NASA Proposed Updates to ICG SSV Booklet

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Proposal 1:
Flight Experiences

Flight Experiences: Need and Background

- Issue: Current booklet edition only provides cursory understanding of multi-GNSS SSV user benefits
  - Chapter 2 “Benefits to users”:
    - Provides cursory descriptions of user mission types and benefits
    - Describes types of benefits expected (performance, mission-enabling, resiliency, operational flexibility) but does not quantify expectations
  - Booklet performance expectations include:
    - SSV metrics as characterized by providers
    - Signal availability derived from global and application-specific analysis
  - Booklet provides no indication of real-world performance experiences or expectations
- Proposed addition: Chapter on flight experiences would enable users to better understand SSV benefits and real-world performance expectations through in-flight examples

Flight Experiences and Future Opportunities: Chapter Scope

- Provider teams share current mission use, receivers employed, mission benefits and observed performance; “mini-paper” 1-2 page descriptions
- Provider teams share future missions, planned receivers employed, expected mission benefits and simulated performance expectations
- Expect to include approximately 5-10 experiences, depending upon international team development support
- See draft template for more details

Draft Template

Spacecraft Mission Name
Mission Organization

Launch date/ planned launch date

Mission Objectives

- Item 1
- Item 2
- Etc,

GNSS Need

Mission Orbit

Navigation Challenges/Uniqueness (e.g. navigation performance, formation flying, precise timing, POD, sidelobe use?)

Current mission or Future mission/dates

Pictorial View of Spacecraft and/or trajectory

GNSS Receiver Employed

- Receiver type
- GNSS Constellations
- # channels
- Frequency bands/modulations
- Etc,

Picture of Receiver

On-orbit or predicted performance

GNSS Visibility

Nav performance

Timing Performance

Relative accuracy (formation flying)

Tabular data and/or plots on first and follow-on page

Flight Experiences and Future Opportunities: Draft Plan

- US collects SUSG Flight Experiences/Future Opportunities (FE/FO) template comments—Aug 15
- US collects SUSG FE/FO mission input suggestions—Aug 15
- US will compile SUSG mission input suggestions and e-mail to team—Sept 4
- Provider/SUSG team members develop 1-2 pager “mini-papers” in line with template and deliver to US team—Oct 17
- Distribution of FE/FO mission inputs to SUSG team for review—Nov 21
- Discussion of compiled flight experiences inputs—ICG-14

Proposal 2:
DOP Analysis

DOP Analysis: Need and Background

- GNSS navigation performance is dependent on multiple factors:
  - Signal strength & visibility
  - Geometric diversity (DOP)
  - Measurement errors
  - User equipment

- Initial release of SSV Booklet considers signal strength/visibility only, as initial proxy for mission navigation performance
  - DOP (geometry) is recognized as contributing factor, but it is not analyzed quantitatively
  - Phase 3 discussions included DOP, but it was pushed to future work

- Classical DOP algorithms are well-known
  - Documented in Phase 3 analysis on FTP: ftp://navigation-office.esa.int/20 - SimulationConfig/30 - Phase 3Config/GEO_DOP_Background.pdf
  - Forms of DOP applicable to sparse signals (HEO, Lunar) are available in literature (Sands 2006): https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070036657.pdf

DOP Analysis: Proposal

- US team proposes the addition of DOP definitions and calculations for each mission-specific scenario
  - GEO, HEO, Lunar

- Two DOP values proposed:
  - PDOP for GEO/HEO cases (combined case only) – needs 4+ signals
  - Generalized PDOP (Sands 2006) for lunar case – ok for sparse signals

DOP Analysis: Analysis Implementation

PDOP (GEO/HEO cases)

- Documented on FTP:
  ftp://navigation-office.esa.int/20 - SimulationConfig/30 - Phase 3Config/GEO_DOP_Background.pdf

- Calculate at each time *t*, **only for combined cases (when 4+ signals in view)**:

(1) $$H = \begin{bmatrix} \frac{\delta\rho_1}{\delta x} & \frac{\delta\rho_1}{\delta y} & \frac{\delta\rho_1}{\delta z} & 1 \\ \frac{\delta\rho_2}{\delta x} & \frac{\delta\rho_2}{\delta y} & \frac{\delta\rho_2}{\delta z} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\delta\rho_n}{\delta x} & \frac{\delta\rho_n}{\delta y} & \frac{\delta\rho_n}{\delta z} & 1 \end{bmatrix}$$ (Geometry matrix for combined constellations)

(2) $$V = (H^T H)^{-1} \qquad \mathrm{diag}(V) = \left[\begin{array}{cccc} V_{11} & V_{22} & V_{33} & V_{44} \end{array} \right]$$ (trace of covariance matrix)

(3) $$\mathrm{PDOP} = \sqrt{V_{11} + V_{22} + V_{33}}$$ (PDOP)

(assumes unit measurement variance $\sigma^2 = 1m^2$)

DOP Analysis: Analysis Implementation

- Generalized PDOP (Lunar case)
  - Documented in Sands (2006): https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070036657.pdf

  - Calculate at each time *t*:

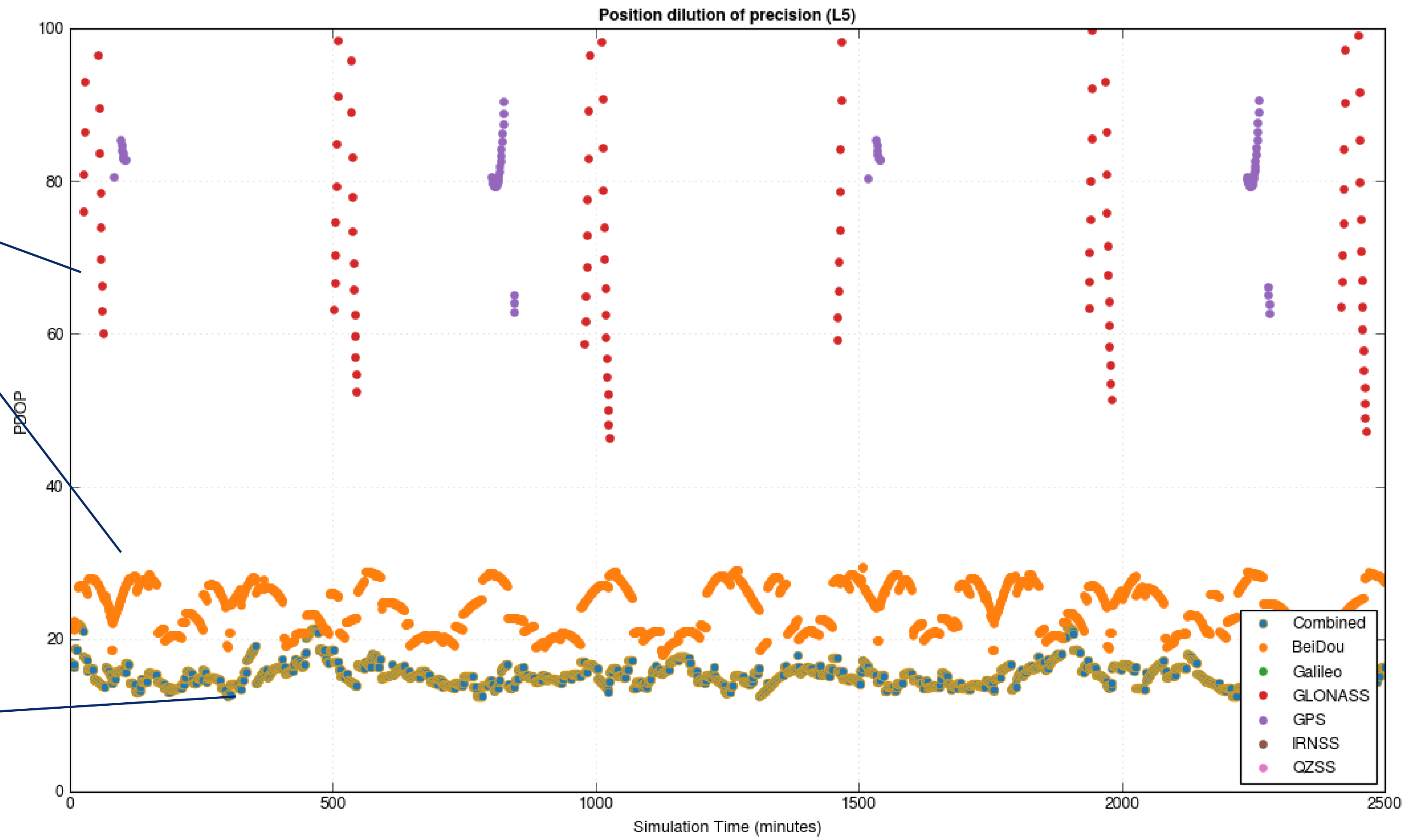
(1) $\tilde{H}_0^T W \tilde{H}_0$ (covariance matrix, *W* = equal-weighting matrix)

(2) $\sqrt{\max\left(eig\left(\left(\sum_{t_0}^{t_n} \tilde{H}_0^T W \tilde{H}_0\right)^{-1}\right)\right)}$ (sum over time and calculate maximum eigenvalues)

DOP Analysis: Example Output (GEO)

Individual cases not included (not continuous)

Combined case



DOP Analysis: Booklet Implementation

- **Modified**:
  - 5.2 Mission-specific performance
    - Addition of general PDOP descriptive language
  - 5.2.1 Geostationary orbit mission & 5.2.2 Scientific highly elliptical orbit mission
    - Addition of PDOP discussion in Results
    - Additional PDOP plot (one plot each, perhaps best/worst case position lines for GEO)
    - Added PDOP column in each result table
      - Column would show average PDOP
      - Likely ”-” for individual constellation rows, figure present for Combined rows
  - 5.2.3 Lunar mission
    - Addition of Generalized PDOP descriptive language
    - Addition of Generalized PDOP plot (one plot)
  - Annex B
    - Addition of PDOP and Generalized PDOP algorithms and detailed results
- **Unchanged**:
  - 5.1 Global space service volume performance

DOP Analysis: Implementation Plan

- US will implement DOP calculations and generate initial results
- Second provider needed for independent verification
- **Notional schedule**:
  - Initial results (GEO/HEO): Aug 15
  - Initial results (Lunar): Sep 19
  - Final results and draft language: Oct 17
  - Final language: ICG-14

Proposal 3:
Identification of Specified Performance

Specified Perf: Need and Background

- Initial revision of SSV Booklet contains SSV template data as published by each provider.
  - *Table 4.2 SSV signal characteristics for each GNSS service provider*
  - Described as "service documented by each individual GNSS service provider, either by formal specification or characterization and analysis."
- GPS and BDS now have SSV specifications.
- Specification status is desirable information for SSV users for future planning purposes.

Specified Perf: Implementation Options

- **Option 1**: Identification in summary table (Table 4.2)
  - Values backed by specification would be marked, such as with bold text, to indicate status.
  - Placement in summary table presents information ”front and center”
  - More information would be contained in provider-specific annexes.
  - Example:

Band	Constellation	Minimum received civilian signal power	
		0dBi RCP antenna at GEO (dBW)	Reference off-boresight angle (°)
L1/E1/B1	GPS	**-184 (C/A)** **-182.5 (C)**	23.5
	GLONASS	-179	26
	Galileo	-182.5	20.5
	BDS	**-184.2 (MEO)** **-185.9 (I/G)**	**25** **19**
	QZSS	-185.5	22

***Bold** values are backed by provider specification. See Annex A for details.

Specified Perf: Implementation Options

- **Option 2**: Identification in Annex A only
  - Specified values identified via bolding in Annex A SSV characteristics tables
  - Additional subsection “Specification Status” in each part of Annex A to contain provider-specific discussion
  - Information will be recorded in Booklet, but not summarized in main body.

Specified Perf: Proposal and Plan

- US proposes to implement **Option 1**, and record specification status in Table 4.2 in addition to Annex A

- US will collect information from providers and update Table 4.2
- US will provide example for update to Annex A.
- Each provider will update Annex A as appropriate.

- Notional schedule:
  - Data provided to US for summary table update – Oct 17
  - US distribution of proposed format for Annex A – Oct 17
  - Updates to Annex A from each provider – Nov 21
  - Final adoption of changes – ICG-14

Proposal 5:
Lunar Analysis Characterization

Lunar Analysis: Need and Background

- Initial revision of SSV Booklet contains high-level summary of lunar analysis results in line with other mission examples
  - Highlights percent 1+ and 4+ signal coverage over entire mission
  - Existing content is highly misleading; coverage is good for initial 50% of simulation, then zero beyond due to effect of C/N0 cutoff
- Analysis summary was rewritten for 2018 ION/IAC papers
  - More accurately captures characteristics of results
  - Drops misleading statistics table

Lunar Analysis: Proposed Text

A lunar scenario was considered in order to explore the boundary of the GNSS SSV beyond Earth orbit. A lunar trajectory from LEO to a lunar fly-by with a return to Earth was simulated (Figure 6). Only the outbound portion was used in this analysis. As with the HEO case, both the zenith-pointing and nadir-pointing user antennas were modelled, with peak gains of 4.5 dBi and 9 dBi, respectively. The spacecraft attitude was kept nadir-pointing.

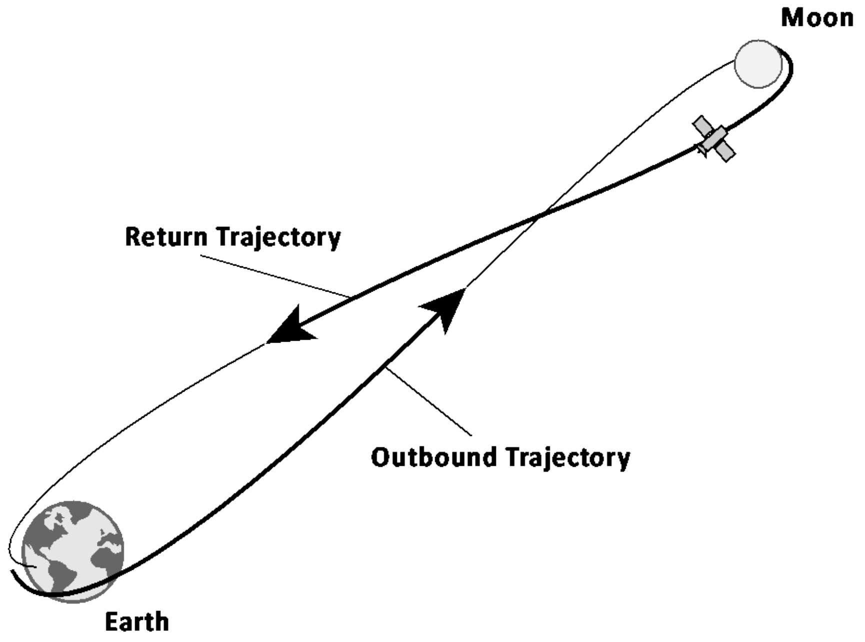


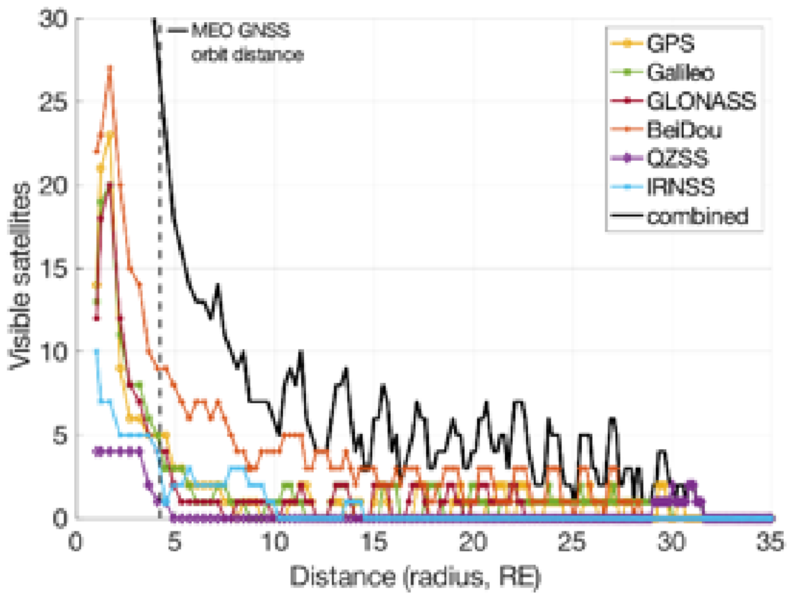
Figure 6: Lunar Trajectory Phases – Only the Outbound Segment Analysed

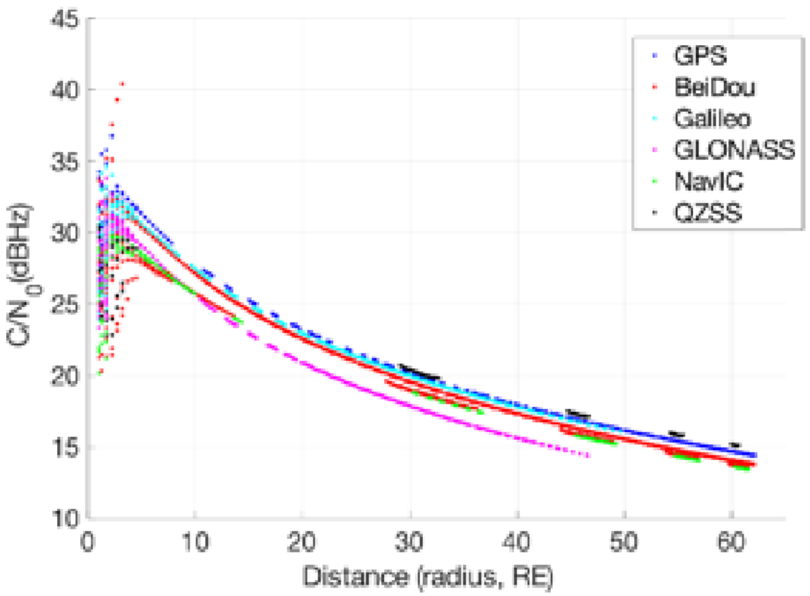
Lunar Analysis: Proposed Text

Figure 7 (Left) shows the general structure of the GNSS signal availability, using the L5 band as an example to capture the contributions of all constellations. Availability is highly dependent on distance from Earth, and user receiver equipment assumptions for the C/N_0 tracking threshold and the user antenna gain. As the distance from Earth increases the availability drops quickly and reaches zero beyond 30 RE, which is approximately 50% of the distance to the Moon. When using all constellations combined the single-satellite availability is nearly 100% to a distance of approximately 30 RE, and zero thereafter. The benefit of the combined multi-GNSS case is best seen above 10 RE, where signal availability is consistently higher than any individual constellation, and often nearly double. Notably, combining constellations does not increase the altitude at which such signals are available; rather, it increases the number of signals available at a given altitude. These results show that navigation with the combined multi-GNSS SSV is feasible for nearly half the duration of a lunar outbound trajectory, well beyond the upper limit of the SSV, and is possibly a solution for navigation for the outbound trans-lunar injection maneuver and return trajectory correction maneuvers.

Lunar Analysis: Proposed Text

Figure 7 (Right) shows the simulated C/N_0 received by the example spacecraft for each individual GNSS constellation and the entire trajectory to lunar distance (60 RE). It shows the reason for the availability drop-off near 30 RE shown in the Figure 7 (Left). The C/N_0 of GNSS signals at the user antenna drops below the 20 dB-Hz minimum threshold beyond 30 RE. If a moderately more sensitive receiver or higher-gain antenna were employed then signal availability would be achievable up to the lunar distance. A simple improvement in antenna gain has been proposed to support lunar vicinity missions such as Gateway.





Lunar Analysis: Implementation Plan

- US will incorporate revised text in Booklet draft
- US will update Annex B with corresponding text
  - Results table will focus on visible range (up to 50% lunar distance)

- Notional schedule:
  - US draft revisions incorporated in Booklet – Oct 17
  - Final revision for adoption – ICG-14

Proposal 6:
Miscellaneous Updates

Misc. Updates

#	Section	From	To (Proposed)	Assignee (Proposed)
1	Figure 3.1	Image cropped on bottom	Corrected figure	ICG
2	Table 4.1	GPS, No. spacecraft (nominal)/orbital planes: 24	27	US
3	Table 5.1	Missing value – L1, BDS, 20 dBHz, 1-signal availability	Insert value	China
4	Figure 5.6	Image low resolution, extra "/" in x-axis label	Corrected figure	China
5	Table 5.11	Format different than other tables	Corrected formatting	ICG
6	Annex A1 GPS SSV Characteristics	Current text	To be updated by provider	US
7	Annex D References	Current text	Update GPS ICDs, add recent papers	US

Proposed schedule: Updates to be provided to SUSG - Oct 17; Adopted at ICG-14.

NASA SSV Draft Video Update

SSV Draft Video Status

- Latest SSV draft video unveiled at Munich Summit SUSG Meeting
- Received initial feedback from Munich participants at meeting as well as additional comments by e-mail and at May 16 SUSG meeting
- Based on feedback, updated draft video to be presented today
- Request final feedback to complete video production and release
- ICG release expected to occur at ICG-14 (India)

SSV Video Comments

Background

- Reviewed by expert SSV team members, international team and general audience
- SSV expert team unanimous comment: very professional video that needs tweaking to make clearer and to resonate with a general audience

Substantiative Feedback

- Too jam-packed—it needs to breathe
- Some transitions are jarring with multiple go-backs to Earth weather
- Narration is very dense and not always in-line with video
- Too many acronyms—remove acronyms
- User benefits are presented several times; giving an appearance of jumping around

SSV Video Comments (continued)

Substantiative Feedback (continued)

- Combining the user benefits together (preferably at the end) will provide a more focused presentation
- Several were concerned about the significant emphasis on weather. Video devotes a great deal of time on this
- Need to make sure the visuals match the words in the script
- Totally missed what the SSV was, what it meant, how it worked
- When new subject started or various applications are presented, need to have words on the screen to reinforce the images
- Remove JAXA/Toyota Lunar video (per request of JAXA) and replace with NASA lunar footage

SSV Video Comments (continued)

Specific Items to Fix

- Need to add a Title
- Need to have a video copy with subtitles and one without subtitles; closed captioning will be done at end
- Get rid of red signal bouncing back from 0:00 to 0:08. It is not correct and confusing.
- Some of the ending logos are incorrect and some are missing (this was added at the 11th hour and was known to be just a place holder)

Current Draft Video Presentation and Feedback Session

- To be supplied

NASA