TREASURE
TRAINING RESEARCH AND APPLICATIONS NETWORK TO SUPPORT THE ULTIMATE REAL TIME HIGH ACCURACY EGNSS SOLUTION

NEWSLETTER

ISSUE 6
May 2020
Project Coordinator Dr Marcio H.O. Aquino

WELCOME TO OUR MAY 2020 ISSUE OF THE TREASURE NEWSLETTER!

Marcio H.O. Aquino Coordinator of TREASURE

These are strange and uncertain times but fortunately, despite the crisis that unfolds around us, the enthusiasm of all involved in TREASURE is still vividly present and we have been lucky enough to be able to continue strong with our project. All of us from the TREASURE project wish and hope our readers are all well and in good spirits. I am pleased to say that the pandemic has not had any significantly disruptive impact on our work so far and that everyone has been able to ensure our research progresses according to plan, and that our project deliverables continue to be submitted in time and with their usual high standards...

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SHORT ARTICLES

• Ionospheric scintillation sensitive tracking models and mitigation tools

The fluctuations in the Global Navigation Satellite Systems (GNSS) signals caused by ionospheric scintillation contribute ...

Kai Guo ESR7

[read more]

• Towards fast and reliable single-receiver integer ambiguity resolution-enabled Precise Point Positioning (PPP) using multi-GNSS and multi-frequency GNSS data

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EXPERTS VOICE

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Jade Morton and Brian Breitsch
University of Colorado Boulder, Boulder, CO, USA

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FROM THE COORDINATOR

These are strange and uncertain times but fortunately, despite the crisis that unfolds around us, the enthusiasm of all involved in TREASURE is still vividly present and we have been lucky enough to be able to continue strong with our project. All of us from the TREASURE project wish and hope our readers are all well and in good spirits. I am pleased to say that the pandemic has not had any significantly disruptive impact on our work so far and that everyone has been able to ensure our research progresses according to plan, and that our project deliverables continue to be submitted in time and with their usual high standards.

This has been possible thanks in particular to the hard work of our fellows, i.e. the TREASURE ESRs (Early Stage Researchers).

In recent months we successfully presented the EC with 9 of our 13 final research deliverables, with now only 4 in the pipeline and on course for submission before the end of August. These are the ESRs' reports on the final stages of their coordinated research work in TREASURE, and represent a massive milestone of our project, one which we are all very proud of.

With regards to our training events, taking into account that our 3rd workshop successfully took place online via MS Teams last month (11-13 May), albeit with a limited audience due to the sudden change in circumstances, we have now only our final conference left, which is scheduled to take place in Lisbon 20-21 October 2020 if circumstances permit. If they don't, we can build on our experience running our 3rd workshop, and this time run a full-fledge online event. Either way you are invited to take part, just watch out for news on the website! The 3rd workshop gave the fellows the opportunity to expose their latest results and findings for appraisal by the Consortium, with a view to guide their final steps in the project. Their presentations can be found here. Highlights include strong collaboration among the fellows, which are now thriving due to the incredible progress of their individual research work and the interaction opportunities they have enjoyed through our coordinated project.

These collaborations and integration of ideas are present in each of the presentations, for example between Hongyang Ma (ESR4) and Brian Weaver (ESR8) on tropospheric modelling for Precise Point Positioning (PPP), Jon Bruno (ESR2) and Dimitrios Psychas (ESR9) on the use of ionospheric tomography to aid ambiguity

Screenshot of the online meeting.

resolution in PPP, or Karl Bolmgren (ESR3) and Francesco Darugna (ESR10) on mitigation of the effects of TIDs (Travel Ionospheric Disturbances) on RTK (Real Time Kinematic) positioning, to name just a few.

As I obviously do not want to spoil your browsing of the whole set of talks, I will only draw your attention to one more, the collaborative talk entitled "Ionospheric Scintillation Forecasting and Mitigation on GNSS Positioning", given by Kai Guo (ESR7) on behalf of a group involving WP1, WP3 and WP4 (please refer to the website if you are not familiar with the project work plan). This interesting collaborative work describes the latest developments in WP1 by Juliana Damaceno (ESR1) on TEC and scintillation forecasting, feeding through to WP3, where Kai is testing the generation of tracking jitter maps based on her scintillation forecasts, which in turn are for the first time used to feed Brian's scintillation mitigation approach for PPP in WP4.

On the competition front TREASURE fellows continued to impress – as reported in our Nov 2019 newsletter, Jon Bruno (ESR2), Francesco Darugna (ESR10) and Lotfi Massarweh (ESR13) were in a team that made it to the finals of the Galileo Masters University Challenge. It so happens that they went all the way to become the winners, as announced on 4 December 2019, at the Space Oscars – Awards Ceremony of the Galileo Masters and Copernicus Masters that took place in Helsinki, Finland, as the festive highlight of the EU Space Week 2019. Well done to Jon, Francesco and Lotfi! Last but not least, our newsletter this time is privileged to display an invited contribution by Professor Jade Morton of University of Colorado, Boulder, who kindly accepted to write us short article on "GNSS Carrier Cycle Slips". Her article is nicely complemented by another two brief notes by TREASURE fellows Dimitrios Psychas entitled "Towards fast and reliable single-receiver integer ambiguity resolution-enabled Precise Point Positioning (PPP) using multi-GNSS and multi-frequency GNSS data " and Kai Guo on "Ionospheric scintillation sensitive tracking models and mitigation tools".

This is it for now, I hope you enjoy the reading and look forward to seeing you at the TREASURE Final Conference in October!

SHORT ARTICLES

Ionospheric scintillation sensitive tracking models and mitigation tools

The fluctuations in the Global Navigation Satellite Systems (GNSS) signals caused by ionospheric scintillation contribute to degrade the receiver tracking loop performance and may lead to significant positioning errors. In the presence of strong scintillation, the tracking loops could even fail to track the signals, posing a serious threat to safety-critical GNSS applications.

This short article addresses part of the TREASURE project research carried out to devise scintillation mitigation techniques to support high accuracy GNSS positioning. The main tasks of the study cover: (1) Modelling the effects of scintillation on GNSS tracking loops by developing novel tracking error models; (2) Generating tracking jitter maps using the output of scintillation sensitive tracking error models; (3) Developing novel scintillation mitigation tools by exploiting the concept of GNSS receiver tracking jitter maps (Sreeja et al. 2011). The study has been undertaken in the scope of TREASURE WP3 (see http://www.treasure-gnss.eu/ for details), in synergy with the research in WP1, so that outcomes from the latter can be suitably incorporated. Meanwhile, the study entails close collaboration with ESR5 and ESR6 in WP3 so that the scintillation and interference mitigation models and tools can be exploited by WP4. Scintillation sensitive receiver tracking error models are analysed and studied in this work. With these models, the receiver tracking jitter is calculated for each satellite/receiver link under different levels of scintillation. By exploiting the network of Ionospheric Scintillation Monitoring Receivers (ISMRs) deployed in the Canadian High Arctic Ionospheric Network (CHAIN), regional tracking jitter maps are generated. The scintillation occurrence and the Phase Locked Loop (PLL) tracking jitter map for GPS L1CA signals at 12:02 UTC on 8 September 2017 are shown as an example in Figure 1.

In general, these maps can be useful to provide receiver tracking conditions under the prevailing ionospheric scintillation scenario, and in particular they may also be used to help mitigate scintillation effects on GNSS positioning.

In the latter case, the performance of the tracking jitter maps is assessed by investigating the improvement in positioning accuracy that can be achieved by using the tracking jitter extracted

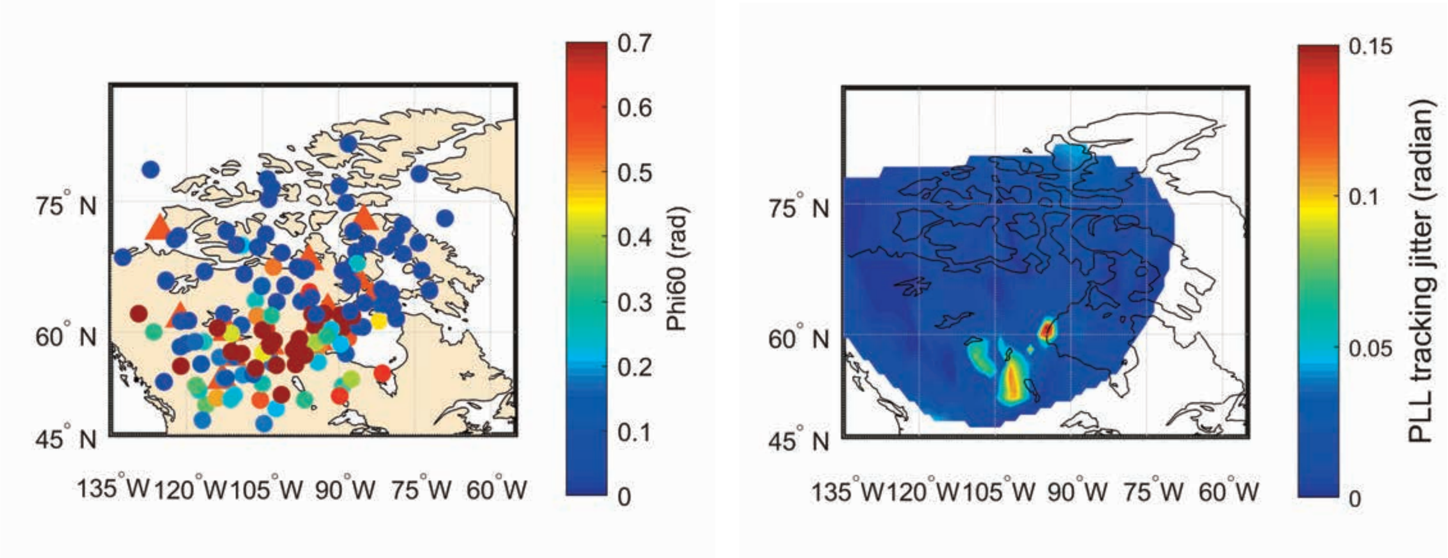


Figure 1. Phase scintillation occurrence captured by the ISMRs in CHAIN (left) and regional PLL tracking jitter map for GPS L1CA signals at 12:02 UTC on 8 September 2017.

from these maps to modify the positioning estimation least square stochastic model following the approach suggested by Aquino et al. (2009). A single layer cosine mapping function and the 2D linear interpolation method were applied. Based on the experiments, results shown in Figure 1 demonstrate the tracking jitter maps can help to improve the GNSS positioning 3D accuracy by up to 73.95% in the presence of scintillation. The research is ongoing and is currently focused on investigating an optimal mapping function and improved interpolation methods to be used in conjunction with the maps.

Kai Guo ESR7

Reference

Aquino M, Monico JFG, Dodson AH, et al. (2009) Improving the GNSS positioning stochastic model in the presence of ionospheric scintillation. Journal of Geodesy, 83(10):953-966.

Sreeja, V, Aquino M, & Elmas, ZG (2011). Impact of ionospheric scintillation on GNSS receiver tracking performance over Latin America: introducing the concept of tracking jitter variance maps. Space Weather, 9, S10002.

Towards fast and reliable single-receiver integer ambiguity resolution-enabled Precise Point Positioning (PPP) using multi-GNSS and multi-frequency GNSS data

During the last few years, there has been an increased adoption of the PPP (Precise Point Positioning) technique by both the academic and the industrial worlds. Based on GNSS (Global Navigation Satellite Systems) code and phase data from a single receiver and precise satellite orbit and clock information, a PPP user can determine their location without the need of a reference station like in relative positioning techniques (e.g. RTK – Real-Time Kinematic) and with a typical accuracy of a few centimeters in static and a few decimeters in kinematic mode. The main benefit of the method is its global positioning approach and the reduction of labour and equipment cost. However, it is well-known that, in the frame of standard PPP, such accuracy can be obtained using data over long observational spans, ranging from tens of minutes to several hours. This has its roots in the incapability to resolve the phase ambiguities to integers, since they cannot be separated from the receiver and satellite hardware biases existing in the code and phase data. To this end, the single-receiver integer ambiguity resolution-enabled PPP concept, namely PPP-RTK, extends PPP by means of providing single-receiver users, in addition to satellite orbits and clocks, with information about the satellite phase and code biases. When properly provided and applied, this information serves in recovering the integerness of the user-ambiguities, necessary to achieve Integer Ambiguity Resolution (IAR) and to reduce the convergence time of PPP solutions. To successfully achieve this, the data-driven ambiguities need to be mapped to their correct integer values, with the reliability of this process depending on the underlying model's strength. It has been shown that a single-constellation dual-frequency ambiguity-fixed positioning solution can reach centimeter-level accuracy when data over multiple epochs are accumulated, ranging from 30 to 60 minutes. In my research work within the scope of the TREASURE project, the capability of the ionosphere-float PPP-RTK model (in which the slant ionospheric delays need to be estimated) to achieve near-instantaneous centimeter-level positioning has been deeply investigated. The widely used GPS dual-frequency ionosphere-float model is weak with regards to its IAR capabilities due to the presence of ionospheric delays. The rapid development and modernization of multiple satellite systems along with a plethora of signal frequencies provide an improved satellite geometry, thus a stronger positioning model, and higher redundancy than the single-system dual-frequency model. To this end, a multi-GNSS multi-frequency PPP-RTK Kalman-filtered user positioning algorithm was developed, based on uncombined measurements, in order to analyze the positioning performance as well as the gain in position precision improvement one should expect after successful IAR. Figure 1 shows the user's performance at the DLF1 station in The Netherlands based on a combined GPS, Galileo and BeiDou triple-frequency model. One can easily observe that such a signal integration is able to provide positioning solutions at the 1.5 cm level within the first 3 minutes of processing using Partial Ambiguity Resolution (PAR), with the precision gain after IAR being equal to 23. Although Full Ambiguity Resolution (FAR) can be realized in several epochs, the model-driven PAR shows its superior performance in achieving fast high-precision positioning since a large enough subset of ambiguities instead of the full can be identified in

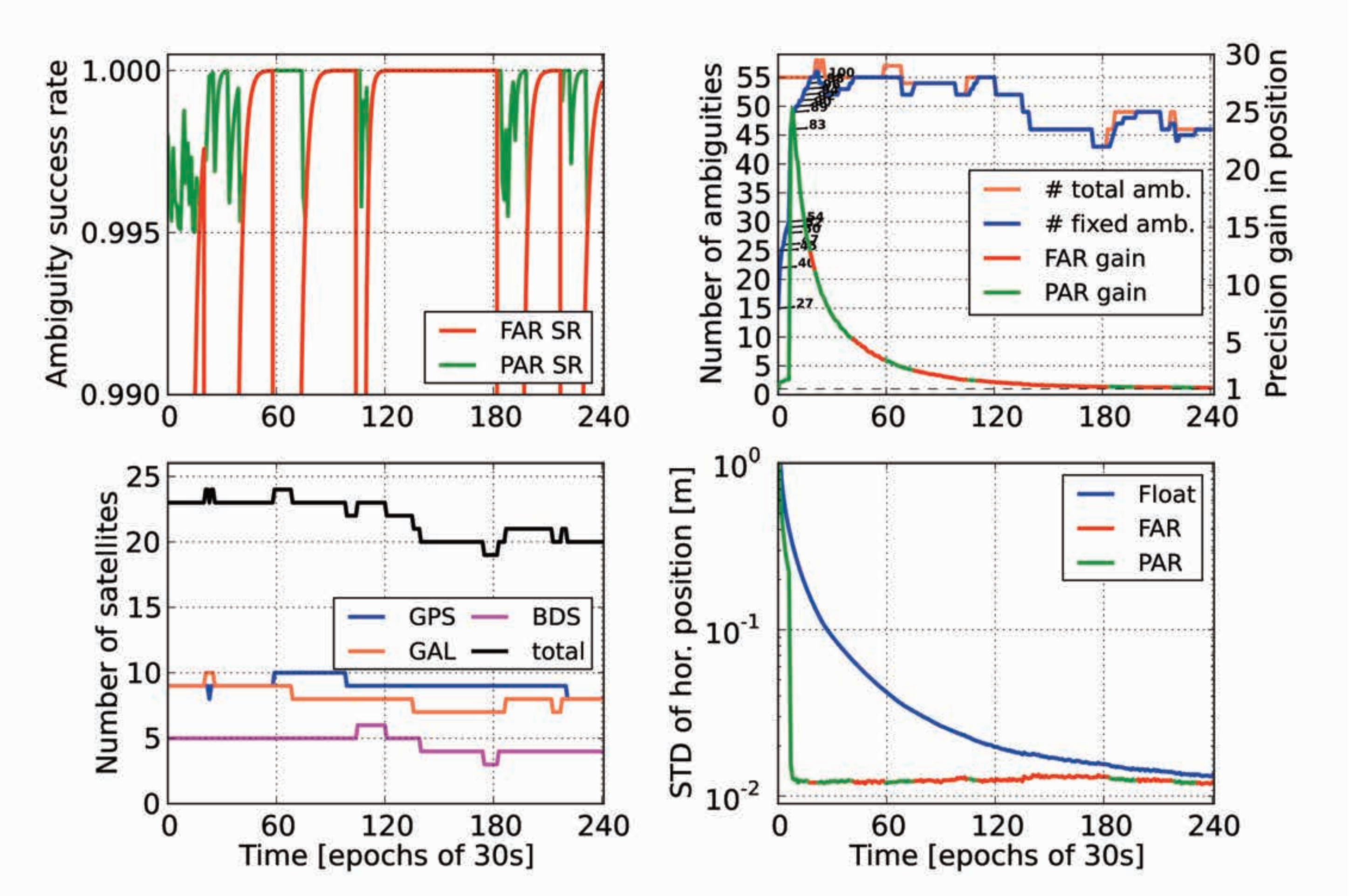


Figure 1. GPS+Galileo+BeiDou triple-frequency (L1/L2/L5+E1/E5a/E5b+B1/B2/B3) full (FAR) and partial (PAR) ambiguity resolution and kinematic positioning performance at station DLF1 (The Netherlands) during the first 2 hours on the 274th day of 2019. Top left Ambiguity Success Rate (SR) for FAR and PAR using a minimum criterion of 99.5%, with the number of tracked satellites shown at the bottom left panel. At top right the number of total and fixed ambiguities over time (with the percentage of fixed ambiguities being shown next to the blue curve) along with the horizontal positioning precision gain after IAR. The precision of the ambiguity-float and ambiguity-fixed horizontal position is shown at the bottom right panel, with FAR being on top of PAR.

order to provide close to optimal positioning solutions. These results are indicative of the effect that the increase in the number of satellites and frequencies have on the ambiguity resolution and positioning performance, which is expected to improve in light of further developments that are part of my ongoing research.

Dimitrios Psychas ESR9

EXPERTS VOICE

GNSS Carrier Cycle Slips

GNSS carrier cycle slips refer to discontinuities in signal carrier phase measurements. Cycle slips are detrimental to high accuracy GNSS applications that depend on carrier phase measurements. This is because carrier phase is a relative measure of the satellite-receiver range and the carrier cycle ambiguity must be resolved in order for carrier phase estimations to be used as precision range measurements. Small carrier cycle slips introduce errors in phase estimations and adversely impact the accuracy of range measurements. Large carrier cycle slips require the reset of carrier phase integer ambiguity resolution process which can be time consuming and computationally demanding. Cycle slip detection and mitigation have been an active research area since the beginning when the civilian application community embarked on utilizing GPS for high accuracy applications. There are two potential root causes for cycle slip occurrences. The first is due to artifacts of receiver signal processing when the Signal-to-Noise Ratio (SNR) is low. A GNSS receiver carrier tracking loop may latch onto a noise or interference spike while estimating the signal carrier phase. The odds of doing so is higher when the SNR is low. Low SNR happens when the signal is blocked by buildings or structures, when the satellite is at a low elevation, when there is destructive multipath interference, or when there are Radio Frequency Interferences (RFI). Figure 1 shows the Total Electron Content (TEC) computed using geometry-free combination of GPS L1 and L2 signals pseudorange (blue line) and carrier phase (red line). While the pseudorange combination is noisy and show multipath effects at low elevations, the carrier phase is smooth but has cycle slips at low elevation. To reduce the probability of cycle slip occurrence due to low SNR, various algorithms have been implemented to boost the SNR and to mitigate multipath and RFI. Setting a masking angle to avoid using signals from low elevation angles is a common practice in GNSS applications. There have also been numerous efforts in detecting the occurrence of cycle slips and methods to "repair" them if cycle slips are detected. The second cause is due to multipath interferences among the signals, which is often overlooked by researchers. When signals travel to a receiver following multiple paths, the combined results can cause signal amplitude fading and carrier phase transitions. These multiple paths phenomena can be the result of signals reflected from solid surfaces or

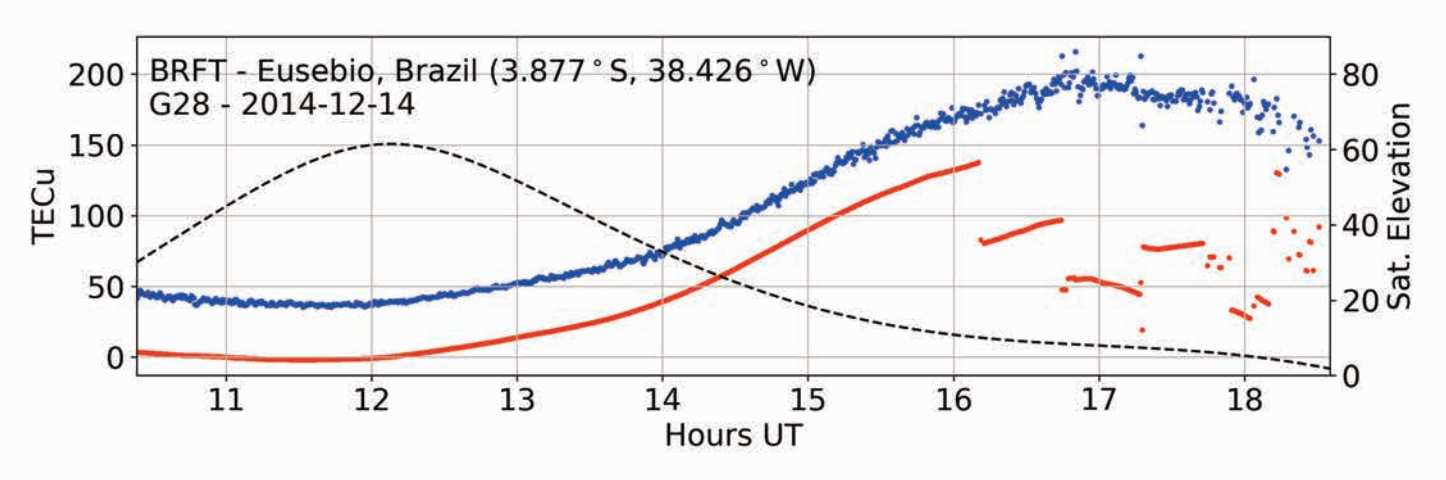


Figure 1. TEC computed using geometry-free combination of pseudorange and carrier phase measurements from an example data set for PRN 28 obtained at a GPS monitoring station in Brazil (BRFT) on December 14, 2014. The pseudorange derived TEC is relatively noisy and shows large multipath fluctuations when the satellite was at low elevations. The carrier phase-derived STEC curve is smooth at most times except at low elevations where there are several carrier cycle slip occurrences. The carrier phase TEC also has a bias due to the carrier cycle ambiguity.

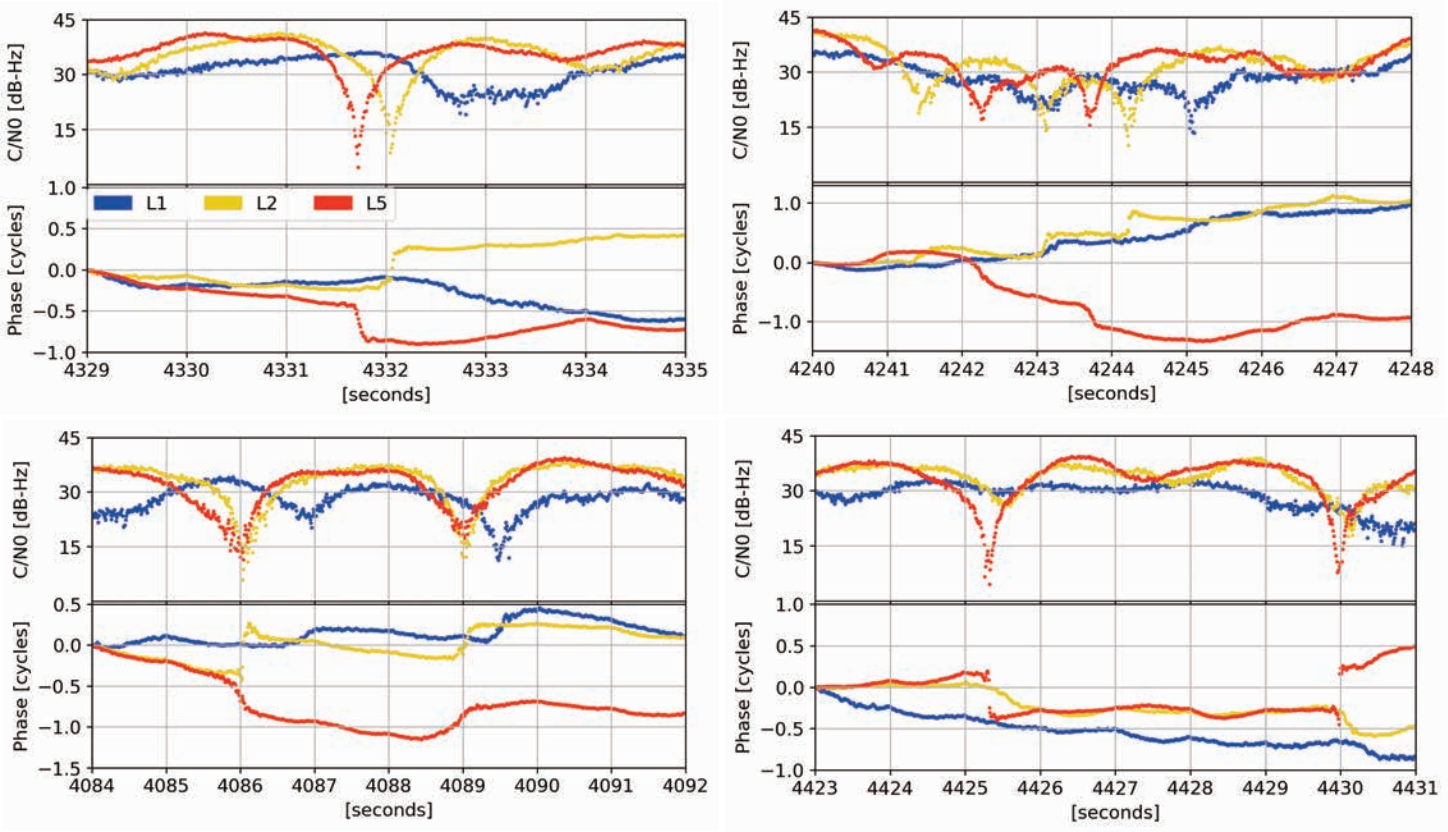


Figure 2. Examples of triple-frequency GPS signal amplitude and detrended carrier phase on PRN 24 collected during strong low-latitude scintillation on Ascension Island on March 10, 2013, with 0 second correspond to 20:01 hours UTC. These strong scintillation data shows that deep amplitude fading and rapid phase transition occur simultaneously.

scattered by structures in the ionosphere plasma or troposphere. The phase transition tends to be relatively small, typically in the order of half to one carrier cycle. However, the phase transition may accumulate over time as the multipath propagation continue. Figure 2 shows several examples of triple-frequency GPS signal amplitude and detrended carrier phase collected during strong low-latitude scintillation on Ascension Island. These strong scintillation data shows that deep amplitude fading and rapid phase transition occur simultaneously. Detection of this second type of cycle slips can be challenging because the phase transition may not be as abrupt as the first type and their magnitudes are relatively small. Numerous algorithms have been developed to detect cycle slips. A popular approach is to apply linear combinations of carrier phase estimations from dual-frequency or triple-frequency carriers. The linear combinations can be geometry-free, ionosphere-free, or geometry-ionosphere-free. Other approaches include single-epoch time difference, windowed filtering, and sequential filtering. While each of these approaches has its own pros and cons, cycle slips in the presence of noisy and dynamic signals remain a challenging problem.

Jade Morton and Brian Breitsch
University of Colorado Boulder,
Boulder, CO, USA

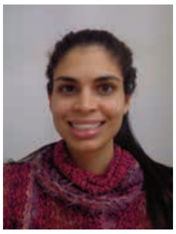
news

The TREASURE Final Conference is scheduled to take place in Lisbon 20-21 October 2020 if circumstances permit. If they don't we will run an online event. Either way you are invited to take part. Several invited speakers have confirmed their attendance, just watch out for news on the website!

UPCOMING EVENTS

EVENT	WEBSITE	DATE	LOCATION
ICL-GNSS 2020, International conference on localization and GNSS 2018	https://events.tuni.fi/icl-gnss2020/ Due to Covid-19, the conference will be hosted in virtual format	2 June – 4 June 2020	Tampere, Finland
2020 ION JOINT NAVIGATION CONFERENCE	https://www.ion.org/jnc/	8-11 September 2020	Convington, Kentucky/Cincinnati, Ohio
ION GNSS+ 2020	https://www.ion.org/gnss/	21 – 25 September 2020	St. Louis, Missouri
ITS WORLD CONGRESS 2020, THE NEW AGE OF MOBILITY	https://itsworldcongress2020.com/	4 – 8 October 2020	Los Angeles, California
WORLD SPACE WEEK	https://www.worldspaceweek.org/	4 – 10 October 2020	
TREASURE FINAL CONFERENCE	http://www.treasure-gnss.eu/future-events/	20-22 October 2020	Lisbon, Portugal
AARSE 2020 CONFERENCE	https://aarse2020.org/index.php	26-30 October 2020	Kigali, Rwanda
SPACE TECH EXPO EUROPE	http://www.spacetechexpo.eu/	17 – 19 November 2020	Bremen, Germany
EUROPEAN NAVIGATION CONFERENCE 2020	https://www.enc2020.eu/en/home/	22-25 November 2020	Dresden, Germany
2020 EUROPEAN SPACE WEEK	https://www.euspaceweek.eu/	7 – 11 December 2020	Bonn, Germany
AGU FALL MEETING 2020	https://www.agu.org/fall-meeting	7 – 11 December 2020	San Francisco, California

TREASURE PROJECT FELLOWS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Karl Bolgrem
ESR3


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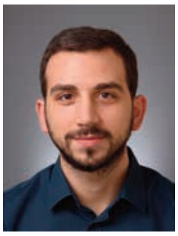
ESR4


Caner Savas
ESR5


Wenjian Qin
ESR6


Kai Guo
ESR7


Brian Weaver
ESR8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