude of the ocean tide effects:
Attraction+Loading > 20 μGal in total amplitude of 8 main tidal waves

/ An important thing in this kind of study is the calibration accuracy of gravimeter and the stability of scale factor.

Location of the gravity site EGAN



Observation and tidal analysis

Gravimeters used in the observation

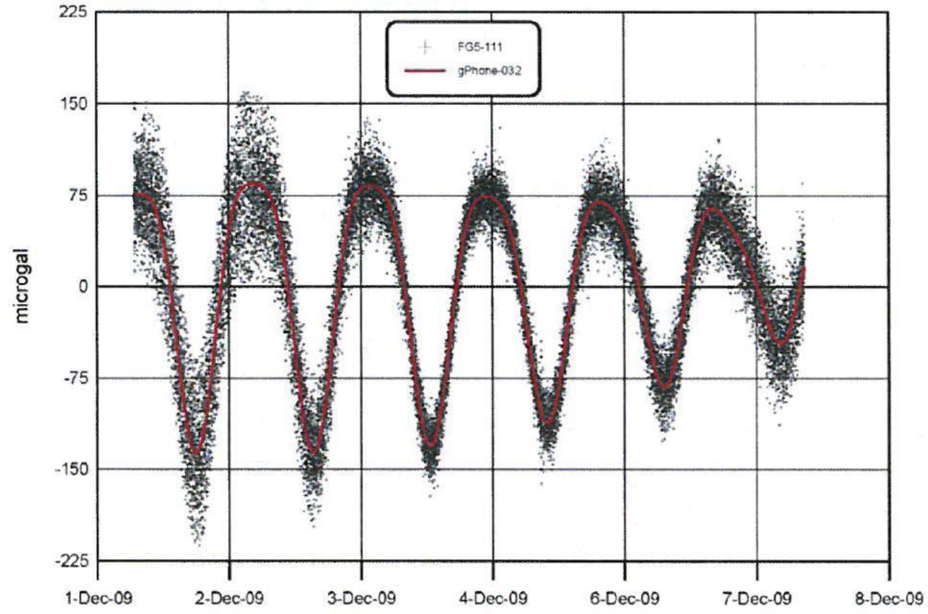
/ gPhone #032 (GP032) of University of Luxembourg

/ L&R G578 (G578) of Tohoku University,
which was improved into a feedback type by Harrison & Sato method (1984).

	GP032	G578
1. Calibration	By FG5#111 in Juneau	By FG5#111 in Juneau
	By comparing with the SG at Walferdange in Luxenboug	By the reading dial of G578
2. Tidal analysis method	BAYTAP-G and ETERNA	BAYTAP-G and ETERNA
3. Data length used in the analysis	297 days (Feb. 14 to Dec. 7 in 2009)	540 days (Jun. 16 2008 to Dec 7 2009)

Result for the calibration at EGAN with FG5#111

Example of the calibration of GP032



Correction to the scale factor (μGal/Volt) of each gravimeter used in this study:

0.995+/-0.002 for **GP032**,

0.997+/-0.002 for **G578**.

Result for the comparison with the superconducting gravimeter OSG-40 at the Walferdange observatory in Luxembourg

	GP032	OSG-40	SG/GP032
O_1	35.385	35.2189	0.99531
K_1	49.2005	49.011	0.99615
M_2	37.5491	37.3846	0.99562
Average			0.9957 ±0.0004
Cal. by FG5			0.995 ±0.002

Note:
/ Observation period: 34.5 days
/ OSG-40 has been well calibrated with FG5s.

Result for the calibrations of G578 with the reading dial

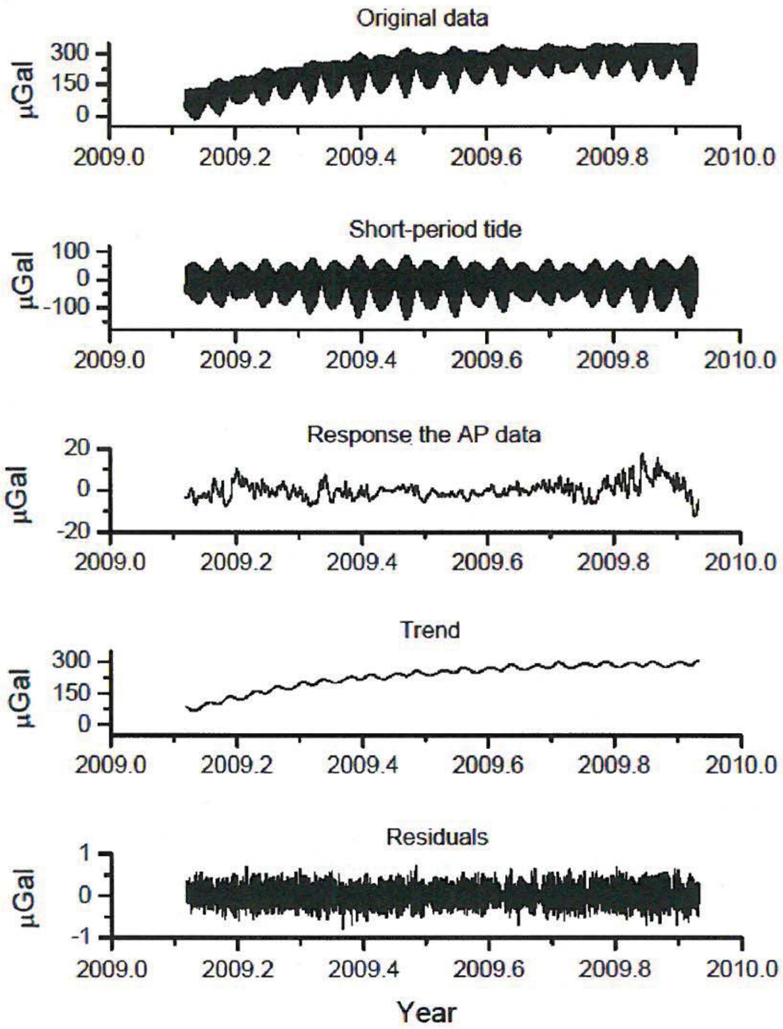
Date	Dial position	Coefficient of 1^{st}-order (Volt/turn)	Coefficient of 2^{nd}-order (volt/turn**2)
Jun.10, 2008	5268.0	1.9418 (0.0004)	-0.00098 (0.00045)
Dec.11, 2009	5268.0	1.9280 (0.0005)	-0.00017 (0.00056)

Note: For both cases, calibrations were done within the range of +/-1.5 turns with the reading dial.

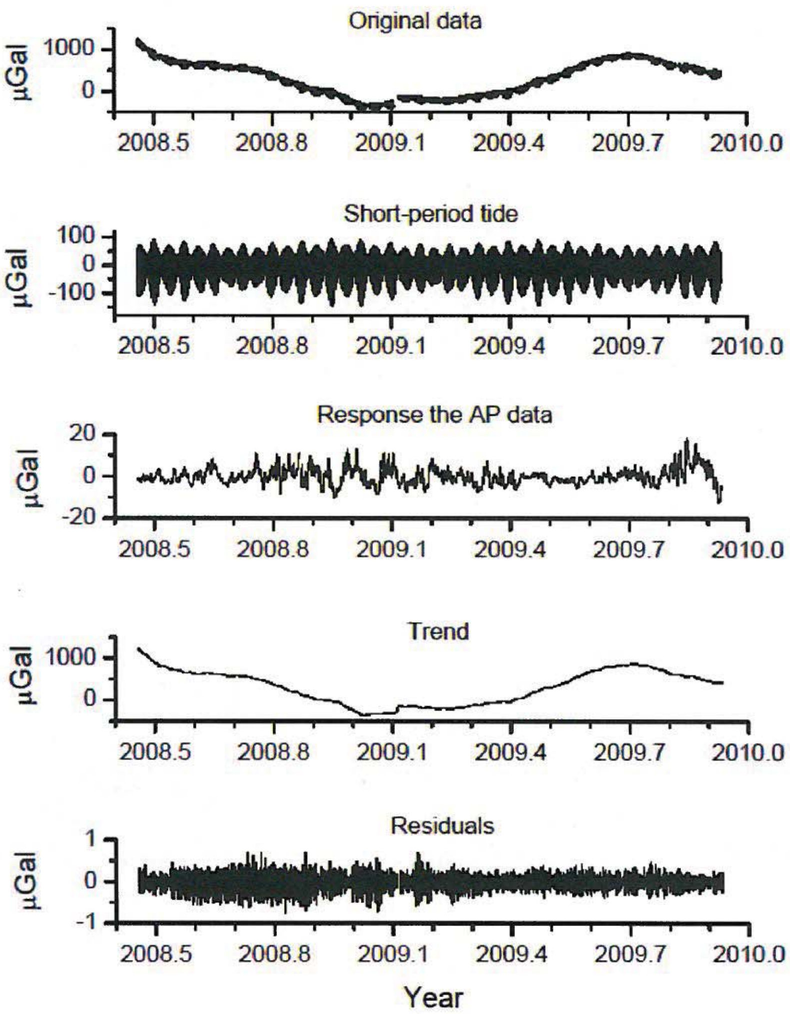
Adapted value = 1.942 (Volt/tern) obtained in Jun. 10, 2008
Mean of two calibrations = 1.935+/-0.007 (Volt/turn)

Ratio =1.935/1.942=0.9965 ⟷ **0.997+/-0.002** **by the calibration with FG5**

BAYTAP-G analysis for the gPhone data at EGAN, Juneau



BAYTAP-G analysis for the G578 data at EGAN, Juneau



Results for the tidal analysis results by BAYTAP-G

	Factor		Amplitude(μGal)		Phase lead (deg)	
	GP032	G578	GP032	G578	GP032	G578
O1	1.19507	1.19741	33.167	33.232	4.16	4.05
K1	1.20345	1.20788	46.974	47.154	4.11	4.20
M2	0.75283	0.74917	15.553	15.477	4.62	4.43
S2	0.95685	0.96224	9.1968	9.2502	12.14	12.86
Error						
O1	0.00043	0.00093	0.012	0.026	0.02	0.04
K1	0.00035	0.00061	0.014	0.024	0.02	0.03
M2	0.00025	0.00036	0.005	0.007	0.02	0.03
S2	0.00050	0.00073	0.005	0.007	0.03	0.04
R. Coefficient (μGal/hPa):	GP032: -0.360+/-0.007			G578: -0.362+/-0.008		
Correction for scale factor:	GP032: 0.995			G578: 0.997		

Note:

Scale factor: Corrected by the calibration with FG5#111

Difference of the observed amplitudes in unit of μGal

O1 wave	BAYTAP-G	ETERNA	Difference
GP032	33.167 (0.012)	33.164 (0.006)	+0.003
G578	33.232 (0.026)	33.238 (0.013)	+0.006
Difference	+0.065	+0.074	

M2 wave	BAYTAP-G	ETERNA	Difference
GP032	15.553 (0.005)	15.528 (0.005)	+0.025
G578	15.477 (0.007)	15.445 (0.008)	+0.032
Difference	-0.076	-0.083	

Note: / Difference of G578 to GP032 or of BAYTAP-G to ETERNA

Difference in the observed tidal phases (+lag, in deg)

O1 wave	BAYTAP-G	ETERNA	Difference
GP032	-4.16 (0.012)	-4.140 (0.0133)	-0.020
G578	-4.05 (0.045)	-4.106 (0.0269)	+0.101
Difference	+0.09	+0.034	

M2 wave	BAYTAP-G	ETERNA	Difference
GP032	-4.62 (0.019)	-4.638 (0.0151)	+0.018
G578	-4.43 (0.028)	-4.443 (0.0226)	+0.013
Difference	+0.21	+0.195	

Note: Difference of G578 to GP032 or of BAYTAP-G to ETERNA

Prediction of the gravity tide including the ocean tide effects

Solid tide:

DDW (1999) model for the elastic or inelastic earth

Load Green's function:

/ For elastic model: PREM

/ For inelastic model:

Real part: PREM

Imaginary part: Q-structure of PREM (Okubo & Tsuji, 2001)

Ocean tide model:

/ Global model: FES2004 (Lyard et al., 2006)

/ Regional model for SE-AK:

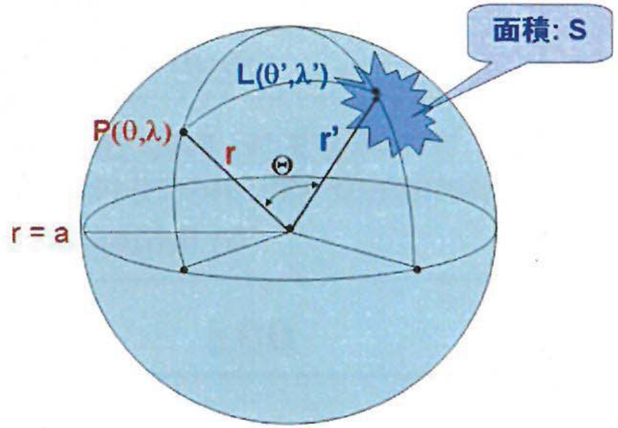
Inazu model (Inazu et al., 2009)

F00 model (Foreman et al., 2000)

Computation of the ocean tide effects

It can be estimated by computing the convolution integral of the loading mass and the load Green's function over the oceans in the world.

$$L(\mathbf{r}) = \rho \int_S G(\Theta) H(\mathbf{r}') dS,$$



where

ρ : density of the ocean water (1,026 $kg^1 m^{-3}$),

$H(\mathbf{r}')$: ocean tide height at the point $\mathbf{r}'$,

$G(\Theta)$: load Green's function,

Θ: loading distance,

dS: surface element.

Regional ocean tide modes used in this study

	Inazu	F00
Method	Integrating the equations of momentum and continuity	Assimilating to the tidal harmonics obtained from T/P data for 5.3 years.
Grid system	Mercator	Triangular grid
Bathymetry	ETOPO2, Sounding data	ETOP05, Smith & Sandwell [1997]
Driving condition	Tidal height variations of F00 on the west and south boundary lines	T/P data at the cross-over points

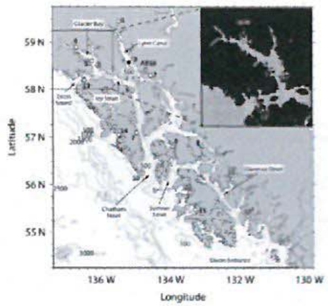
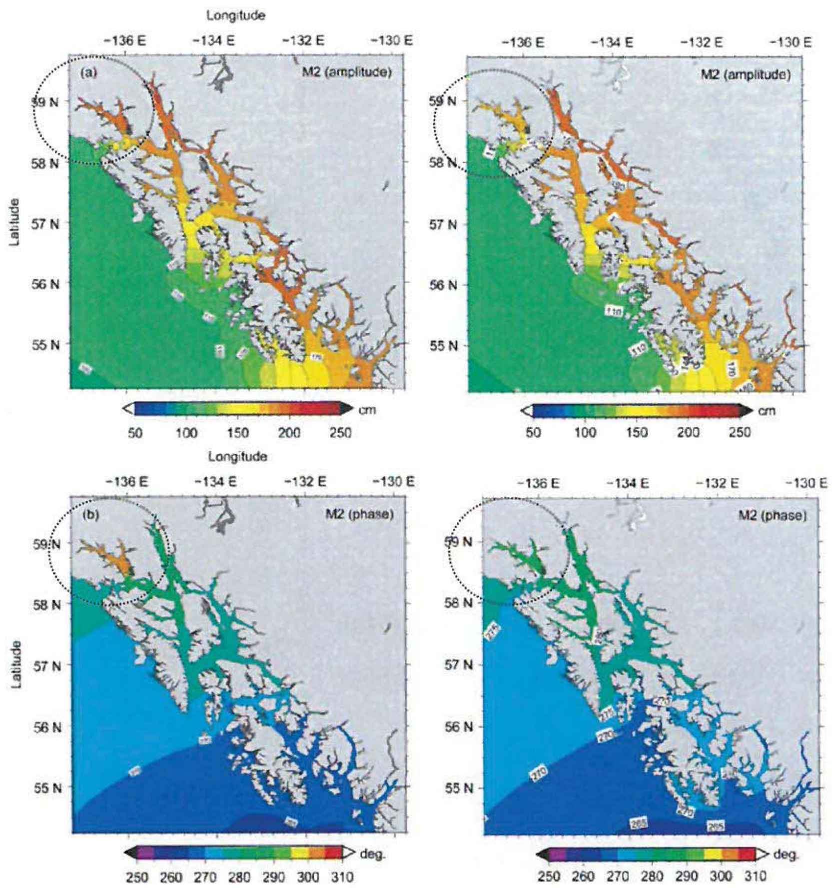
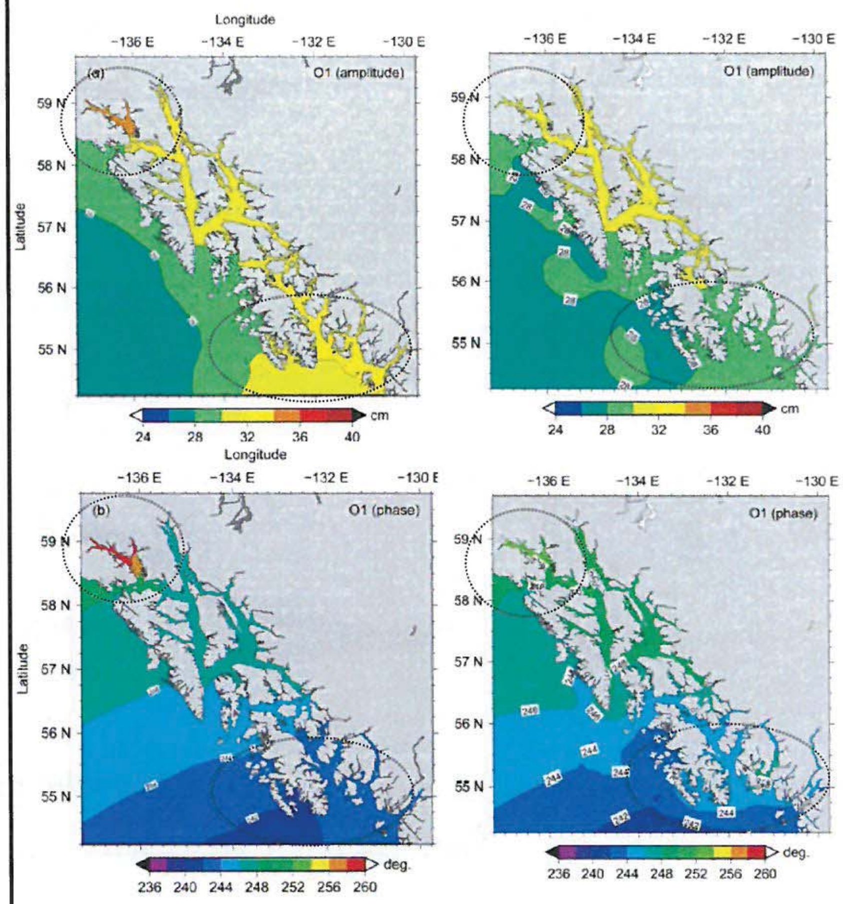


Figure 2. The triangular grid for the finite element model.

Comparison of two models

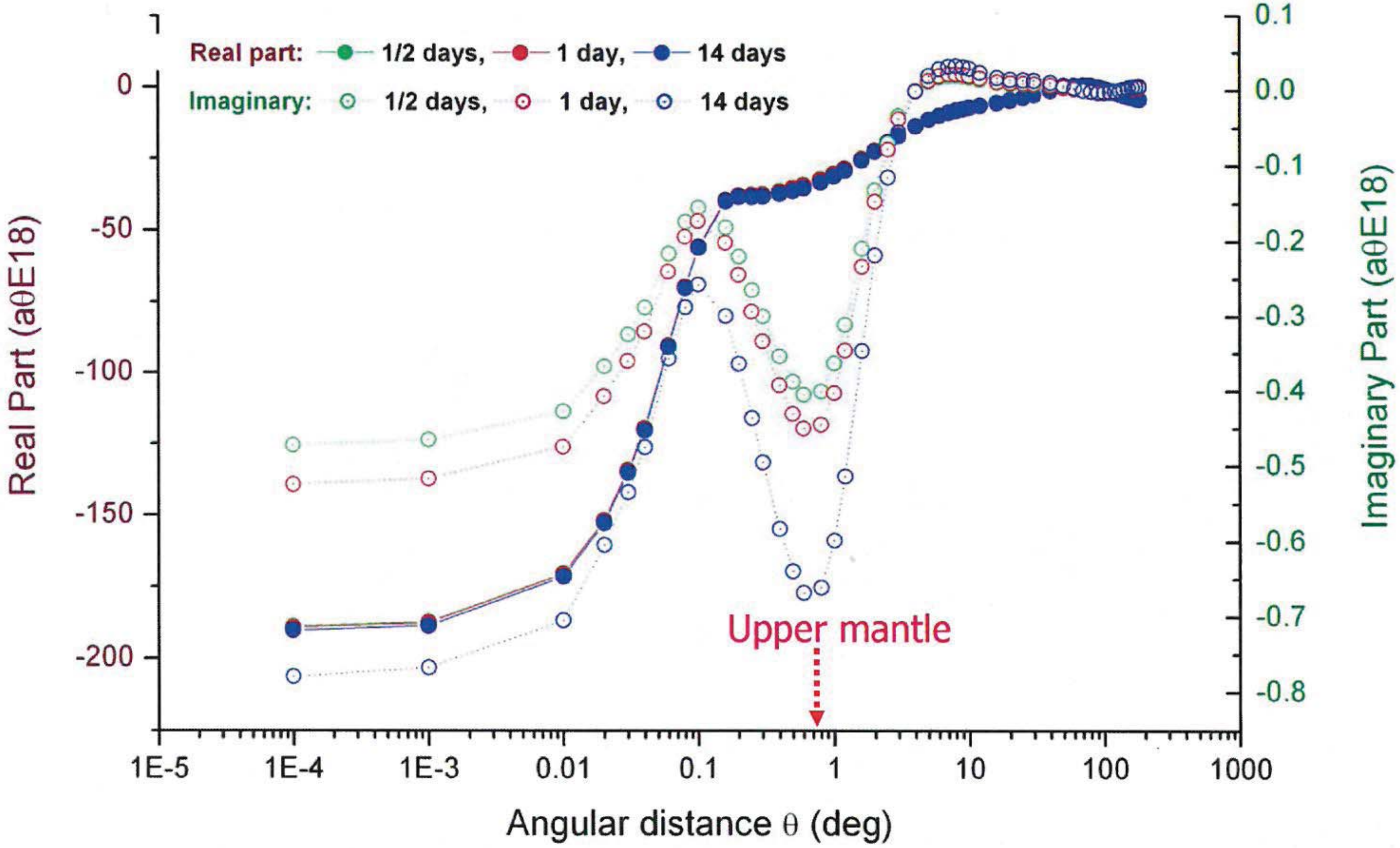
M2	O1





Dynamic Load Green's Function for Gravity

(Model: 1066A with PREM Q)



Note: This figure is referred to the dynamic Love number computed by Okubo & Tsuji (2001).

Computed Ocean Tide Effects

O1 wave	Newt.	Newt.	Elastic Load		Inelastic Load	
	FES+INZ	FES+F00	FES+INZ	FES+F00	FES+INZ	FES+F00
AMP	1.031	1.028	1.522	1.554	1.515	1.547
PHS	295.81	295.59	293.55	293.54	293.76	293.77
Sum AMP			2.552	2.584	2.543	2.575
Sum PHS			294.46	294.45	294.65	294.64

M2 wave	Newt.	Newt.	Elastic Load		Inelastic Load	
	FES+INZ	FES+F00	FES+INZ	FES+F00	FES+INZ	FES+F00
AMP	2.736	2.739	5.132	5.161	5.282	5.312
PHS	188.86	188.52	186.68	293.76	186.77	186.15
Sum AMP			7.866	7.897	8.017	8.049
Sum PHS			187.44	186.93	187.48	186.96

*Note: 1. FES +F00 > FES+INZ,

2. M2 = about 3 times of O1

Comparison with the model predictions

O1 wave	Obs. Mean	Elastic model		Inelastic model	
		DDW+INZ	DDW+F00	DDW+INZ	DDW+F00
AMP	33.211	33.134	33.136	33.190	33.193
PHS	-4.11	-4.02	-4.00	-4.06	-4.04
O-C AMP		0.077	0.075	0.021	0.018
O-C PHS		-0.09	-0.11	-0.05	-0.07

M2 wave	Obs. Mean	Elastic model		Inelastic model	
		DDW+INZ	DDW+F00	DDW+INZ	DDW+F00
AMP	15.492	16.208	16.165	16.093	16.047
PHS	-4.52	-3.60	-3.38	-3.72	-3.48
O-C AMP		-0.716	-0.664	-0.601	-0.555
O-C PHS		-0.92	-1.14	-0.80	-1.04

*Note: 1. Difference between the elastic and inelastic cases: M2 > O1

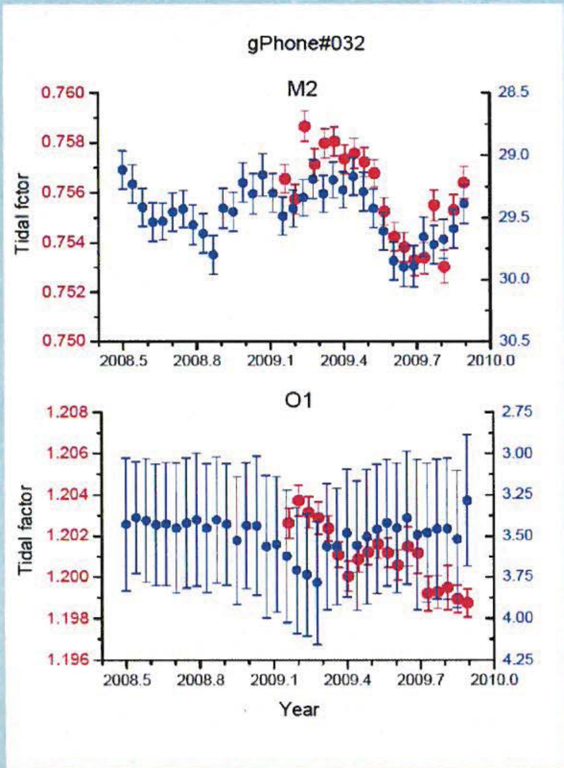
2. It may be related to the scale of spatial variation (M2 >> O1).

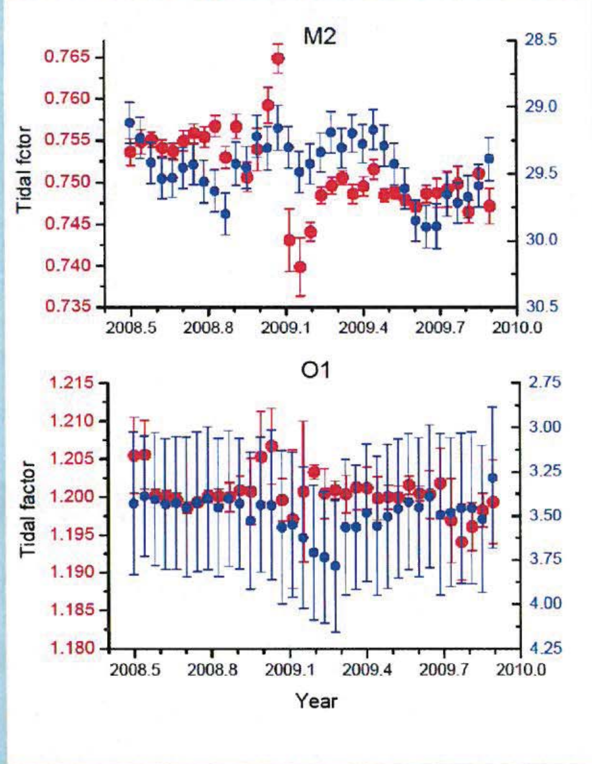
Possible error sources

1. Observation errors

Observed gravity tide may be affected by the temporal changes of ocean tide, which are coursed by the ocean variability.

Time variations in the observed tidal factors of the gravity tides and ocean tides



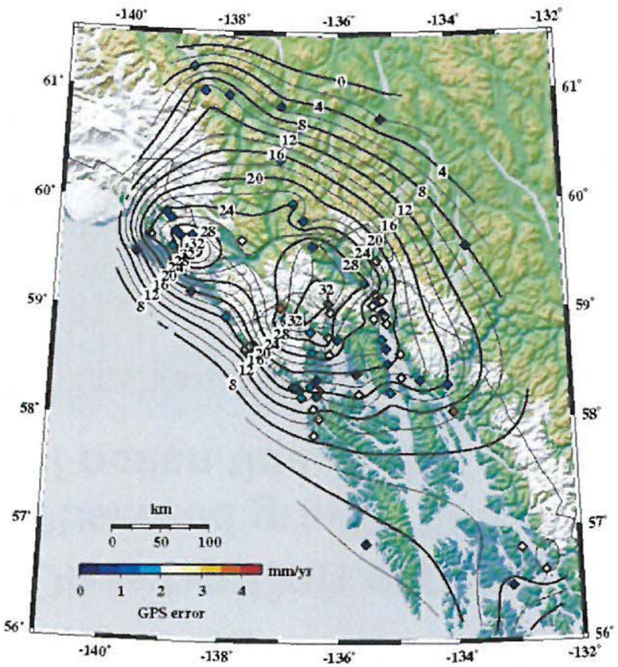


Note: Variability of the ocean may change by year.

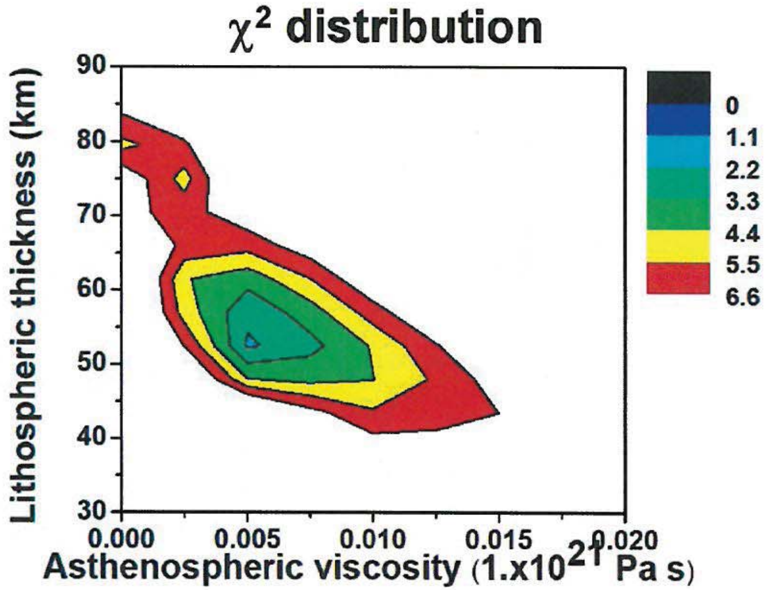
2. Error in the convolution integral

Convolution $$L(\mathbf{r}) = \rho \int_S G(\Theta) H(\mathbf{r}') dS,$$

2.1 Green's function G(Θ)

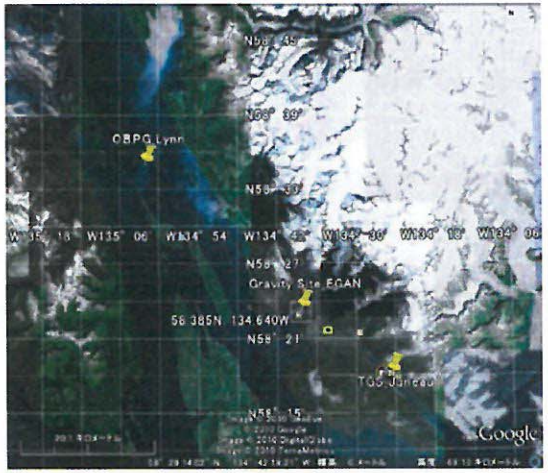


Larsen et al.(2009)



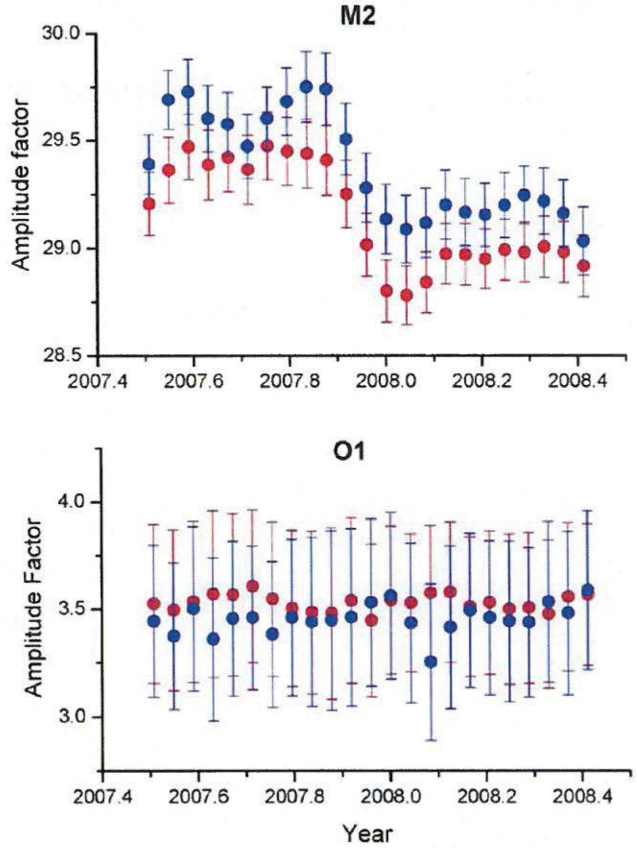
Sato et al. (2010)

2.2. Time variation in the ocean tides:



Time variations in the amplitude factor of ocean tide

(Red: OBPG at Lynn, Blue: Tide gauge at Juneau)



Note:

/ Time variation:
OBPG data show very similar variation to that in the tide gauge data.

It suggests that the variation in the tide gauge data is not a steric change (i.e. changes in temperature and salinity).

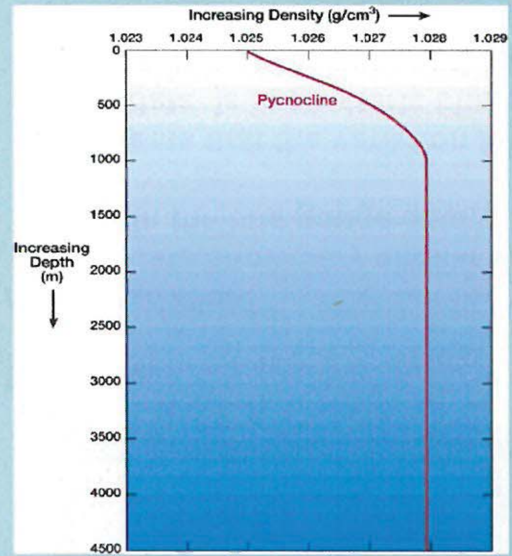
So, these change shall actually produce the loading changes.

/ Variability: M2 >> O1

Difference in M2 by location is larger than O1.

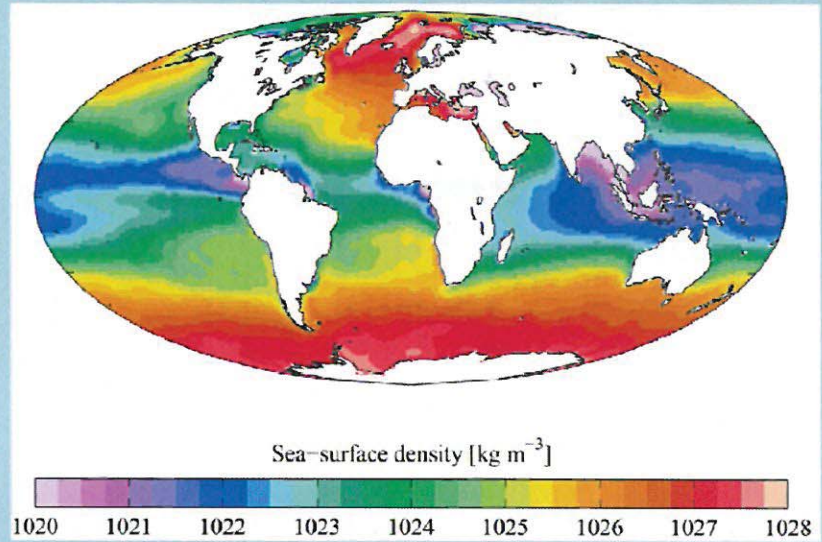
2.3. Density of the ocean water

Depth change in the density



(after WOA)

Surface density of the ocean water in the world



(after WOA)

We used a value of 1026 kgm^{-3} in our computation of convolution integral.

(Mean depth of the area of regional model: 1363 m over 1,4635 grid points)

The right figure indicates that the rage of density variations is within 1024+/-4 kgm^{-3} (+/-0.4%).

Summary:

1. Calibration for the scale factors of the gravimeters:

   Accuracy of the calibration for the scale factors by FG5#111 are at the order of 0.2 % for both gravimeters of GP032 and G578.

   We have confirmed that, during the observation period, the scale factors were stable within 0.05% and 0.7% for GP032 and G578, respectively.

2. Observation errors:

   They are 0.005-0.007 μGal and 0.01-0.03 μGal for M2 and O1 waves, respectively.

   Although the available data length of GP032 is about 1.8 times shorter than that of G578, the observation errors of tidal amplitudes obtained from GP032 are about 2 times smaller than that of G578.

   The reason may be mainly due to higher stability of GP032 than G578 to the environmental changes in such as the room temperature. Also the auto levering system of G032 might contribute to the small observation error of this gravimeter.

3. Comparison with the model prediction:

/ The final differences between the observations and the model predictions are within 0.02-0.08 μGal and 0.8-1.1 μGal for O1 and M2, respectively.

/ Our comparisons clearly suggest that the model predictions with the inelastic earth model explain the observations better than those with the elastic model (i.e. about two times).

/ The difference in M2 is far larger than the amplitude differences in the observations from two gravimeters (i.e. systematic error) and, of course, the observational formal 1σ errors.

Further studied are needed:

Why the M2 tide shows so large difference in the comparison with the predicted tides?

A possible error source is the load Green's function used here, because the GPS observations in SE-AK indicate a very low asthenospheric viscosity at the order of 10^{-18} Pa s over this area.

We must also carefully estimate the effects of the seasonal variability in the M2 ocean tide.
It is desired to continue the observation more than 1 year at least in order to reduce this effect.


Thanks for your attention