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Enhancement of Augmentation Signal Availability by SBAS Implementation with the QZSS Constellation

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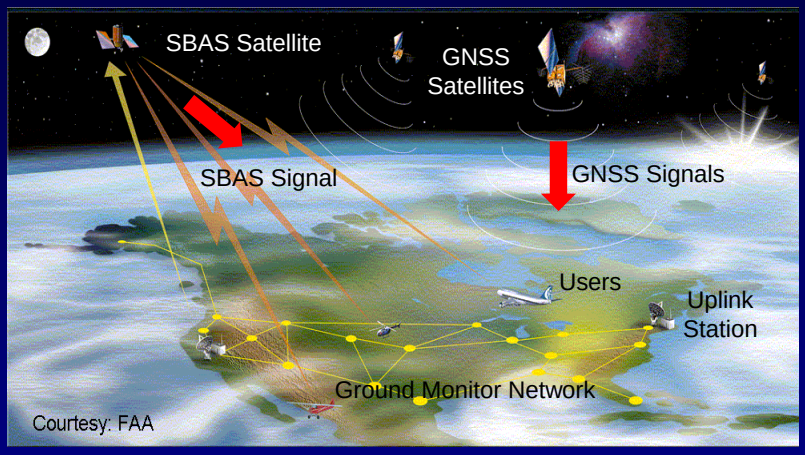
Introduction

- SBAS: Satellite-Based Augmentation System
  - International standard augmentation system.
    - ➢ *Transmits Augmentation information from the SBAS satellite.*
      - ◆ Augments GNSS in terms of integrity and accuracy.
    - ➢ *Current standard: Single-frequency SBAS on L1 transmitted by GEO.*
    - ➢ *US WAAS, Japanese MSAS, European EGNOS, Indian GAGAN.*
- DFMC SBAS: The Second Generation SBAS
  - Dual-Frequency Multi-Constellation SBAS.
  - ENRI has been conducting DFMC SBAS experiment via QZSS L5S signal.
- Innovation: Augmentation Service by IGSO Satellites
  - DFMC SBAS could be transmitted by IGSO SBAS satellite.
    - ➢ *Including QZSS IGSO.*
    - ➢ *Possible solution for applications where GEO signal is likely blocked.*
    - ➢ *Enables SBAS service independent of the latitude of the service area by combination of dual-frequency operation and IGSO transmission.*

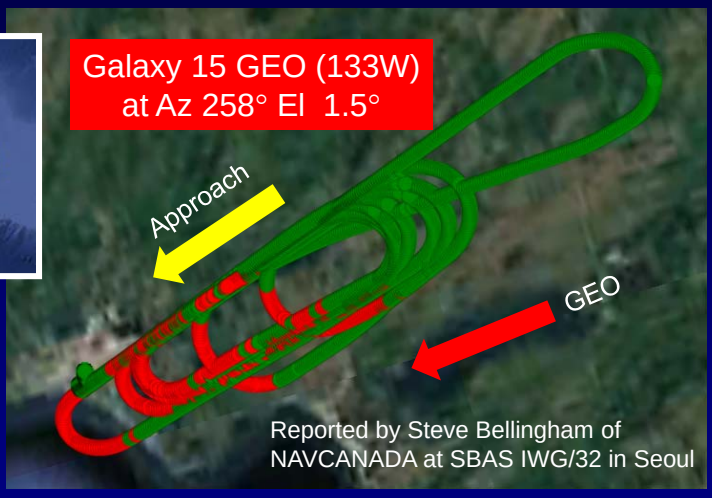
SBAS Architecture



- Monitors consistency of GNSS signals on the ground.
- Transmits differential correction and integrity information via SBAS satellite.

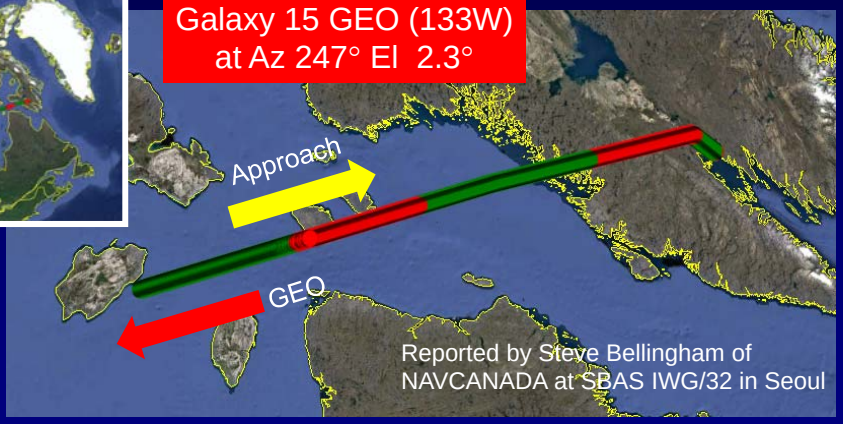
Limitation: The current standard (L1 SBAS) allows transmission only from GEO

NAVCANADA Reports



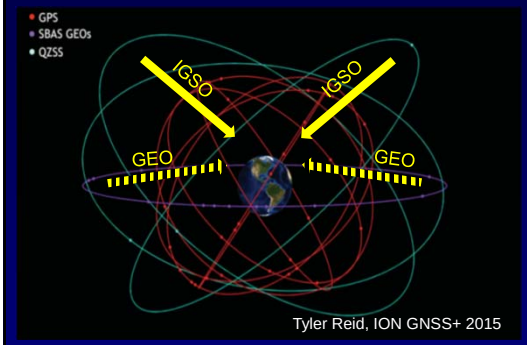
- CRJ circuits at Stephenville, NL (48.6N 58.6W).
- GEO signal is likely blocked due to attitude (pitching and banking).

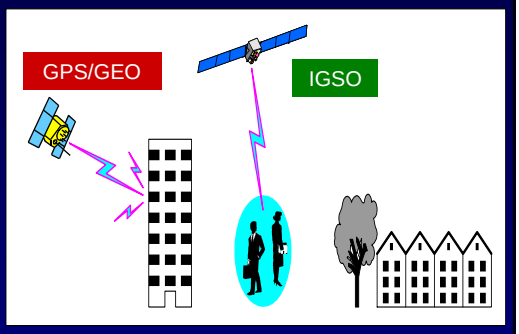
NAVCANADA Reports



- Dash-8 arrival at Iqaluit, NU (63.7N 68.5W).
- They has also reported similar situation for departure.

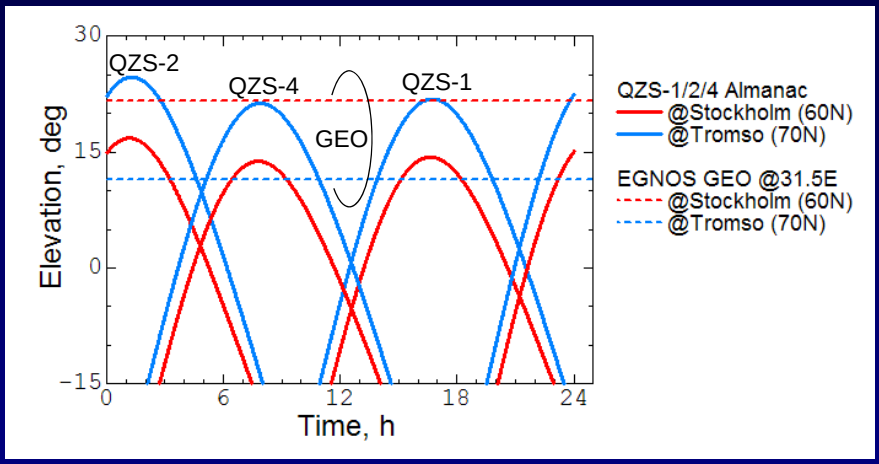
Solution: Usage of IGSO





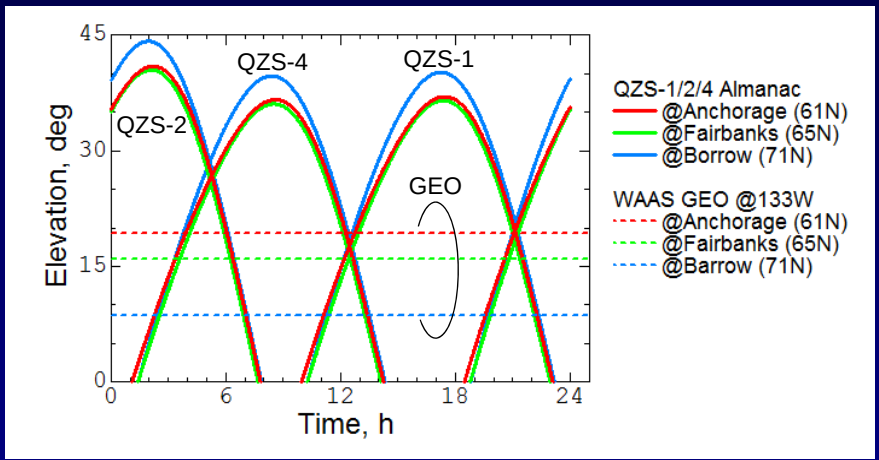
- DFMC SBAS could be transmitted by non-GEO satellites like QZSS IGSO.
- Improves availability of augmentation signals where GEO signal is blocked.
  - *Arctic/Nordic regions, mountain area, urban canyon,…*
  - *Navigating Arctic routes and precise positioning for resource exploration.*
  - *Note DFMC SBAS is not influenced by ionosphere even in Equatorial regions.*
    - Seamless service from Equator to Poles, mountain to urban canyons…

Visibility from Nordic Region



- Elevation angles computed from QZS-1/2/4 almanacs.
- QZSS IGSO satellites are visible in Nordic region; Elevation is higher than EGNOS GEO at some location.

Visibility from Alaska



- Elevation angles computed from QZS-1/2/4 almanacs.
- QZSS IGSO satellites are visible in Alaska region; Could transmit signals always from higher elevation than WAAS GEO.

DFMC SBAS by IGSO Satellites

- The Current SBAS
  - Single-Frequency service transmitted by GEO.
    - *Limited availability in the low latitude regions due to the ionospheric activities.*
    - *GEO signal is likely blocked for some applications.*
- DFMC (Dual-Frequency Multi-Constellation) SBAS
  - The second generation SBAS following the current SBAS.
    - *Eliminates ionospheric effects thanks to dual-frequency operation.*
      - Robust navigation service everywhere in the coverage.
    - *Could be transmitted by non-GEO SBAS satellites like QZSS IGSO.*
  - Standardization activities ongoing by the ICAO.
- New Feature: Transmission by Non-GEO SBAS
  - DFMC SBAS could be transmitted by non-GEO satellites like QZSS IGSO.
  - Improves availability of augmentation signals where GEO signal is blocked.

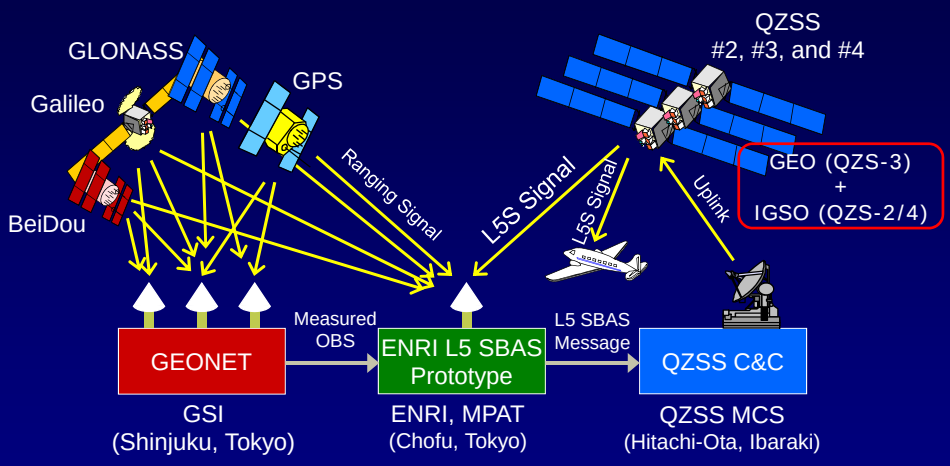
Status of Standardization

- ICAO (International Civil Aviation Organization) has been discussing DFMC SBAS standards.
  - NSP (Navigation Systems Panel) has prepared the technical baseline SARPS (standards and recommended practices).
  - Defined as L5 SBAS using L5 frequency.
    - *L5 SBAS will be added to the current SARPS defining L1 SBAS.*
  - RF specification and message contents are almost fixed.
    - *Validation activities are ongoing.*
    - *Allows Non-GEO SBAS transmission as well as other new capabilities.*
  - Target: Adoption by End of 2020 (NSP/7 meeting).
- EUROCAE has discussed receiver specifications.
  - WG-62 is preparing MOPS (Minimum Operational Performance Standards) for DFMC SBAS receivers.
    - *GPS/Galileo-capable L1/L5 dual-frequency processing.*
  - Processing non-GEO SBAS signals is defined and likely optional function.

Prototype DFMC SBAS

- Prototype DFMC SBAS Developed by Japan
  - The second generation SBAS following L1 SBAS.
    - *Eliminates ionospheric effects thanks to dual-frequency operation.*
      - Vertical guidance service everywhere in the coverage.
  - Electronic Navigation Research Institute, National Institute of Maritime, Port and Aviation Technology has developed the prototype.
    - *GPS/GLONASS/Galileo/QZSS-capable dual-frequency SBAS.*
    - *Compliant with the draft standards of L5 SBAS being discussed at ICAO.*
      - With 8-bit preamble and no Manchester encoding.
      - Helps validation activities ongoing at ICAO.
- DFMC SBAS Experiment has been Conducted with QZSS
  - The First L5 SBAS experiment with live L5 signal from the space.
    - *Using QZSS L5S augmentation signal transmitted from QZS-2, -3, and -4.*
  - Prototype DFMC SBAS is used for the experiment.
  - Began the experiment on 23 Aug. 2017 via L5S signal of QZS-2 IGSO.
    - *Now transmitting from QZS-2/4 IGSO and QZS-3 GEO.*

Experimental Configuration

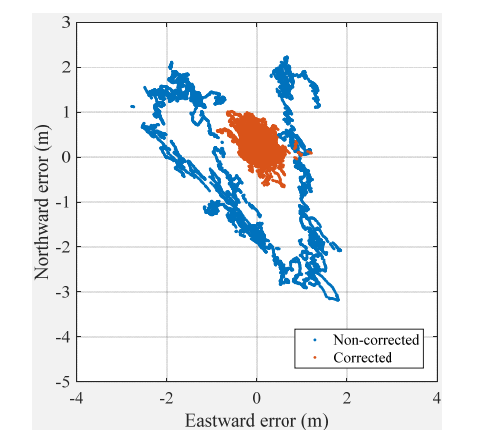


- Supports DFMC
- Provides observation in real time

- Operates in real time
- Dual-Frequency
- Supports GPS, GLONASS, Galileo, and QZSS

- Uplink L5 SBAS message stream for transmission

Real Time Experiment

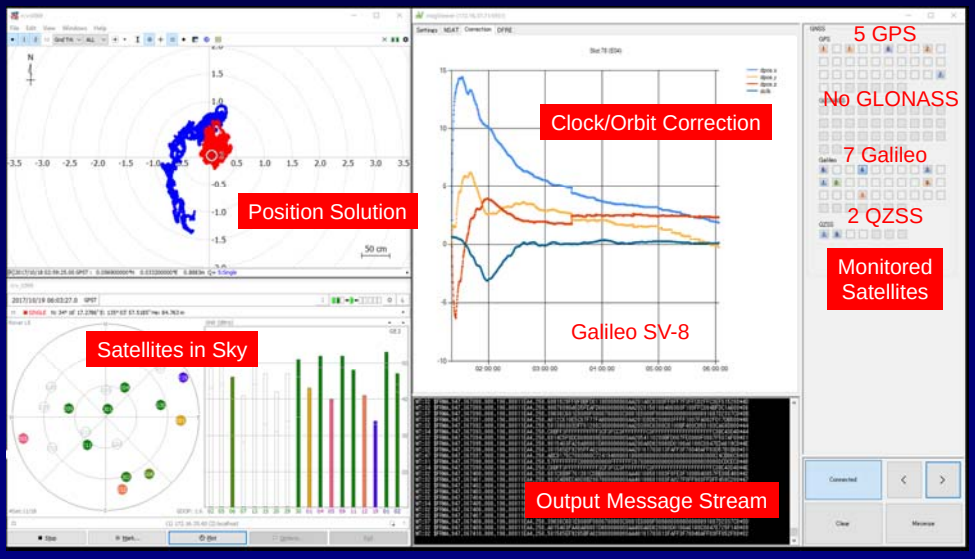


Monitor Stations

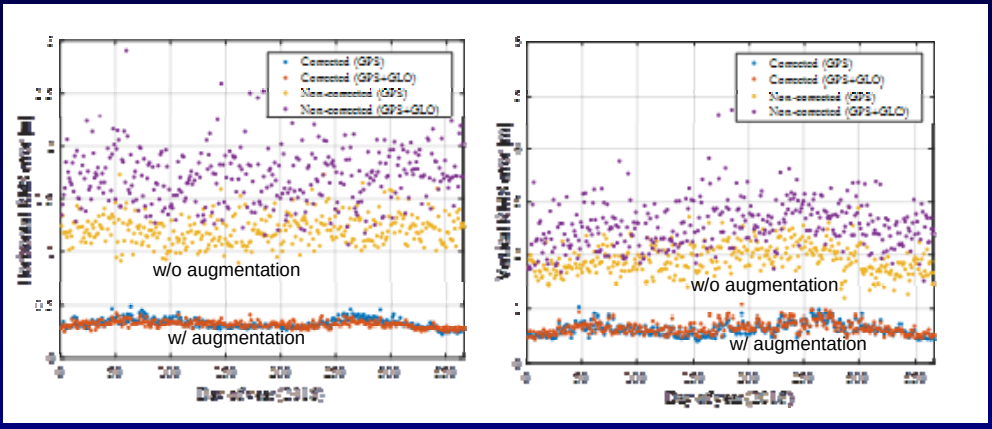
- GPS+Galileo+QZSS
- Dual Frequency (L1+L5)
- DFMC L5 SBAS
- Location:
  GEONET 950369 (Wakayama)
- Period:
  2017/11/13 01:00 - 07:00 (6H)

- Evaluation of L5 SBAS message generated in real time.
  - *Supporting GPS, Galileo, and QZSS in L1/L5 dual-frequency mode.*
- Confirmed that L5 SBAS augments multi-constellation of GPS+Galileo+QZSS.

Real Time Experiment



Long-Term Stability Test

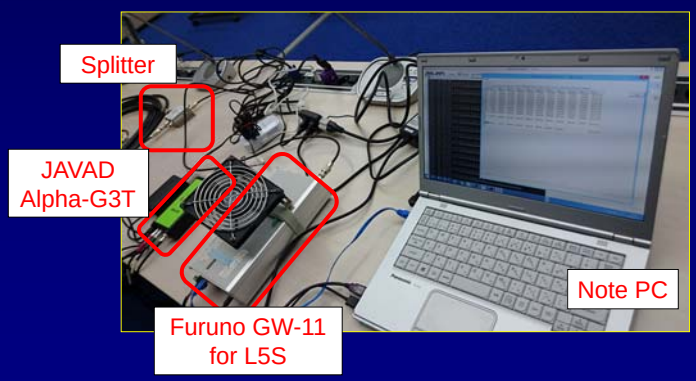


Horizontal Accuracy | Vertical Accuracy

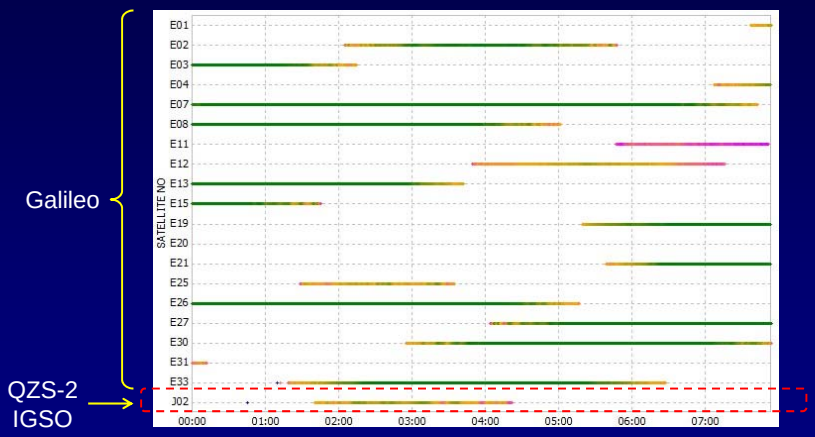
- Evaluated long-term performance using archive data at GEONET 950369 Wakayama.
  - *Prototype DFMC SBAS runs not in real time for this test.*
- Confirmed stable performance for a year; Horizontal ~0.5m and Vertical ~1m.

Reception Trial in Prague

- Preliminary Action with GSA (European GNSS Agency)
  - The first trial to receive L5S signal in Europe.
  - Conducted on March 21-22 at the GSA HQ.
  - Will be followed by the trial in Nordic Region hopefully in this summer.

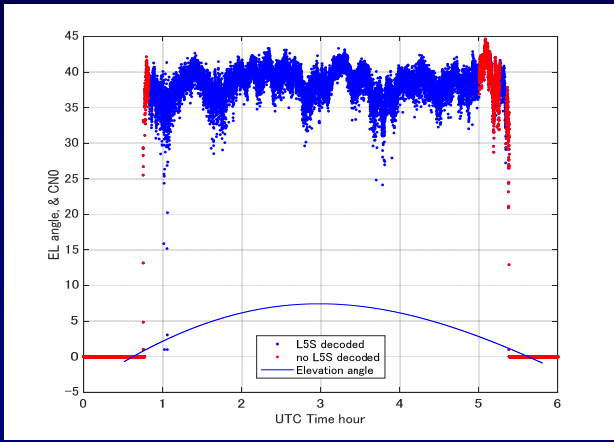


Observed L5 Signals



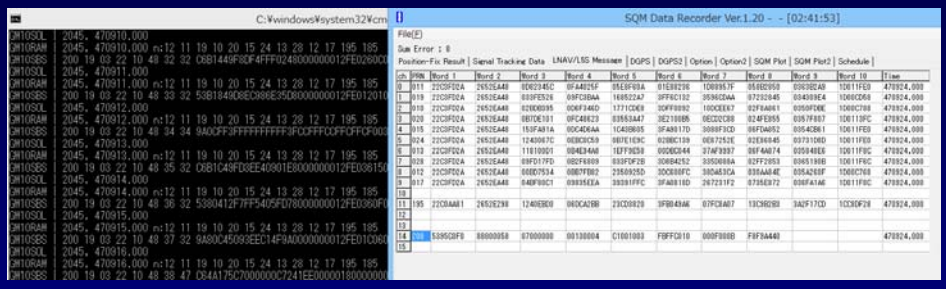
- Observation by JAVAD Rx: Many Galileo satellites are tracked.
- Observation by Furuno Rx: QZS-2 IGSO above 5 deg. elevation during night time in CET.

L5S Signal Reception



- QZS-2 L5S signal observed by Furuno Rx.
- 0 to 7 deg. elevation with C/N_0 of 30 to 45 dB-Hz.
- L5S message stream successfully decoded.

Decoding L5S Message Stream



Logging Decoded Messages

Decoded L5 SBAS Message

- QZS-2 L5S message stream successfully logged and decoded.
- Contains L5 SBAS message.
  - *Confirms the message transmission only: The message has been generated based on domestic stations within Japanese territory.*

Conclusion

- SBAS: International Standard Augmentation System
  - Augments GNSS in terms of integrity and accuracy.
  - The standardization of DFMC SBAS is ongoing by the ICAO.
    - *Eliminates ionospheric effects thanks to dual-frequency operation.*
    - *Could be transmitted by non-GEO SBAS satellites like QZSS IGSO.*
  - ENRI has been conducting the DFMC SBAS experiment by its own prototype via QZSS L5S signal; Recently reception trial in Prague.
- IGSO SBAS Concept
  - Possible solution for applications where GEO signal is likely blocked.
    - *High latitude/polar regions, mountain area, urban canyon,…*
    - *Navigating Arctic routes and precise positioning for resource exploration.*
  - Enables SBAS service independent of the latitude of the service area by combination of dual-frequency operation and IGSO transmission.
  - *Discussions with the northland countries are welcome!*
- Contact for more discussion:

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