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Development of the Estimation Service of the Earth's Surface Fluid Load Effects for Space Geodetic Techniques

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Load Displacement Estimation Service

Temporal change of surface loadings due to the mass redistribution of the fluid envelope of the Earth, i.e., atmosphere, hydrosphere, and cryosphere deform the Earth, and cause the coordinate changes of the observation sites. The coordinate changes can be measured by space geodetic techniques such as VLBI and GPS. From the viewpoint of crustal movements, such displacements due to these noises **should be eliminated**.

However it is not easy to estimate the influences of loads. So, we are planning to develop the displacement database based on the web. This database runs as a **service to calculate the load displacements** at **arbitrary time** and **arbitrary location** by **arbitrary users**. This service can estimate the several loads such as atmospheric load (AL), non-tidal ocean load (NTOL), continental water load (CWL).

Estimation of the load influences

The deformation of the Earth's surface due to loading can be estimated by convolution integral with the Farrell's Green function (Farrell, 1972). The radial elastic deformation is given by a global integral:

$$L(\theta',\lambda') = \rho \iint H(\theta,\lambda) G_L(\phi) T(\alpha) dS$$

where ρ is the mean density of the loading material, H is the data of the mass variations, G_L is the mass-loading Green's function of displacements (Farrell, 1972), and T is a combination of the trigonometric functions of azimuth (α). G_L is a function of the angular distance (ϕ) between the estimation point with coordinates (*colatitude*, *longitude*) = (θ', λ') and the loading point (θ, λ).

Load Displacement Database

Concept

Eliminate the load influences which can estimate

- Can't ignore the load influences in modern geodesy
- Must eliminate the load influences to research the non-secular and non-periodic displacement
- Can estimate the load influences which were caused from geophysical phenomenon

Database runs as a service to calculate the load displacements at arbitrary time and arbitrary location by arbitrary users based on the web.

✓Input
site coordinates
(x, y, z / lat, lon, height)
date and time
(yyyy, mm, dd [hh])

✓Output
load displacement
(x, y, z / lat, lon, height)
time series / global grid

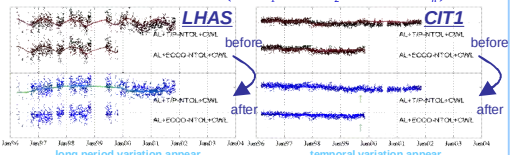
✓Options
kinds of load
Atmospheric load
(surface pressure: NCEP, JRA, ...)
Non-tidal ocean load
(sea level : altimeters / data assimilation: ECCO)
Continental water load
(soil moisture model)
Snow load
(snow depth)
Land-Sea grid

Examples of Load Correction

GPS Site Coordinates Time Series

We tested the load correction to GPS site coordinates time series (IGS and GEONET).
The corrected time series were calculated as follows:
(We removed trend and steps due to the earthquakes and volcanic activities from the original time series.)

$$Corrected\ GPS = GPS - (Load_1 + Load_2 + \cdots + Load_n)$$

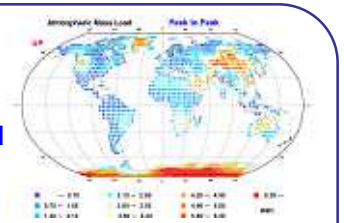


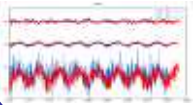
Periodicity
The annual amplitudes have decreased in most cases, the decrease percentage was about 20%.
(AL+T/P-NTOL+CWL)

Time Series
The important signal which hid appears after load correction. It is thought that these signals show the change in a more local environment.
It can't be evaluated by the decrease percentage.

Land-Sea Mask
5'x5' grid

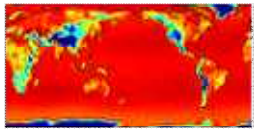
Load





Atmospheric Load
Non-tidal Ocean Load
Continental Water Load
Snow Load
...

Global Data



Surface Pressure
Sea Level
Ocean Bottom Pressure
Soil Moisture
Snow Depth
...

Analyst

Station Coordinates
(x, y, z / lat, lon, height)
Station Name
(IVS, IGS, ILRS)

Load Displacement

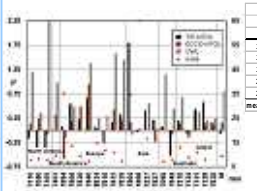
GPS Analysis with Load Correction

NICT is developing the software for precise orbit determination named concerto. Concerto version 4 for time transfer (c4gps) is a special version to analyze the GPS data. We added additional function to correct load influences. Now we are adjusting the software, but we are planning to provide the **load corrected time series** of the arbitrary GPS sites.

	Specification for c4gps
Observation	GPS Code & Carrier Phase, PPP/single difference
Earth rotation	IERS Conventions 2003
Displacement of reference points	IERS Conventions 2003 Solid Earth Tides, Ocean Loading, Pole Tide Antenna phase center offsets and variations **Load Displacement** (atmospheric load, non-tidal ocean load, continental water loca, etc.)
Models for atmospheric propagation delays	Tropospheric model (NMF, GMF, KARAT) Ionospheric model, Phase wind-up, etc.
Parameter estimation	batch of linear least squares method

Examples of SLR analysis with Load Correction

For analysis of the SLR data we used the **'concerto' v4** and added additional functions to the program to include the effects of **3D LOAD** fluctuations.



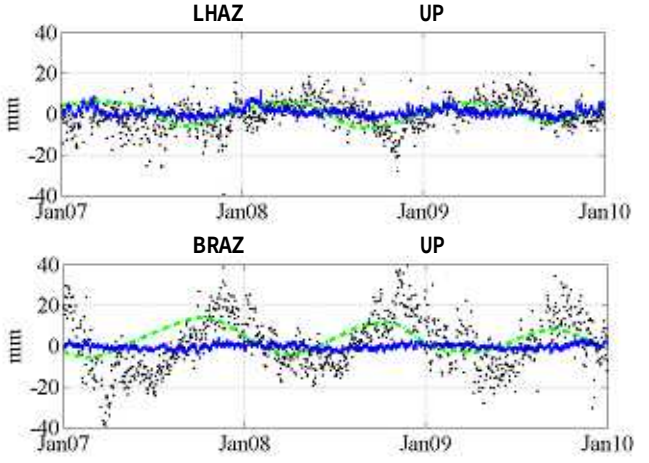
The percent improvement in the station-by-station RMS values of the precise SLR analysis for major stations. The non-tidal ocean load from Topex/Poseidon indicated as black bars and ECCO model indicated as gray bars, and the continental water load indicated as white bars.

Takiguchi, H., T. Otsubo and Y. Fukuda Earth, Planets and Space, 58, 2, e13-e16, 2006.

The overall result of the precise SLR analysis. In the first column, the annual weighted RMS results of the (1) baseline case are listed. For the second to fourth column, the weighted RMS and the improvement percentage from the baseline case are shown for the case (2) to (4).

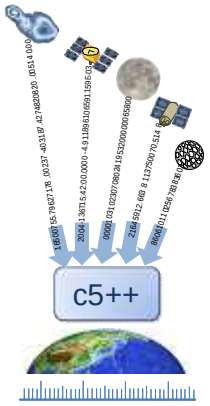
	(1) none		(2) T/P-NTOL		(3) ECCO-NTOL		(4) CWL	
	rms		rms		rms		rms	
	(mm)		(mm)	(%)	(mm)	(%)	(mm)	(%)
199701	9.535		9.534	0.010	9.519	0.168	9.470	0.682
199801	9.473		9.477	-0.042	9.445	0.296	9.323	1.583
199901	9.205		9.209	-0.043	9.206	-0.011	9.136	0.750
200001	9.738		9.737	0.010			9.679	0.606
200101	9.249		9.279	-0.324			9.214	0.378
mean	9.440		9.447	-0.07	9.390	0.2	9.364	0.8

With regard for the NTOL(ECCO) and the CWL, the weighted RMS values almost always get smaller. On average, the weighted RMS decreased **0.2%** for mass-loading displacement corrections using the ECCO-NTOL, and **0.8%** for CWL.
We show the percent improvement in the station-by-station RMS values. A large reduction was observed for North American, South American, Europe and Australia stations when using CWL.



Vertical component of GPS site coordinate time series which calculated using c4gps.
Displacement time series of continental water load which calculated using load displacement database.
Displacement time series of atmospheric load which calculated using load displacement database.

References
Takiguchi H., Y. Fukuda, J. Geod. Soc. Japan, 52, 2, 141-154, 2006a.
Takiguchi H., T. Otsubo, Y. Fukuda, Earth, Planets and Space, 58, e13-e16, 2006b.



Switch to c5++ from c4gps

Now we are developing the new version of concerto named c5++ which is written by c++ based on IERS conventions 2003 (2010). C5++ will also include VLBI as additional space geodetic technique. Recent result is presented by Hobiger et al., "Towards fully automated processing of VLBI sessions results from ultra-rapid UT1 experiments" in this meeting. In near future, we are planning to switch to c5++ from c4gps.

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