The Ohio State University IGS LEO/GPS Pilot Project: Status and Future Plans

Dorota Brzezinska, Jay Kwon and C. K. Shum

Department of Civil and Environmental Engineering and Geodetic Science

The Ohio State University

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Chang-Ki Hong and Tea-Suk Bae
Outline

- OSU IGS/LEO Associate Analysis Center (AAC)
- Mission and operational aspects
- POD techniques supported
- Kinematic POD for CHAMP: test results
- Summary and Conclusions
Established in 2000

Major objectives:

- Near real-time POD for operational use in radio occultation technique of excess path delay estimation
- Post-processed LEO POD
- Atmospheric profiling for GPS Meteorology
- Establishing a network of permanent GPS stations
- Triple difference dynamic GPS POD (OSU GODIVA; Grejner-Brzezinska 1995; Yang, 1995; Goad et al. 1996; Kwon, 1996)
LEO POD techniques currently supported
  ✓ Triple difference kinematic (OSU software)
  ✓ Dynamic (University of Texas, MSODP1)

POD techniques under implementation at OSU
  ✓ Reduced dynamics
  ✓ Dynamic

Measurements from current and future satellite missions
  ✓ Microlab 1, SAC-C, CHAMP, GRACE, COSMIC

Atmospheric profiling
Great Lakes GPS Network (by 2002)
- OSU 16-station network accepted by NSF/SuomiNet collocated at tide gauges
- Part of the NOAA CORS supported by other partners
- Additional 6 NOAA CORS stations at tide gauges

The ultimate goal
- Combined use of ground-based and space borne observations for potential 2D atmospheric tomography
- Atmospheric profiling in near-real time
- Investigate possible enhancement of Great Lakes Forecasting System
Occultation Technique of WV Retrieval: Occultation Geometry
Occultation Technique of WV Retrieval

- **Fundamental measurements**
  - GPS phase atmospheric excess during occultation
  - Bending angle $\alpha$ derived from phase excess
  - Refractivity $N$ derived from bending angle by Abel inversion

- **Orbital quality requirements**
  - LEO 3D velocity should be $< 0.1$ mm/s
  - GPS orbits should be $< 50$ cm
  - Kinematic POD with 30 cm 3D RMS should allow $T$ retrieval better than $1^\circ$ K up to 35-40 km
**Estimated Temperature Error [K] Induced by the Errors in GPS/LEO Orbits: Simulation Results**  
(Langley, 1999; Zhao, 1998)

<table>
<thead>
<tr>
<th>LEO Altitude [km]</th>
<th>Orbit Accuracy [cm]</th>
<th>Orbit Accuracy [cm]</th>
<th>Orbit Accuracy [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post-processed (few days to 2 weeks)</td>
<td>Rapid Solution (1-2 days)</td>
<td>Predicted</td>
</tr>
<tr>
<td>GPS LEO</td>
<td>5 &lt;15</td>
<td>10 &lt;30</td>
<td>50 &lt;100</td>
</tr>
<tr>
<td>750</td>
<td>0.1° to 40 km 0.05° to 25 km</td>
<td>0.6° to 40 km 0.2° to 25 km</td>
<td>2.5° to 40 km 0.3° to 25 km</td>
</tr>
<tr>
<td>450</td>
<td>0.3° to 40 km 0.1° to 25 km</td>
<td>0.9° to 40 km 0.2° to 25 km</td>
<td>3.6° to 40 km 0.6° to 25 km</td>
</tr>
</tbody>
</table>
Since SAC-C and CHAMP occultation data were not available, GPS/MET data were used for testing.
Kinematic POD

**Advantages**
- No gravity model error affects the solution
- Fast (potential for near-real time)
- Quality solution for good PDOP

**Disadvantages**
- No dynamics to compensate for bad geometry
- Requires correct coordinates for a starting epoch
- No solution or weak solution for bad geometry
IGS reference stations and GPS orbit data or OSU GODIVA

LEO observation data

Binary local data base

Station clock error estimation

Station clock error estimation

Detect cycle slips

Construct triple phase differences

LEO orbit interpolation between epochs of observation

LEO POD

A priori values for LEO and station coordinates

Normal matrix

Reduce normal matrix

Solution and update of the a priori values

OSU Kinematic POD

Geodetic Science The Ohio State University
OSU Kinematic POD: Processing Model

- CS are detected using:
  - 1\textsuperscript{st} and 4\textsuperscript{th} differences of
    - ionospheric residual
    - phase/code geometry free linear combination
  - double difference geometry/ionosphere free phase/range linear combination
    - tested value: wideline ambiguity (Gao and Li, 1999)

- Least Squares Batch Solution
  - approximated solution: DD range observations
  - the optimal length of a batch is still investigated
  - optimal base geometry is still investigated
Kinematic POD: CHAMP Test Data

- Test data set: 3 – 5:30 pm, May 21, 2001
- Corresponds to approximately 1.5 revolution
- Data interval 10 s (30 s) CHAMP (IGS stations)
- Different station number tested
- The best solution obtained for the test data set is for 66 stations
  - elevation cut off 5° (CHAMP) and 10° for the stations (next figure)
  - double difference based CS detection
Kinematic Orbit: CHAMP
Kinematic Solution: Bad Geometry

(1) Number of satellites over epochs 1868 to 1878.

(2) Number of stations over epochs 1924 to 1938.

(3) Number of satellites over epochs 2018 to 2027.

(4) Number of stations over epochs 2071 to 2075.
Kinematic Solution: Cycle Slips

Blue square – no CS
Red square – CS

Section 2, 13 epochs
CS Detection Based on DD Phase/Range Combination

![Graph showing ambiguity over epochs with a standard deviation (sd) of 0.3984.](image)
### CHAMP Kinematic POD: Effects of GPS Cycle Slips for 24-h Data

Based on ion residuals

<table>
<thead>
<tr>
<th>Station</th>
<th>Cycle Slip Ratio(%)</th>
<th>Station</th>
<th>Cycle Slip Ratio(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAMP</td>
<td>13</td>
<td>KOSG</td>
<td>0.1</td>
</tr>
<tr>
<td>ALGO</td>
<td>0.4</td>
<td>MADR</td>
<td>0.9</td>
</tr>
<tr>
<td>FAIR</td>
<td>3</td>
<td>TIDB</td>
<td>0.1</td>
</tr>
<tr>
<td>GOLD</td>
<td>0.2</td>
<td>TROM</td>
<td>0</td>
</tr>
<tr>
<td>KOKB</td>
<td>2</td>
<td>YELL</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Based on DD phase/range combination (Gao & Li, 1999)

20% (66 stations)
Difference between RSO and Kinematic POD

Graph showing the difference in meter changes over epochs from 1800 to 2100. The graph compares X, Y, and Z changes over time.
3-D difference between RSO and Kinematic POD
Conclusion and Summary

- Presented analysis focus on CHAMP data quality for May 21, 2001
- Only relative fit to reference orbit shown
- Software modules to be added:
  - body to inertial transformation
  - offset correction from GPS receiver to CoM
  - CS fixing
- Additional study needed to determine an optimal processing batch length and the number of stations
- Implementation of DD technique?