Monitoring of the groundwater variation in urban area, by combining GRACE data and in-situ gravity measurements

Yoichi Fukuda, Keiko Yamamoto
Graduate School of Science, Kyoto University
Toshiyuki Nakaegawa
Meteorological Research Institute, JMA
Jun Nishijima
Graduate School of Engineering, Kyushu University
RIHN (Research Institute for Humanity and Nature)
Project 2-4: Human Impacts on Urban Subsurface Environments
http://www.chikyu.ac.jp/USE/

- Assess the effect of human activities on the urban subsurface environment, especially in Asian coastal cities
  - where population numbers and density have expanded rapidly and uses of subsurface environment have increased.

- Goal is evaluate the relationship between the developmental stage of cities and various subsurface environmental problems, including
  - extreme subsidence,
  - groundwater contamination,
  - subsurface thermal anomalies.

Address sustainable use of groundwater and subsurface environments to provide for better future development and human well-being.
Human Impacts on Urban Subsurface Environments
Monitoring of the Groundwater Variation in Urban Area, by Combining GRACE Data and in-situ Gravity Measurements

**Satellite measurements**
Using the GRACE data for estimating and removing regional gravity variations.

**In-Situ measurements**
Evaluating groundwater flow systems, water mass balance in and around the developing cities by means of precise gravity measurements combined with kinematic GPS surveys.

**Contents**
- Outline of the research plan about in-situ measurements.
- Preliminary results using GRACE data.
Precise Gravimetry on Land

Infinite water table of 1 m thickness = About 40 $\mu$Gal gravity change
Preferable accuracy of gravimetry for hydrologic studies: About 10 $\mu$Gal
(Not easy to achieve by means of a spring-type relative gravimeter)

A method combining absolute and relative gravimetry

- Absolute gravimetry at selected control points
- Relative gravimetry at many positions around the area

Detecting groundwater variations as mass variations

Water level
Schedule

- 2006 Sep. Jakarta
  presurvey without AG
- 2007 Feb. Bangkok
  presurvey without AG
- 2007 Oct – Dec
  - Installation and test of AG in Japan
- 2008 -2010
  - Feb (Mar) Bangkok
  - Aug (Sep) Jakarta
Survey Area in Bangkok

50km

80km
Observation Wells in Bangkok
Observation Wells in Jakarta
GRACE Measurements of Mass Variability in the Earth System

Tapley et al., Science, Vol. 305, July, 2004
Why GRACE is Important?

\[ P = E + R + G + \Delta S \]

- **P**: Precipitation
- **E**: Evaporation
- **R**: River runoff
- **G**: Groundwater runoff
- **\( \Delta S \)**: Storage
4 River Basins in the Indochina Peninsula

- Catchment Area

<table>
<thead>
<tr>
<th>River</th>
<th>Drainage Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salween</td>
<td>330 000</td>
</tr>
<tr>
<td>Chao Phraya</td>
<td>178 000</td>
</tr>
<tr>
<td>Irrawaddy</td>
<td>425 000</td>
</tr>
<tr>
<td>Mekong</td>
<td>814 000</td>
</tr>
<tr>
<td>Total</td>
<td>1 750 000</td>
</tr>
</tbody>
</table>
Newly Released GRACE Level 2 Data

- (Monthly) geopotential coefficients
- De-aliasing model

〇: UTCSR RL02, ●: JPL RL02, ◎: GFZ RL03

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>2004</td>
<td>◎</td>
<td>●</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>2005</td>
<td>◎</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
Example of an Spatial Filter

Optimal filter for the river basins by the modified method of Swenson et al. (2003)
Model Estimation of GW Storage

Global Reanalysis Data (GANAL) → Observation

Surface Met. Data

JMA-SiB Model (Simple Biosphere Model)

Snow depth

Soil Moisture, Snow Depth

GW Run off

River runoff Model (GRivet)

GW Storage

P = E + R + G + △S
Resolving Power of the GRACE Data

(a) 4 rivers combined

(b) Mekong

(c) Irrawaddy

(d) Salween

(e) Chao Phraya

GRACE: JPL RL02
GRACE data sets and the GW model

(a) Water Thickness Eq. [mm] vs Date

- Model
- UTCSR RL02

(b) Water Thickness Eq. [mm] vs Date

- Model
- JPL RL02

(c) Water Thickness Eq. [mm] vs Date

- Model
- GFZ RL03
Summary

• GRACE is useful to detect relatively long wavelength mass variations, at least the spatial size of Mekong or Irrawaddy river.
• GRACE data provide constraints to improve hydrological models.
• Through the model parameters, we can combine satellite gravity data and in-situ gravity data for more accurate monitoring of local to regional scale water variations.