COSMIC-2 Precise Orbit Determination

Jan P. Weiss, Doug Hunt, Bill Schreiner, Teresa VanHove
COSMIC Program, University Corporation for Atmospheric Research, Boulder, CO
Adrian Jäggi, Daniel Arnold
Astronomical Institute of the University of Bern

Abstract
We present initial results for post-processed GNSS orbit and clock estimation for the FORMOSAT-7/COSMIC-2 (Constellation Observing System for Meteorology, Ionosphere, and Climate) constellation. The six COSMIC-2 satellites launched on June 25, 2019 into a 24 deg inclination orbit. The primary Tri-GNSS Radio-occultation Receiver System (TGRS) payload tracks GPS and GLONASS signals on two upward looking precise orbit determination (POD) antennas. We evaluate three GPS and GPS+GLONASS POD solutions applied at the COSMIC Data Analysis and Archive Center using the Bernese GNSS Software. The obtained results are very consistent for the six satellites. Orbit precision estimates are below the 10 cm and 0.1 mm/s 3D position and velocity requirements, respectively. A test case applying carrier phase ambiguity resolution indicates this technique may support the generation of more precise orbits in the future.

Introduction
- COSMIC-2 (Constellation Observing System for Meteorology, Ionosphere, and Climate) launched into a 24 deg inclination orbit on June 25, 2019
- FM 1 was lowered to its operational ~525 km orbit altitude in August 2019
- FM 2-6 remain in ~725 km initial orbit during study period
- The mission objective is to provide an operational constellation for the continuous and uniform collection of atmospheric and ionospheric data for input to daily near-real-time weather forecasts, space weather research, and climate change studies
- COSMIC-2 is a partnership between National Oceanic and Atmospheric Administration (NOAA, USA) and National Space Organization (NSPO, Taiwan)
- Primary payload is the JPL Tri GNSS Radio-occultation System (TGRS) for precise orbit determination (POD) and atmospheric radio occultation (RO)
  - Two upward looking choke-ring antennas for POD and ionospheric sensing (data rate 1 Hz), facing velocity and anti-velocity directions
  - Two high-gain phased arrays for RO measurements (data rate 50/100 Hz)
- Data types:
  - Pseudorange, carrier phase, signal-to-noise ratio
  - GPS L1/C/A, L2P, L2C
  - GLONASS L1C/A, L2C/A

POD Strategy
- Evaluating post-processing POD solutions for data collected October 1-31, 2019
- Three solution sets are evaluated
  1) Antenna 1 (rear), GPS data only
  2) Antenna 1 (rear), GPS + GLONASS data
  3) Antenna 2 (forward), GPS data only
- The POD strategy is summarized in the following table

<table>
<thead>
<tr>
<th>Category</th>
<th>Key Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation data</td>
<td>L1 and L2 pseudorange and carrier phase</td>
</tr>
<tr>
<td>GNSS orbit/keys</td>
<td>CODE final product</td>
</tr>
<tr>
<td>Orbit arc</td>
<td>24 hours</td>
</tr>
<tr>
<td>Data interval</td>
<td>30 sec</td>
</tr>
<tr>
<td>Antenna calibrations</td>
<td>Transmitter: IGS standard applied L1C offsets only; phase center variations not considered</td>
</tr>
<tr>
<td>Apriori LEO orbit</td>
<td>Dynamic FM pseudorange only kinematic solution</td>
</tr>
</tbody>
</table>
| Dynamic orbit solution estimated parameters | Epoch state
  - Constant and 1/rev acceleration in radial, cross-track, along-track
| Reduced dynamic orbit solution estimated parameters | Epoch state
  - Constant and 1/rev acceleration in radial, cross-track, along-track
  - Stochastic acceleration in radial, cross-track, along-track every 60 min, with ambiguity resolved
  - Carrier phase only
| Receiver clock                | White noise stochastic estimated every 30 sec                                   |

Data Volume
- The figure below shows the average daily number of 30 sec phase observations by antenna and GNSS
- Due to operational or POD processing issues, solutions are not generated on all days, as summarized in the table; fewer observations are scheduled on antenna 2, so fewer processed days are expected

<table>
<thead>
<tr>
<th>Number of days antenna 1</th>
<th>Number of days antenna 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>30</td>
<td>24</td>
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<tr>
<td>31</td>
<td>20</td>
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<tr>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>27</td>
<td>16</td>
</tr>
</tbody>
</table>

Results
- The average and std. dev. of the daily phase residual RMS are given below
- In general, all solutions are very consistent in terms of mean RMS, while GLONASS and antenna 2 GPS residuals show more variation (~0.4 mm and ~0.2 mm 1-s, respectively)

Ambiguity Resolution Test
- Data from Oct. 1 for FM 1, antenna 1, are processed with carrier phase ambiguity resolution
- Using a recently released CODE GNSS product
- Comparing the reduced dynamic and kinematic estimated orbits processed with (red) and without (blue) ambiguity resolution yields much better agreement with ambiguity resolution
- This demonstrates the feasibility of applying ambiguity resolution for COSMIC-2 to improve orbit precision

Summary and Future Work
- All six satellites perform consistently in terms of data volume collected, postfit residual statistics, and orbit precision metrics
- Mission requirements for orbit determination are already met
- Further improvements expected from
  - Tuning of reduced dynamic estimation strategy
  - Use of phase center variation calibrations
  - Ambiguity resolved processing
  - Combined processing of the antenna 1 and 2 data (currently under evaluation)
  - Improved antenna reference point offset vectors (potential mismodeling in radial direction under investigation)