



TRANSMIT - Training Research and Applications Network to Support the Mitigation of Ionospheric Threats, an FP7 Marie Curie Initial Training Network. The project addresses in particular ionospheric threats to Global Navigation Satellite Systems (GNSS) and related applications, in areas such as civil aviation, marine navigation and land transportation.

[www.transmit-ionosphere.net](http://www.transmit-ionosphere.net)

## INSIDE THIS ISSUE

*"The Radio Occultation (RO) technique has now more than four decades of history and started with NASA's planetary exploration missions. Main results of the application of this technique are the retrieval of accurate profiles of refractivity, temperature, pressure and water vapour in the neutral atmosphere and electron density in the ionosphere".*

The global coverage offered by two RO planned missions (EUROPEAN and USA/TAIWAN constellations) will improve the worldwide capability to monitor the ionosphere from space and benefit, among others, the TRANSMIT science-services-users community, as evidenced in the article by Riccardo Notarpietro from EUMETSAT, Darmstadt, Germany and Politecnico di Torino, Turin, Italy. TRANSMIT's Early Stage Researchers (ESR) Muhammad Mubasshir Shaikh, Tommaso Panicciari and Marko Vuckovic tell us about their ongoing studies on RO ionospheric monitoring, ionospheric imaging, and ionospheric scintillation effects on GNSS.

## NEWS

The TRANSMIT final open event will be held 17 and 18 November 2014 at Liege (Belgium), Palais des Congrès, within the 11<sup>th</sup> European Space Weather Week (ESWW11), whereby TRANSMIT is inserted into the session entitled "Modelling the Earth's ionosphere and solutions to counter ionospheric threats to GNSS applications". The conference will also kindly host the TRANSMIT splinter session, which will take place Tuesday 18 November (14.00-15.30) at the Auditorium Rogier, and will focus on presentation and open discussion on the TRANSMIT prototype. See more in the Update/Status section of the newsletter.

## SAD NEWS

We were deeply saddened by the news that Kees de Jong from Fugro Intersite B.V. (The Netherlands) suddenly passed away on Friday 31<sup>st</sup> October 2014 from brain hemorrhage. He was an unconditional supporter of the TRANSMIT project and became not only a fantastic professional advisor to all of us, but also a great friend and colleague. He was the author of the Expert's Voice article of the TRANSMIT newsletter issue N.2 (May 2013), in which he insightfully discussed the impact of the ionosphere in precise offshore GNSS positioning. He will be deeply missed by all who had the privilege to meet him, and especially by all involved in TRANSMIT. We will be forever indebted to him. Our thoughts are with his family at this sad moment.

The TRANSMIT Consortium

## Update Status

Marcio Aquino

Hello all and welcome to the November 2014 issue of the TRANSMIT newsletter! Following on from our previous issue, the project has now concentrated on the development of the TRANSMIT prototype demonstrator and its web interface. As the fellows approach the end of their research projects (and some of them have already been awarded their PhD!), the demonstrator has evolved to incorporate the most recent results of their work, through specific links that lead to the topics of their research and showcase how they can be exploited to assist users in countering the effects of a perturbed ionosphere. To that effect we are very excited to give you first hand the link to our web interface:

[www.transmit-prototype.net/](http://www.transmit-prototype.net/)

As a way to give you a hint before you click on and experience it live, here is what the home page looks

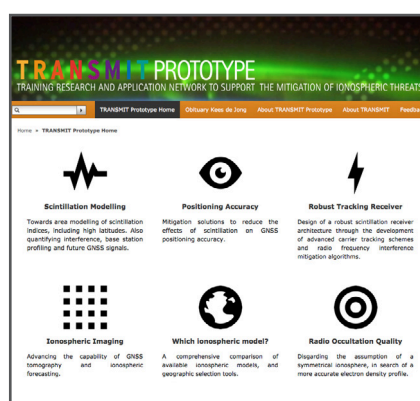


Figure 1 • Home page of the TRANSMIT demonstrator

like (Fig. 1). Behind each of the icons on the home page is the result of 3 years hard work of the TRANSMIT fellows towards achieving this combined set of tools that represent the project's main research outcome. Clicking on the icons you will find the tool description, examples of processing results and (in some cases) a live demo. As the project ends in Feb 2015, the web

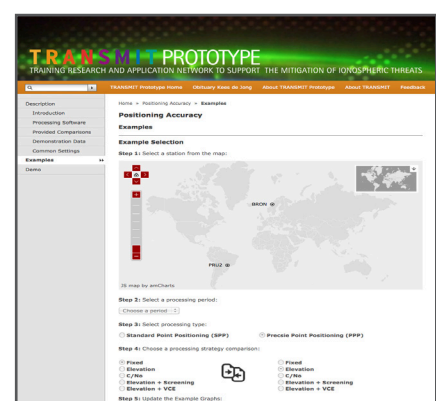


Figure 2 • "Positioning Accuracy" tool of the TRANSMIT demonstrator

interface is still undergoing further improvement and will in the meantime gradually progress towards its final form, therefore some of the tools not being fully implemented as yet. But we are in no doubt that you will have an exciting experience by trying out what is already there.

[continues to page 3]

# Ionospheric monitoring by means of GNSS Radio Occultation: history, potentiality and future



**Riccardo Notarpietro**<sup>1,2</sup>  
<sup>1</sup>EUMETSAT, Darmstadt, Germany  
<sup>2</sup>Politecnico di Torino, Turin, Italy

GNSS Radio Occultation (RO) certainly deserves to be defined as one of the most challenging remote sensing techniques for the monitoring of the atmosphere from space. The principle is simple: when a radio frequency signal emitted by a spacecraft passes through an intervening planetary atmosphere before arriving at the receiver, it is delayed and the ray path it follows is bent because of atmospheric refraction. Phase and amplitude measurements collected by suitable receivers on board an orbiting satellite, normally placed on a Low Earth Orbit (LEO), allow the retrieval of the atmospheric parameters (in form of vertical profiles) causing such refraction effects.

The RO technique has now more than four decades of history and started with NASA's planetary exploration missions. The implementation of the GPS system gave an opportunity for a global monitoring of the Earth's atmosphere by RO [1]. Main results of the application of this technique are the retrieval of accurate profiles of refractivity, temperature, pressure and water vapour in the neutral atmosphere [2], and electron density in the ionosphere [3, 4]. For a more complete history of GNSS RO see [5]. When a RO instrument tracks a GPS signal as it is occulted by Earth's atmosphere, it records the carrier phase change on the microwave links at L1 and L2 with millimeter-scale precision. After removal of the effects of the relative motion between the GPS and the LEO satellites and of the effects of clock drifts in the transmitter and

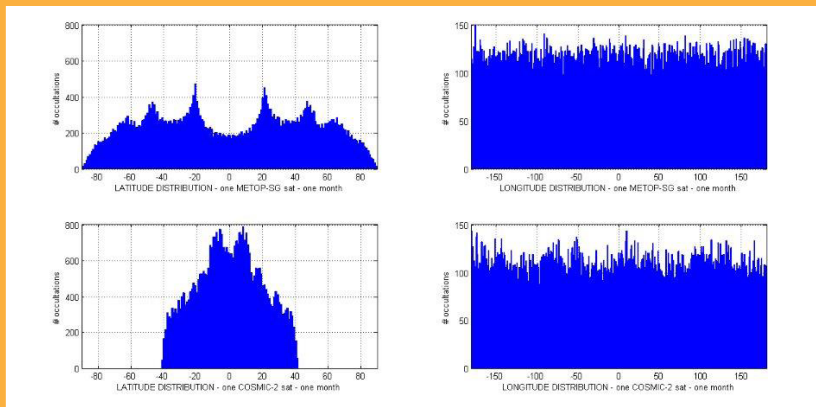


Figure 1 • Geographical distribution (left: latitude; right: longitude) of expected ionospheric soundings for one of the METOP-SG (top) and COSMIC-2 (bottom) receivers. The figure shows the geolocations of occultation points placed at 80 km height – Ionospheric sounding will start (end) for rising (setting) occultations from (to) this point. *Courtesy for providing the data: Axel von Engel and GRAS TEAM @ EUMETSAT*

receiver, the remaining residual phase is due to the atmosphere only. If the signals cross only ionospheric layers, such residual phases are directly proportional to the total electron content (TEC). In a RO configuration, data are collected from both the zenith antenna normally available for navigation purposes and the occultation antennas (placed in the velocity and antivelocily directions). Therefore, TEC data from positive and negative elevation angles can be made available. For a LEO satellite placed at an orbit of 800 km, TEC from the zenith antenna will be mainly generated by the topside ionosphere and plasmasphere, while TEC evaluated from negative elevation angles will take into account all the ionospheric effect characterizing a limb sounding geometry below the satellite orbit.

All these TEC observations have demonstrated to provide a benefit in several fields for:

- Space weather applications [6] (see also the good overview provided in [7]);
- Monitoring the layered structure of the ionosphere [8], up to identify the occurrence frequency, seasonal maps and irregularities of the sporadic E layer (see the review in [9] and references therein);
- Data assimilation: in this case the higher vertical resolution of limb sounding observations (close to 1 km) certainly represents an added value with respect to the standard ground based observations [10];
- Ionospheric imaging: both kind of TEC data have been used to image the 3D-4D topside ionosphere and plasmasphere [11];
- Monitoring scintillation activity by

means of the observed signal-to-noise intensity fluctuations of the GPS signals [12];

- Retrieving of vertical profiles of electron density from the LEO altitude to the bottom of the ionosphere, considering TEC observations with negative elevations [13].

The first of a series of opportunities to demonstrate the RO concept came with the GPS-MET investigation led by the Universities Corporation for Atmospheric Research (UCAR) with funding from NSF, NOAA, and NASA [14]. The extraordinary success of the GPS-MET concept mission (1995) had inspired a series of other RO missions. The era of the operational use of Radio Occultation observations for weather and climate monitoring started in 2001 with the Challenging Minisatellite Payload (CHAMP) and the twin Gravity Recovery and Climate Experiment (GRACE) missions (in 2002). In 2006, USA/Taiwan cooperation launched the Formosa Satellite Mission-3/Constellation Observing System for Meteorology, Ionosphere, and Climate (FORMOSAT-3/COSMIC) [15], the first satellite constellation for Radio Occultation sounding. Contemporaneously Europe launched the first of three MetOp satellites that currently form the EPS - EUMETSAT Polar System [16]. All these MetOp satellites (MetOp-A and B were launched respectively in 2006 and 2012, while MetOp-C is expected to be launched in 2017) carry on board, among other sensors, a Radio Occultation payload (the GRAS receiver [17]).

What about the future? Two big missions are currently planned and scheduled to be launched starting from 2018.

[continues to page 3]

## Update Status

[continues from page 1]

Hoping not to spoil your visit to the site, we would like nevertheless to just briefly show you what you will find if for instance you opt to explore the 'Positioning Accuracy' tool (Fig. 2).

This tool, developed by TRANSMIT fellow Peter Kieft, is dedicated to provide different solutions aiming to mitigate the effects of ionospheric scintillation on GNSS positioning. The user can select different strategies for comparison, as well as a time span and either a low or high latitude station. For now only a limited number of case studies has been considered for the purpose of demonstrating the tool capability.

Showcasing these tools is the main objective of the prototype demonstrator and the web interface. It is the proof of concept and the blueprint for a potential real world service to be developed in the future. We will be very keen to have your feedback on our demonstrator and web interface.

We are also glad to confirm that TRANSMIT will have a strong presence in the session entitled "Modelling the Earth's ionosphere and solutions to counter ionospheric threats to GNSS applications" at the 11th European Space Weather Week (ESWW) in Liege, Belgium, 17-21 November 2014. Please have a look at the program at <http://www.stce.be/esww1/>. A dedicated TRANSMIT splinter session

is also confirmed at the conference, and will take place on 18 November at 14:00PM.

Finally, as announced in our last issue, the proceedings of the TRANSMIT 2014 Workshop that took place in Torino earlier this year are now available through open access publishers InTech, in the form of a book titled "Mitigation of Ionospheric Threats to GNSS: an Appraisal of the scientific and technological outputs of the TRANSMIT project", please visit: <http://www.intechopen.com/books/mitigation-of-ionospheric-threats-to-gnss-an-appraisal-of-the-scientific-and-technological-outputs-of-the-transmit-project>

Have a nice reading and we hope to see you in Liege! ☺

## THE EXPERT'S VOICE

[continues from page 2]

One will be managed by ESA/EUMETSAT.

This is the EPS-Second Generation, the follow on from the EPS missions. It will be made up of 6 satellites launched on a polar orbit at 815 km height and equipped with the new state of the art European GNSS-Radio Occultation receiver.

The other, COSMIC-2, the follow on from FORMOSAT-3/COSMIC, will be managed by USA/Taiwan cooperation and will be made up of two 6-satellites constellations.

The first constellation will be launched in a low inclination and lower height orbit (24°, 520 km height). The second (actually only planned but not

yet funded), on a higher inclination orbit (72°, 750 km height). Both missions will provide RO data in near real time for both neutral atmosphere and ionosphere soundings (for the EPS-SG case the timeliness requirement to make products available is 70 min from the observation). GNSS-Radio Occultation receivers on both constellations will be characterized by improved tracking strategies/ algorithms and improved sampling rates (up to 250 Hz for the EPS-SG). As a baseline, EPS-SG receivers will be able to track modernized GPS (GPS-M) and GALILEO signals while COSMIC-2 receivers will be developed considering GPS-M and GLONASS signals

(we are talking about ~1200 occultations/day/ receiver). In both cases, receivers will be prepared for correctly handling all the other GNSS signals (doubling the expected number of occultations/day). Just to provide an idea of the expected potentiality in observing the ionosphere, Fig. 1 shows how good the global coverage assured by the two EUROPEAN and USA/TAIWAN constellations will be. In this figure, one month of simulated geographical distributions of ionospheric occultations are shown, considering only one of the COSMIC-2 satellites and one of the EPS-SGs ☺

### Further Reading

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[15] Anthes R.A. et al., The COSMIC/FORMOSAT-3 Mission: Early Results, *Bull. Amer. Meteor. Soc.*, 89, 313-333, doi: 10.1175/BAMS-89-3-313, 2008.

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## Galileo robust tracking algorithms under ionospheric scintillation

Marko Vuckovic | ESR12

The presence of electron density irregularities in the ionosphere may cause rapid temporal fluctuations in both amplitude and phase of the Global Navigation Satellite System (GNSS) signals. This phenomenon, known as ionospheric scintillation, is typically characterized by scintillation indices [1, 2, and 3]. Most commonly used indices, S4 and  $\sigma_{\phi}$ , describe amplitude and phase fluctuations of the signal. Scintillation can affect the performance of the GNSS receivers decreasing the final positioning accuracy and, in a worst case, leading to the total loss of lock. The density of free electrons varies in a complex manner with geographical location, time, season and solar and magnetic activity, causing negative impact on GNSS systems. The effect is especially pronounced in equatorial and polar regions, where scintillation activity may be very high. Design and implementation of new GNSS systems, such as the European Galileo system, will provide more signals implementing new modulations over a larger number of bandwidths. This enriched scenario will allow the design of more robust tracking schemes against scintillation and thus improve the performance of the system.

In order to develop a robust tracking architecture for Galileo signals, a third order Phase Lock Loop (PLL) and a Kalman Filter (KF) have been considered. While PLL requires a proper selection of loop parameters in the presence of scintillation events, KF can be used to minimize the mean square error generated by Numerically Controlled Oscillator (NCO) [4]. Both PLL and KF were implemented into a Matlab based software receiver and in-phase and quadrature-phase outputs

of the prompt correlator were used to estimate the S4 and  $\sigma_{\phi}$  indices. The research activity was based on both measured and simulated Galileo data. The measurements were performed in the equatorial region (Vietnam) employing a data collection station located at the Hanoi University of Technology and jointly managed with Politecnico di Torino and ISMB research lab. E1 and E5 signals were also generated using a Matlab based signal generator. In the case of simulated Galileo signals, simulated scintillation signal amplitude and phase, shown in Fig. 1, were generated according to the Cornell scintillation model [5] and combined to the simulated signals. The acquisition and post-processing algorithm used for analyzing both measured and simulated Galileo signals are based on a modified version of Matlab Borre's software receiver [6]. The Galileo E1 signal has been processed as a BOC(1,1) in order to avoid high sampling rates and the generation of 4-level local codes as it would be needed to have a full demodulation of the CBOC modulation employed in the Galileo OS on E1.

Fig. 2 shows scintillation indices S4 and Phi60 ( $\sigma_{\phi}$ , evaluated over one minute) for both measured and simulated Galileo data affected by different levels of equatorial scintillation. Good correlation between the results obtained by the Septentrio PolaRxS and the software receiver has been obtained [3] using a standard 3rd order PLL tracking architecture. In the case of simulated signals, the obtained values of scintillation indices, for both amplitude and phase, are in agreement with the parameters set in the scintillation model. As it can be seen, during the period without scintillation, the signal amplitude for both measured and simulated data fully overlap. Furthermore, Fig. 3 shows the comparison of scintillation indices for measured E1c Galileo OS signal obtained by professional receiver (PolaRxS) and Matlab software receiver (SRx) for both standard 3rd order PLL and KF carrier tracking architecture. For this particular case, where the amplitude scintillation index is around 0.3, both architectures showed good performances and results are similar with those obtained by professional receiver.

Further tests are being performed for both measured and simulated signals affected by different levels of scintillation using the KF-based tracking architecture(s) in order to design more robust tracking algorithms in presence of ionospheric scintillations :

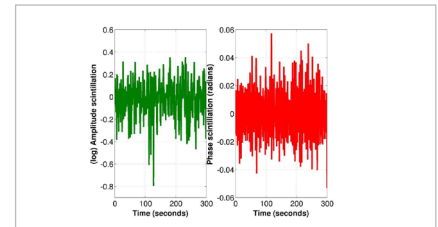


Figure 1 • Simulated scintillation signal amplitude and phase according to the proposed Cornell scintillation model [5] combined with the simulated E1c and E5a1 Galileo signals.

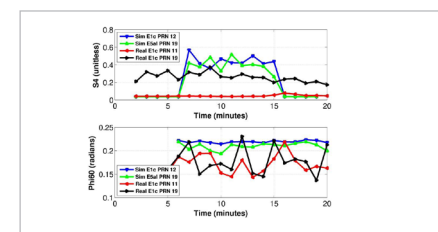


Figure 2 • Amplitude and phase scintillation indices for both measured and simulated Galileo OS signals using standard PLL carrier tracking architecture implemented into a Matlab-based software receiver.

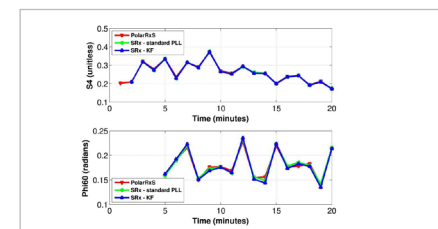


Figure 3 • Amplitude and phase scintillation indices comparison of measured E1c Galileo OS signal obtained by professional receiver (PolaRxS) and Matlab software receiver (SRx) for both standard 3rd order PLL and Kalman filter (KF) carrier tracking architecture.

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## Mitigating the Impact of Spherical Symmetry Hypothesis from Radio Occultation (RO) Data Inversion in the Ionosphere

Muhammad Mubasshir Shaikh | ESR4

Spherical symmetry is a common assumption applied to Radio Occultation (RO) observations in the ionosphere. Corresponding techniques are very effective for RO data inversion especially in case of small ionospheric horizontal electron density (Ne) gradients. Nevertheless, during disturbed geomagnetic periods, large electron density gradients may be experienced. Consequently this could lead to failure of spherical symmetry hypothesis producing

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erroneous Ne(h) profiles as output. After performing a thorough study on the qualitative and quantitative aspects of ionospheric asymmetry, we have developed an asymmetry index [1] that is able to quantify the level of asymmetry present in the ionosphere with respect to time, location and prevailing solar and geomagnetic activity. A good correlation has been found between the evaluated asymmetry and the errors produced by onion-peeling algorithm for corresponding RO events. As part of TRANSMIT prototype, using asymmetry index, processor 3C [2] will produce global asymmetry maps using different ionospheric backgrounds (calculated using NeQuick, IRI and MIDAS) for quasi-horizontal TEC observations. By querying these global maps of asymmetry and for a given RO event, the processor is able to predict the expected level of ionospheric asymmetry and its potential impact on RO inversion products, obtained using standard onion-peeling algorithm (based on spherical symmetry hypothesis). Furthermore, research is being performed to implement an improved RO data inversion approach based on model adaptation by assimilating slant-TEC (STEC) data. STEC here is calculated for the portion of the ray that is below the LEO orbit (between points A1 and A2 shown in Fig 1(a)). This may be done by using an ionospheric electron density model driven by its local ionization parameter.

To achieve this, for each ray of the RO event, we have forced the background ionospheric model to produce a STEC value close with the one available from the real RO event, varying the instantaneous value of its local ionization parameter. In other words for each ray of the RO event we have defined the ionization parameter that minimizes the difference between experimental and the corresponding modelled STEC. We named this ionization parameter as 'Az\_n' (where 'n' is the number of ray). This set of ionization parameters (as shown in Fig 1) together with the associated ray perigee positions is then used to calculate the Ne(h) profile (Fig 2) using the background model. Fig 2 shows two examples of how model-aided inversion has improved the RO data inversion. However the technique, currently under development, is not able to improve the results of standard inversion technique in all cases and being worked out for further improvements :

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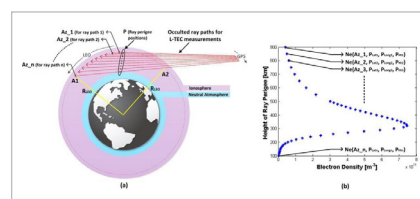


Figure 1 • Application of the concept of using local ionization parameter of an ionospheric model to reduce the cost function between the experimental and modelled STEC. (a) Illustrates geometry of a real RO event with the indication of how 'Az\_n' parameter has been calculated for each ray separately. Number of 'Az\_n' values will depend on the number of rays and consequently number of STEC values present in the RO event. (b) is the resulting electron density profile calculated using the same ionospheric model. This profile is a function of 'Az\_n' and ray perigee positions (P) associated with each ray of the RO event.

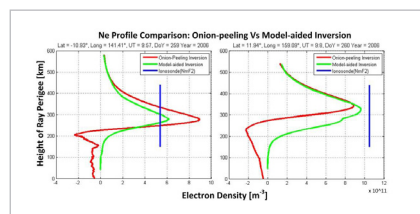


Figure 2 • Comparison of electron density profiles obtained by performing onion-peeling inversion (standard technique) and model-aided inversion on two COSMIC radio occultation events. Data from NeQuick electron density model has been used in model-aided inversion to improve the standard inversion.

## Multiresolution tomography of ionospheric electron density

Tommaso Paniciari | ESR9

The ionosphere is an ionized medium that affects the electromagnetic signal that travels through it. It is possible to image the state of the ionosphere by means of the Computerized Ionospheric Tomography (CIT). CIT is denoted as an inverse problem and reconstructs three-dimensional maps from observations that are in the form of slant Total Electron Content (TEC). The reconstructed maps can be used to study the dynamics of the ionosphere and their effect on the Global Navigation Satellite System (GNSS) signal. Those effects are due to ionospheric structures that evolve in time with different scale and position and are very difficult to predict. The correct localization of those structures can help to study the ionosphere and eventually compensate the errors. Furthermore, ground-based receivers tend to be unevenly and sparsely distributed on the Earth's surface.

This causes the inverse problem to be ill-posed and the reconstruction difficult to solve. Therefore, the definition of the problem in a regularized form is required. In the context of TRANSMIT, at the University of Bath we focused on resolving ionospheric structures at multiple scales by means of CIT techniques. This was obtained by exploiting a new regularization form (for CIT) based on the concept of sparsity. Basis functions can be used to describe the horizontal variation of the ionosphere, and the standard approach is based on spherical harmonics. Instead, for the sparse regularization, wavelet basis functions are used. In fact, wavelets can represent structures at different positions and scales efficiently and compactly. The concept of sparsity is used in this context to promote the solution with few basis functions. This is not possible to obtain with the standard approach. Figures 1a and 1b show a reconstruction obtained with spherical harmonics and wavelets, respectively, during the day of the 30th September 2000 at 0318 UT [1]. The observations were collected within a time window of 9 minutes, with a sample rate of 30 seconds. The maps have a resolution of 1x1 degree in latitude and longitude and show Vertical TEC distributions in TEC units. A ring oscillation phenomenon (i.e. the ripples in Figure 1a) is present due to the high number of basis functions to be estimated with spherical harmonics. This is due to the global support of the spherical

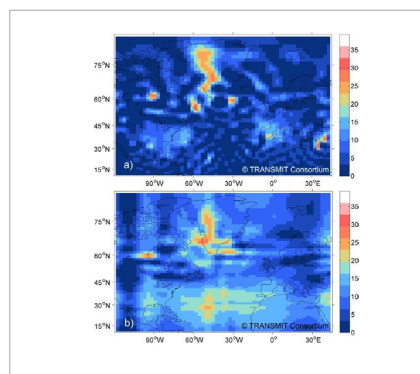


Figure 1 • Vertical TEC distribution reconstructed by: a) spherical harmonics; b) wavelets. Values are in TECU

harmonics. This effect is not present with wavelets which have more compact support (see Figure 1b). Therefore they can potentially produce more accurate high resolution maps. The concept of sparsity can be beneficial for CIT where observations are unevenly and sparsely distributed and the reconstructions indicate sparse regularization as a valid alternative to the standard approach :

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FORTHCOMING EVENTS

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**EVENT                                      WEB SITE                                      DATE                                      LOCATION                                      DEADLINE/TYPE**

**2014**

XII International Conference on Substorms (ICS-12)	<a href="http://www.stelab.nagoya-u.ac.jp/ICS-12/">http://www.stelab.nagoya-u.ac.jp/ICS-12/</a>	November 10-14, 2014	Shima JAPAN	June 30, 2014 Conference
11th European Space Weather Week	<a href="http://www.stce.be/esww1/">http://www.stce.be/esww1/</a>	November 17-21, 2014	Liege BELGIUM	June 1, 2014 TRANSMIT Final Conference
47th AGU Fall Meeting	<a href="http://fallmeeting.agu.org/2014/">http://fallmeeting.agu.org/2014/</a>	December 15-19, 2014	San Francisco CALIFORNIA - USA	August, 2014 Conference

**2015**

European Navigation Conference 2015	<a href="http://www.enc2015.eu/">http://www.enc2015.eu/</a>	April 7-10, 2015	Bordeaux FRANCE	Conference
ION's Pacific PNT Conference	<a href="http://www.ion.org/pnt/index.cfm">http://www.ion.org/pnt/index.cfm</a>	April 20-23, 2015	Honolulu, HAWAII	November 14, 2014 Conference
1 <sup>st</sup> URSI Atlantic Radio Science Conference (URSI AT - RASC)	<a href="http://www.at-rasc.com">http://www.at-rasc.com</a>	May 18-22, 2015	Gran Canaria Spain	December 15, 2014 Conference
14 <sup>th</sup> International Ionospheric Effects Symposium, IES2015	<a href="http://ies2015.bc.edu">http://ies2015.bc.edu</a>	May 12-14, 2015	Alexandria, VA, USA	December 15, 2014 Symposium
International Conference on Localization and GNSS, ICL-GNSS	<a href="http://www.icl-gnss.org/2015/index.php">http://www.icl-gnss.org/2015/index.php</a>	June 22-24, 2015	Gothenburg, SWEDEN	February 28, 2015 Conference
The 28 <sup>th</sup> International Technical Meeting of the Satellite Division of The Institute of Navigation ION GNSS+ 2015	<a href="http://www.ion.org/gnss/future-meetings.cfm">http://www.ion.org/gnss/future-meetings.cfm</a>	September 14-18, 2015	Tampa, Florida, USA	International Meeting

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## TRANSMIT Project FELLOWS



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OKSANA POLZUYA



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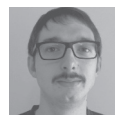
MARIJA CORALIC



TOMMASO PANICARI



PAVEL NAJMAN



FEDERICO DADALT



PETER KIEFT



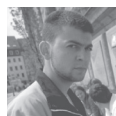
MELANIA SUSI



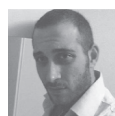
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## TRANSMIT Project PARTNERS

TRANSMIT counts on an exceptional set of partners, encompassing both academic excellence and top end users, including the aerospace and satellite communications sectors, as well as GNSS system designers and service providers, major user operators and receiver manufacturers. There is currently no assistance against ionospheric threats in Europe and TRANSMIT will promote step-change research that will enable Europe to minimise disruption and consequential societal costs associated with them. It will promote European competitiveness by ensuring the contribution of top centres of excellence in the field and by adopting a global approach to the problem. There are two types of partners in TRANSMIT, namely level 1 and level 2 partners.

