Multi-GNSS SISRE Assessment: What Science can do for Hikers, Bikers and the rest of Mankind

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Based on a paper by

O. Montenbruck[1)], P. Steigenberger[1)], A. Hauschild[1)]

1) DLR, DE

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300 South Charles Street
Baltimore, MD 21201
USA

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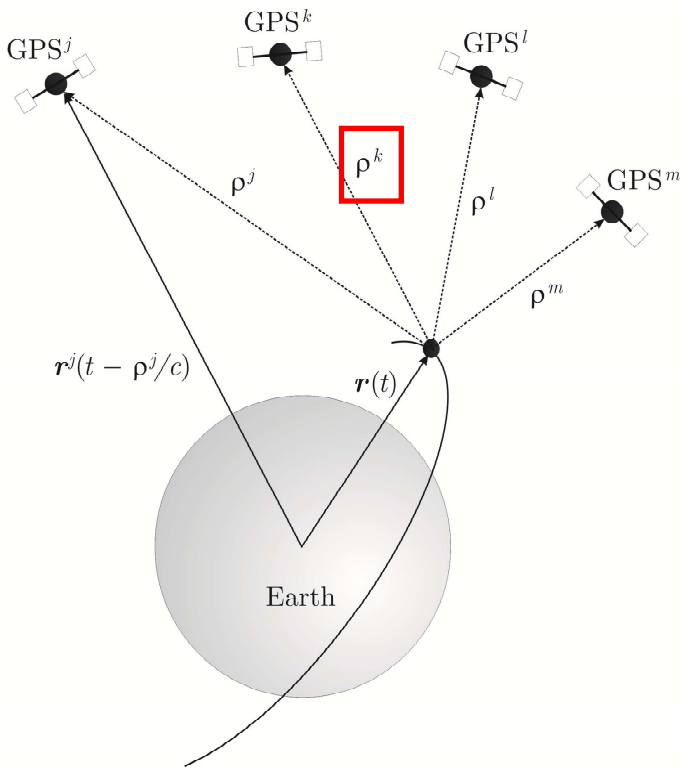
Reference

The SISRE-related part of the presentation is based on

Montenbruck O., Steigenberger P., Hauschild, A. (2018)
Multi-GNSS signal-in-space range error assessment –
Methodology and results.
Advances in Space Research,
https://doi.org/10.1016/j.asr.2018.03.041
or
https://authors.elsevier.com/a/1X1Sb~6OibD1T (till June 30)
Available on-line, 19 pages.

GNSS and SPP

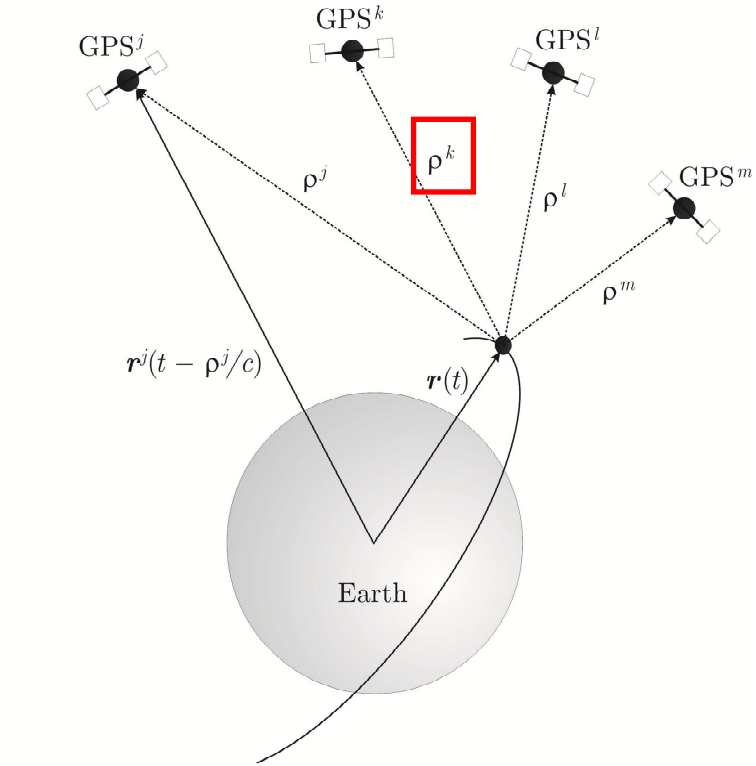


$$\mathrm{UNE} = \mathrm{DOP} \cdot \sqrt{\mathrm{SISRE}^2 + \mathrm{UEE}^2}$$

The "normal" users access a GNSS through Single Point Positioning (SPP), providing the instantaneous 3-d position and the time synchronization of the user receiver w.r.t. to GNSS time.

The User Navigation Error (UNE) is a function of the Dilution of Precision (DOP), the Signal in Space Error (SISRE) and the User Equipment Error (UEE).

SISRE



SISRE statistics may be generated, if the ranges ρ.. are calculated …

- **(a) with the GNSS-provided broadcast information (satellite ephemerides and clock corrections)**
- **(b) with accurate satellite positions & clock corrections**
- **for known user positions *r*(*t*) on the Earth and/or in the Earth-near space**

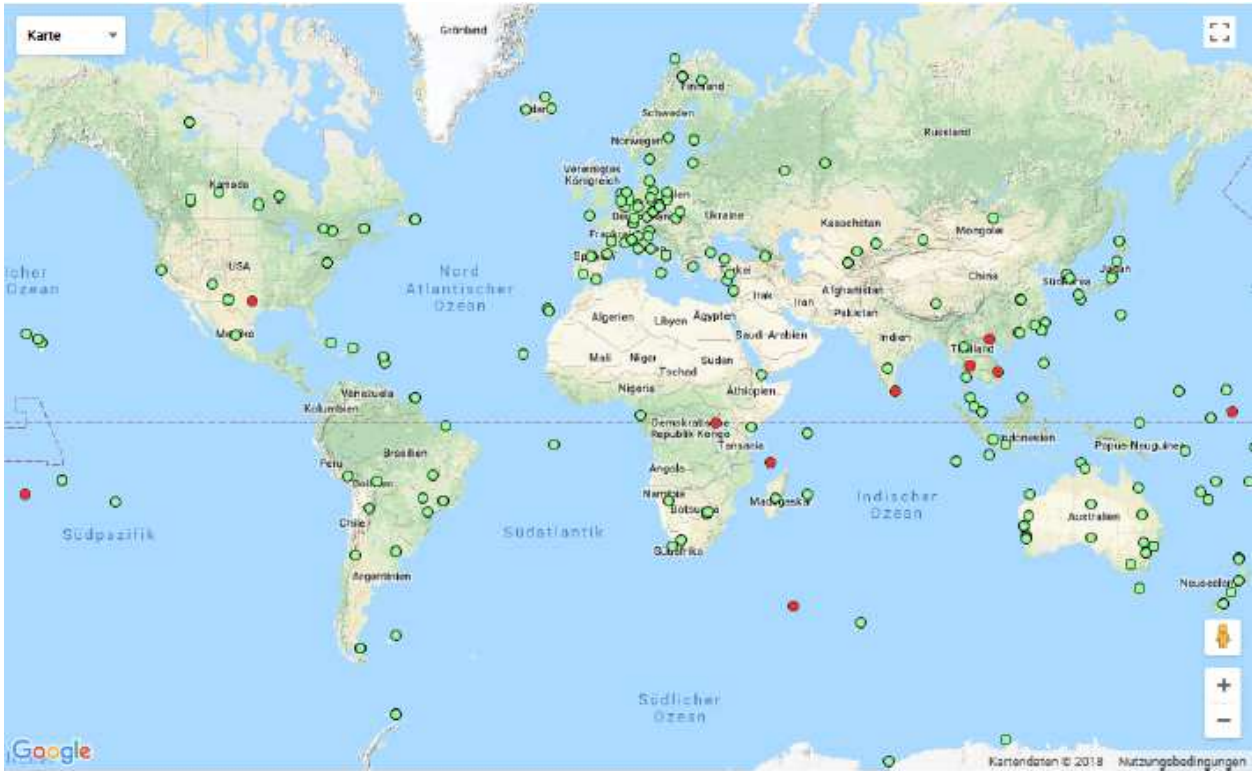
SISRE

Montenbruck et al. (2018) use orbits and clock corrections as obtained from the IGS-MGEX (Multi-GNSS Experiment) as "true" satellite & receiver clock information to generate SISRE statistics.

The statistics of the differences "broadcast—precise ranges" characterize the SISRE-performance of all partially or fully operational GNSS.

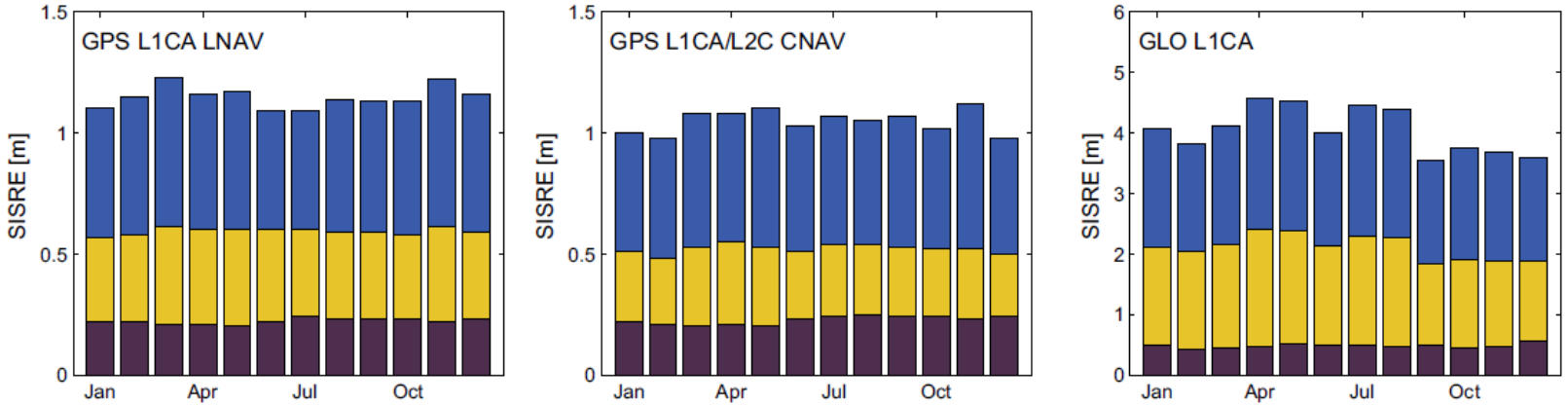
The orbit- and clock-contributions to SISRE can be provided separately.

IGS-MGEX ground-tracking network



In 2018 about 230 Multi-GNSS stations of the IGS track a combination of Galileo, Beidou, QZSS, in addition to GPS and GLONASS and may be used for the SISRE assessment.

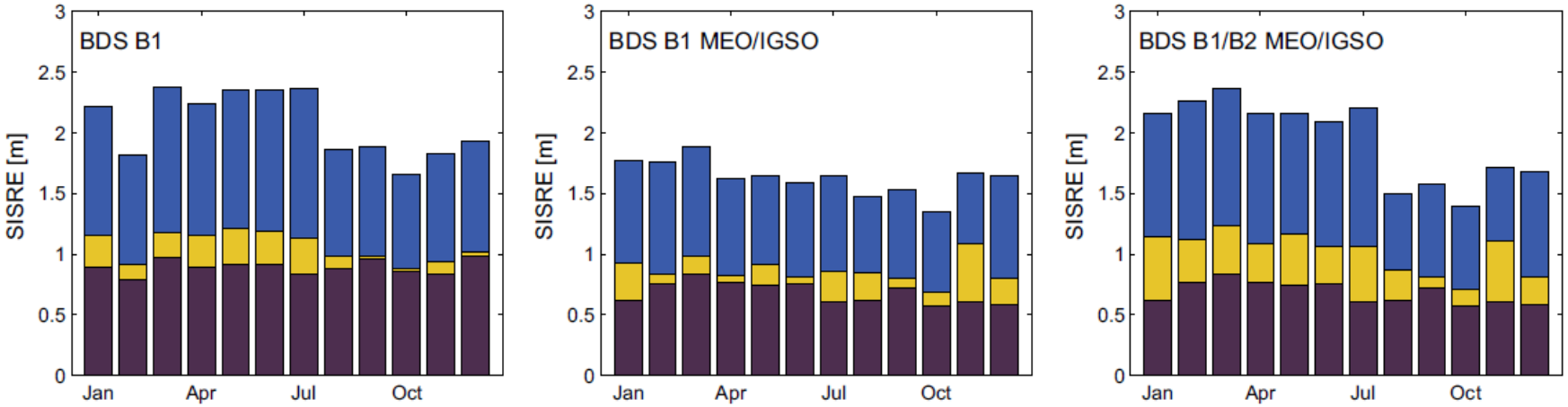
Multi-GNSS SISRE Assessment



Monthly SISRE in 2017 of GPS and GLONASS (note scales!). Upper boundaries of

- **Magenta bar: orbit-only RMS SISRE**
- **Gold bar: RMS SISRE (orbit+clocks+biases)**
- **Blue bar: 95th percentile SISRE**

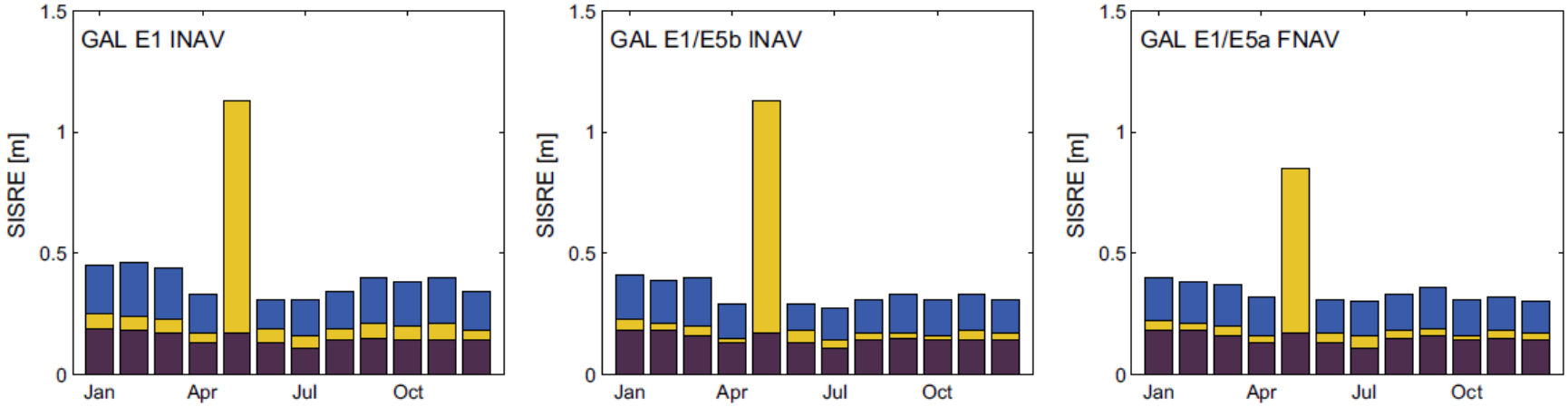
Multi-GNSS SISRE Assessment



Monthly SISRE in 2017 of Beidou-2 System (note scales!; B1 single frequency, B1/B2 dual freq.). Upper boundaries of

- **Magenta bar: orbit-only RMS SISRE**
- **Gold bar: RMS SISRE (orbit+clocks+biases)**
- **Blue bar: 95th percentile SISRE**

Multi-GNSS SISRE Assessment



Monthly SISRE in 2017 of Galileo (scale as for GPS!).

Upper boundaries of

- **Magenta bar: orbit-only RMS SISRE**
- **Gold bar: RMS SISRE (orbit+clocks+biases)**
- **Blue bar: 95th percentile SISRE**

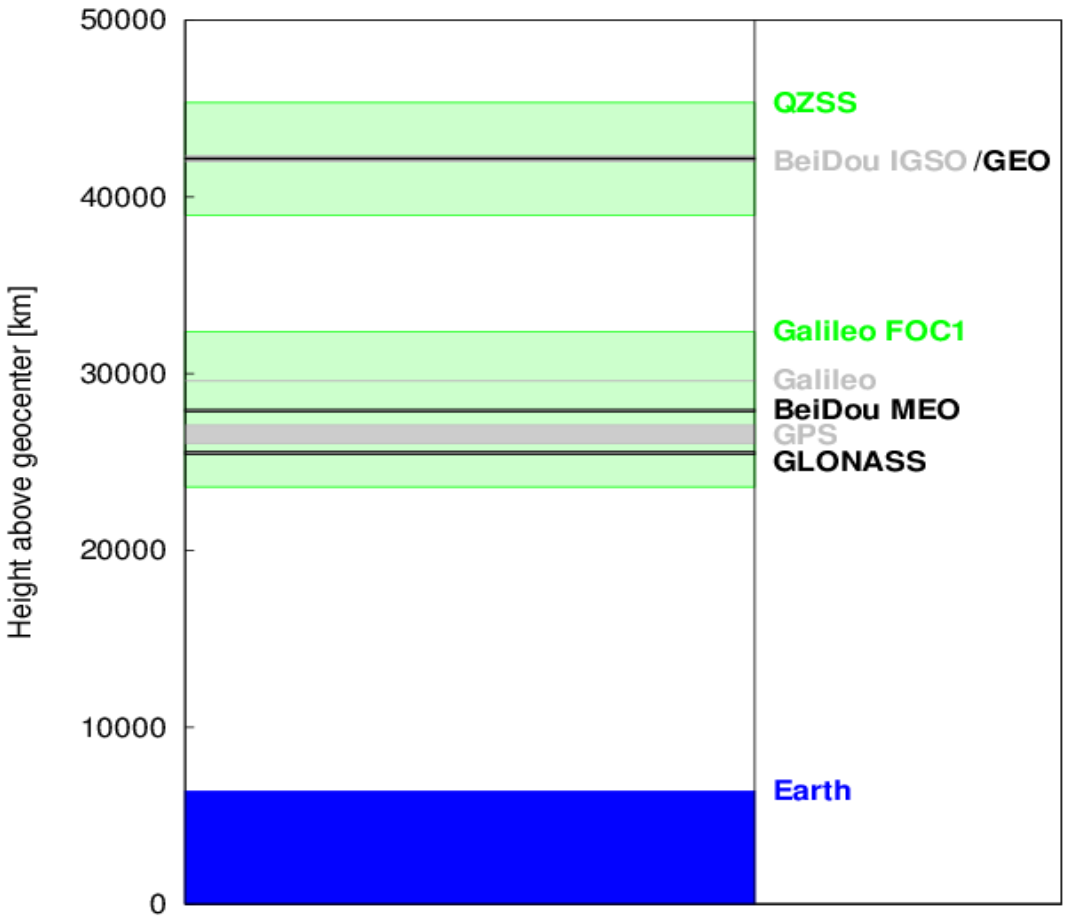
Multi-GNSS SISRE Assessment

Based on data from January to December 2017
global monthly average RMS SISRE of

- **0.2 m, 0.6 m, 1 m, and 2 m were obtained for**
- **Galileo, GPS, Beidou-2, and GLONASS, respectively.**

- **for GPS and GLONASS orbit errors contribute only a moderate part to SISRE; the SISRE budget is dominated by clock errors.**
- **For Galileo and BeiDou, the RMS SISRE for orbits and clocks is only slightly larger than orbit-only contribution.**
- **Galileo benefits from the use of highly stable satellite clocks and short ephemeris update intervals (typically < 100 minutes).**
- **Beidou minimizes the overall range error in the broadcast generation rather than fitting orbits and clocks individually.**
- **GLONASS provides the largest SISRE values, due to the FDMA (Frequency Division Multiple Access) modulation.**
- **The outlier of the Galileo SISRE in May was due to problems in the ephemerides update.**

GNSS Status, May 2018



81 (soon 84) GNSS & RNSS satellites are currently analyzed at CODE.

The satellites have different characteristics (s-m axes *a*, eccentricities *e*, inclinations *i*) and different signals, tracking modes.

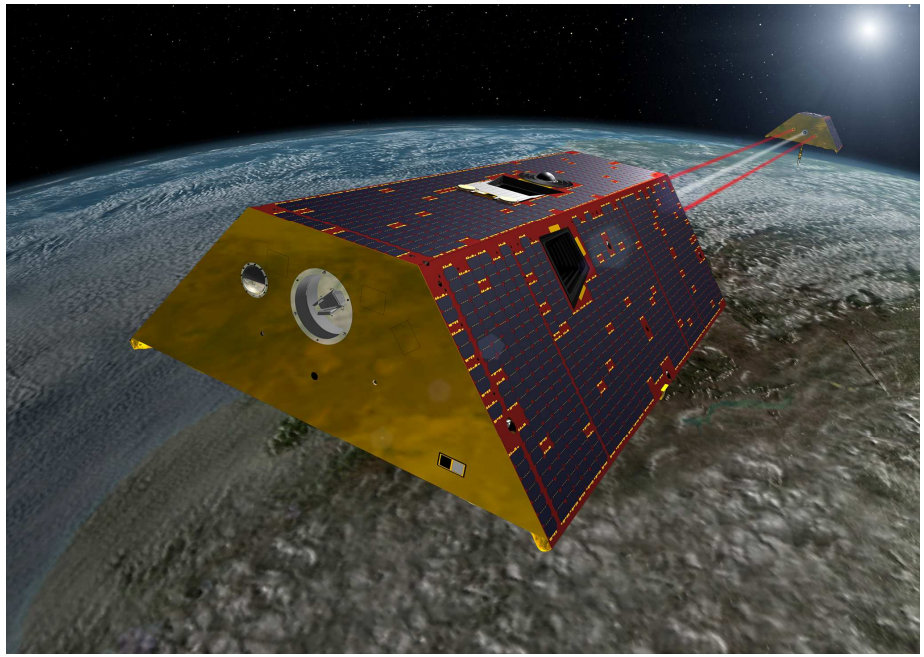
QZS-1,-2,-4 and Galileo FOC-1,-2 satellites are in elliptical orbits (e≈0.075, e≈0.16, respectively)

There are 31 satellites in the GPS constellation, 24 in GLONASS, 14 in Galileo, 15 in Beidou-2, 4 in QZSS.

Galileo approaches full constellation beginning of 2019.

[Private communication, Lars Prange (CODE AC), and Oliver Montenbruck, DLR]

GRACE-FO Launch, May 19 (?)



GRACE-FO is the successor of the US/German GRACE mission, 2002 – 2017 (October, end of GRACE science mission).

The GRACE-FO twin satellites measure the Earth's variable gravity field using GPS, microwave & laser inter-satellite link, and accelerometers.

Ruth Neilan

- **In April 2018 Ruth Neilan stepped down as Director of the IGS Central Bureau and as member of the PNT Board.**
- **1993 – 2018 she was the director of the IGS Central Bureau – and its soul.**
- **The international representatives and the members of the science subcommittee of PNTAB are most grateful to Ruth for a very long, very fruitful cooperation, for her vision, and for her friendship.**
- **We wish Ruth a exciting next phase of her life!**

Summary

The article (Montenbruck et al, 2018) illustrates the value of permanent IGS-MGEX monitoring and data analysis for the "normal" users (hikers, bikers, astronauts in Low Earth Orbits) and for providers of GNSSs.

- **The SISRE is an excellent key performance indicator for individual GNSS, which does, however, not account for constellation differences (# of satellites, inclination, # of orbital planes).**
- **The analysis performed by Montenbruck et al. (2018) is "slightly more complex" than our summary suggests → read the informative article.**

The era of 3+ fully deployed GNSS is about to begin, rendering the MGEX indispensable.

Ruth Neilan was the soul of the IGS for a quarter of a century!