Continental Water Storage Changes from GRACE Line-Of-Sight Range Acceleration Measurements

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VI Hotine-Marussi International Symposium, Wuhan, China
May 29-Jun 2, 2006
Summary

Process GRACE data for hydrological studies

• Contemporary method:
  Monthly mean gravity field estimates (GRACE L2 products) after appropriate Gaussian/isotropic smoothing

• Alternative method
  Satellite-to-satellite K-Band Range (KBR) rate data (GRACE L1B)

• This study
  In-situ Line–Of-Sight (LOS) gravity difference based on KBR range acceleration
    • Observation equation
    • Results
Observation Equation

\[ \ddot{\rho}_{12} = \ddot{\mathbf{r}}_{12} \cdot \mathbf{e}_{12} + \frac{\mathbf{\ddot{r}}_{12}}{\mathbf{r}_{12}} - \dot{\rho}_{12}^2 \]

\[ \mathbf{\ddot{r}}_{12} \cdot \mathbf{e}_{12} = (\mathbf{g}_2 - \mathbf{g}_1) \cdot \mathbf{e}_{12} + (\mathbf{a}_2 - \mathbf{a}_1) \cdot \mathbf{e}_{12} \]

Line of Sight (LOS) gravity difference

\[ g_{LOS} = (\mathbf{g}_2 - \mathbf{g}_1) \cdot \mathbf{e}_{12} \]

\[ g_{LOS} = g_{\text{mean earth LOS}} + g_{\text{n body LOS}} + g_{\text{tides LOS}} + g_{\text{atmosphere LOS}} + g_{\text{hydrology LOS}} + g_{\text{others LOS}} \]

our interest is the hydrological information

http://www.und.edu/instruct/eng/fkarner/pages/cycle.htm

GRACE/CSR

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Procedure

A priori inter-satellite orbits

KBR range acc. measurements

Gauss-Markov Model with stochastic constraints

Yes

No

| $|r_{12,i} - r_{12,j-1}| < \epsilon$ ? |

Acc. & Att. measurements

Adjusted orbits

Various models

Estimate KBR empirical parameters and accelerometer biases

Calculate in situ LOS gravity difference

Next step is regional inversion

Tides, atmosphere, etc.

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Global ground track

On May 01 2004

North America

Siberia

Amazon
Without KBR range acceleration, cannot calculate KBR empirical parameter and accelerometer biases correctly.
Profiles over North America and Siberia

Unit: $\mu$gal

North America

Siberia
Using different orbits

Difference of LOS gravity differences by using CSR and GFZ orbit

Unit: \( \mu gal \)

The difference is \( 10^{-2} \) of signal
Regional inversion

- Connects LOS gravity difference observable to water storage change
- Inversion based on assumption of a stochastic process

\[
g^{\text{hydrology}}_{\text{LOS}}(r_1, \theta_1, \lambda_1; r_2, \theta_2, \lambda_2; t) = G\rho_w (R\Delta \theta)(R\Delta \lambda) \sum_{i=1}^{N} \left\{ \left( C_{i,1} V\left( \frac{1}{l_1} \right) - C_{i,2} V\left( \frac{1}{l_2} \right) \right) \Delta h_i \sin \theta_i \right\} \cdot e_{12}
\]
Amazon area and Local ground track

The Amazon drainage basin

Orinoco basin

http://www.extremescience.com/AmazonRiver.htm

www.icsu-scope.org/.../scope42/image/fig3.1

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Comparison of water storage change

Apr., 2003

Gaussian smoothing (600km)  Regional estimation (preliminary results, this study)

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Comparison of water storage change

Gaussian smoothing (600km)

Regional estimation (preliminary results, this study)

Square root of PSD (degree RMS) of estimated water height

Degree, n (20,000km/spatial resolution)
Using the Fredholm integral equation to solve for continental water anomaly

(using KBR range instead of KBR range acceleration)

Fredholm integral equation

\[
\rho_{12}(\tau) = (1-\tau)\rho_{12}(t_A) + \tau\rho_{12}(t_B) - T^2 \int_0^1 K(\tau, \tau') \ddot{\rho}_{12} (\tau') d\tau'
\]

Kernel function

\[
K(\tau, \tau') = \begin{cases} 
(1-\tau)(\tau'), & 0 \leq \tau' \leq \tau \\
(\tau)(1-\tau'), & \tau \leq \tau' \leq 1 
\end{cases}
\]

\[
\ddot{\rho}_{12} = g_{\text{mean earth}}^{LOS} + g_{\text{n body}}^{LOS} + g_{\text{tides}}^{LOS} + g_{\text{atmosphere}}^{LOS} + g_{\text{hydrology}}^{LOS} + g_{\text{others}}^{LOS} + a_{\text{LOS}}^{LOS} + \frac{\dot{\rho}_{12}}{|\mathbf{r}_{12}|} - \ddot{\rho}_{12}^{2}
\]

Need to find a way to evaluate integral fast
Conclusion

• Developed a method to calculate in situ LOS gravity difference using KBR range acceleration
• Used the LOS gravity difference to estimate water storage change regionally
• Compared with the results from L2
• Loading effect considered

• Future work:
  • Test our method on other regions
  • Using KBR range (as in the previous slide) instead