Earth, Planets and Space

GNSS and SAR Technologies for Atmospheric Sensing

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PREFACE

Open Access

Special issue "GNSS and SAR Technologies for Atmospheric Sensing"

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Abstract

Recent advances in the field of atmospheric and ionospheric sensing by GNSS and SAR technologies were discussed during two workshops held in February 2016 and October 2016 in Italy, hosted by GEOlab of Politecnico di Milano under partial support of the JSPS Bilateral Open Partnership Joint Research Projects. Another symposium was held in March 2017 at the Research Institute for Sustainable Humanosphere of Kyoto University, to discuss (1) the water vapor and ionospheric maps retrieval from space-borne and airborne SAR, (2) ionosphere and troposphere monitoring by the ground-based GNSS network and radio occultation, (3) mesoscale numerical weather prediction models and data assimilation, and (4) ground-based remote-sensing techniques, such as a wind profiling radar. This special issue collects high-quality papers that describe the findings reported during these three meetings, not limited to GNSS and SAR, but also including ground-based atmospheric sensing systems and numerical weather prediction models.

Background and scope of the special issue

(a) JSPS Japan–Italy bilateral collaborative program and related meetings.

In 2011, a study on the detection of local-scale precipitable water vapor (PWV) variations, by means of a hyper-dense GPS and QZSS receiver network, was carried out at the Research Institute for Sustainable Humanosphere (RISH) of Kyoto University. This study was conducted in collaboration with the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA), and with the participation of Dr. Eugenio Realini, originally from Politecnico di Milano (PoliMi), Italy, during his stay as a postdoc researcher at RISH.

The hyper-dense network was deployed near Uji, Japan, and comprised 15 receivers with inter-distances of about 1–2 km, covering an area of about 10 km × 6 km. The study demonstrated the possibility of detecting PWV variations within the Uji network area, by exploiting high-elevation slant delays to increase the horizontal resolution of the retrieved PWV field (Sato et al. 2013). The collaborative work on the Uji hyper-dense network continued in the following years, allowing for simulations and comparisons between the GNSS-derived and NWP-derived PWV (Oigawa et al. 2014, 2015).

Stemming from these activities, a JSPS bilateral collaborative program between RISH of Kyoto University and GEOlab of PoliMi was initiated for the period 2015–2017, to strengthen the collaboration between the two research groups. The following sections describe the workshops and seminar that were held in Italy and Japan under this program.

GEOlab-RISH workshop in Milan, Italy

The first GEOlab-RISH Joint Workshop on Observations and Models for Meteorology was held at the Leonardo Campus of PoliMi, Italy, from February 22 to 24, 2016. The workshop was meant as an interdisciplinary meeting for the presentation of research activities in the fields of GNSS Meteorology, SAR troposphere analysis, mesoscale NWP models, and data assimilation. More than 30 participants joined the workshop, including representatives of the following organizations: RISH, Kyoto University (JP), MRI-JMA (JP), GEOlab, PoliMi (IT), Geomatics Research & Development srl (IT), Italian Space Agency/eGEOS (IT), University La Sapienza of Rome (IT), University of Genoa (IT), Gter srl (IT), GFZ (DE), Saphyrion Sagl (CH), University of L'Aquila/CETEMPS (IT), TU Delft (NL), TU Wien (AT), IRA-INAF (IT), Datameteo

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(IT). Several students from both master's and doctoral courses attended as well.

The topics presented at the workshop included:

- GNSS meteorology
- Hyper-dense GNSS networks for troposphere analysis
- Innovative GNSS receiver technology and data processing
- Innovative GNSS data processing and analysis
- Ionospheric delay estimates and models
- SAR troposphere products, analysis, and methods
- NWP models
- GNSS radio occultation
- Ground-based measurements

GEOlab-RISH seminar in Como, Italy

From October 11 to 13, 2016, a Seminar on application of GNSS, SAR, and NWP models was held at Como Campus of Politecnico di Milano. On this occasion, 18 researchers and scientists from Japan, Italy, Denmark, and Germany gave selected presentations on the following topics:

- Review of the state-of-the-science of GNSS meteorology, GNSS-RO, SAR, and NWPs
- Ongoing projects and experiments (including real-time PWV monitoring with a hyper-dense GNSS network, and assimilation of slant total delay into an NWP model)
- Prospective projects (including SAR and GNSS experiments in the SYNERGY project, and the project of a hyper-dense GNSS network in Tokyo)

The end of the seminar saw active discussion between the groups involved in the bilateral program on future steps of the collaboration, including the organization of the second GEOlab-RISH Joint Workshop to be held in Kyoto, Japan.

(b) RISH symposium and a tour to the Shigaraki MU observatory

The 2nd GEOlab-RISH Joint Workshop on GNSS and SAR Technologies for Atmospheric Sensing, as a joint conference of the 331st Symposium on Sustainable Humanosphere, was held at the Uji Campus of Kyoto University in Kyoto, Japan, from March 6 to 9, 2017. The specific purpose was to discuss the technological development and applications of various atmospheric remote-sensing techniques and numerical models, following the 1st GEOlab-RISH joint Workshop and seminar held in Italy in 2016. The workshop attracted 54 participants from Japan, Italy, Germany, Indonesia, China, Taiwan, Singapore, and South Korea. A total of 44 oral presentations, including 12 invited talks, were delivered in the following sessions:

- SAR
- GNSS: ionosphere modeling, ionosphere variations, ionosphere irregularities, new applications, GNSS meteorology, and GNSS radio occultation
- Numerical weather prediction models
- Ground-based radio and optical remote-sensing techniques

The discussions at the end of the workshop covered future collaborative studies in these fields, as well as a proposal for the publication of a special issue. The workshop included a site visit with a technical tour of the Shigaraki MU (middle and upper atmosphere) Radar, which is known as the most capable atmospheric radar in the world and is also one of the largest in Asia. Introduction of various atmospheric remote-sensing instruments, such as the radio acoustic sounding system (RASS) and Raman lidar, was covered in the tour of the MU observatory. Furthermore, visits were organized to a traditional pottery production site in Shigaraki and the Byodoin Temple in Uji, followed by an authentic Japanese tea ceremony experience.

(c) Scope of the special issue

This special issue consists of eight papers on the measurement techniques and scientific outcomes of the behavior of the Earth's atmosphere and ionosphere, utilizing the accurate positioning data obtained by SAR and GNSS. In addition, as a novel application of the ground-based remote sensing of the atmosphere, the other paper discussed development of the radio acoustic sounding system (RASS) for measuring the atmospheric temperature in the tropical troposphere. A total of nine papers are published in this special issue.

Water vapor and ionospheric maps retrieval from space-borne SAR

Satellite-based interferometric synthetic aperture radar (InSAR) has been growing over the past nearly three decades, as a powerful technique to detect surface deformation signals with unprecedented spatial resolution. In contrast to GNSS technology, however, its applications to atmospheric science have been rather limited because the higher radar frequencies, such as C- and X-band, have often hampered interferometric coherence, particularly over vegetated areas. Since the launch of the Advanced Land Observing Satellite (ALOS) by Japan Aerospace

Exploration Agency (JAXA) in 2006, and its follow-on ALOS2 in 2014, both of which carry L-band Phased Array-type L-band Synthetic Aperture Radar (PALSAR and PALSAR2); however, a growing number of reports of crustal deformation over vegetated areas have been published. InSAR application to meteorology has also been progressing gradually.

Kinoshita et al. (2017) detected wave-like tropospheric propagation delay signals associated with mountain lee waves by the ScanSAR-mode InSAR observation by PALSAR2 and examined the reproducibility of the signal by numerical weather simulations. Although mountain lee waves have been noticed in a number of previous strip-map-mode InSAR observations, Kinoshita et al. (2017) reveal a more complete image with the use of ScanSAR mode and demonstrate the uniqueness and usefulness of InSAR for meteorological application, such as the ability to map the detailed water vapor distribution regardless of cloud cover.

Regarding ionospheric impacts on InSAR phase data, no operational corrections for ionosphere have been performed even in L-band InSAR data processing, because SAR imaging is based on a single carrier frequency. Thus, there has been uncertainty about how much dispersive and nondispersive phases are included in L-band InSAR images. The actual waveform of a radar pulse is, however, frequency-modulated and has a finite bandwidth around the central carrier frequency. The range split-spectrum method (SSM) can virtually allow for dual-frequency SAR imaging like GNSS, by splitting the finite bandwidth of the range spectrum. Furuya et al. (2017) reported a detection of another midlatitude Es by PALSAR2 InSAR and applied the SSM to separate dispersive and nondispersive components in the InSAR image. While InSAR SSM allows separation of the phase anomaly into dispersive and nondispersive components, their results indicate that small-scale nondispersive signals, with similar spatial scale, remain at the same locations.

Ground-based GNSS network and radio occultation (RO)

Since the 1990s, GNSS has been widely used and has become an essential part of the earth observation systems as well as a basic infrastructure for human daily lives. It provides information on electron density, refractivity, temperature, and water vapor under all-weather conditions that aid atmospheric study as well as operational weather forecasting. The GNSS remote sensing is roughly classified into two methods. The first method utilizes signal delay observed by ground-based GNSS receivers, while the other method employs ray bending caused when the radio path between a GNSS satellite and a GNSS receiver in the low Earth orbit (LEO) traverses the Earth's atmosphere. With the advances in GNSS technology, new research fields such as local-scale water vapor variation associated with deep convection, water vapor monitoring over the ocean, and 3D tomography are beginning to produce results.

Ferrando et al. (2018) present a procedure, termed G4 M (GNSS for Meteorology), which produces 2D PWV maps with high spatiotemporal resolution based on a simplified mathematical model, PWV variations with respect to a "calm" moment, and heterogeneity index (an indicator of a local severe meteorological event). The G4M maps were compared with meteorological simulations of a severe weather event that occurred in Genoa (Italy).

Barindelli et al. (2018) processed GNSS and weather station datasets for two heavy rain events and evaluated the relationship between the time variations and the evolution of the rain events. The results showed a signature associated with the passage of the widespread rain front over each GNSS station. The smaller-scale event of a few kilometers was not detected by the regional GNSS network, but strong fluctuations in water vapor were detected by a low-cost station.

Shoji et al. (2017) conducted experimental observations using shipborne GNSS antennas to assess the GNSS PWV over the ocean, from October 19, 2016, to August 6, 2017. A quality control (QC) procedure based on the amount of ZTD time variation was proposed. After the QC was applied, the retrieved PWVs agreed with the radiosonde observations with a 1.7-mm RMS difference, a −0.7 mm bias, and 3.6% rejection rate. The differences in the GNSS PWV versus radiosonde observations were compared to the atmospheric delay, the estimated altitude of the GNSS antenna, the vessel's moving speed, the wind speed, and the wave height.

Taking advantage of the ground-based GNSS-total electron content (TEC) data derived from the nationwide dense GNSS network (GEONET) in Japan, Muafiry et al. (2018) examined 3D ionospheric irregularities during the five cases of midlatitude *Es*, using a tomography technique. Muafiry et al. also performed several resolution tests to assess the accuracy of the results and demonstrated the presence of positive electron density anomalies at the E region height. The morphology and dynamics turned out to be consistent with those reported by earlier studies.

Noersomadi (2017) investigated a comparison of temperature (T) profiles from three retrievals of COSMIC GPS-RO (i.e., atmPrf2010, atmPrf2013, and rishfsi2013) with different height resolution around the tropopause. The mean T profiles are consistent between atmPrf2010 and atmPrf2013, but rishfsi2013 results are slightly colder (warmer) than two other

retrievals below (above) the tropopause, respectively. Comparison of three retrievals and 134 co-located radiosondes shows that the mean T difference at the cold point of the tropopause from the radiosondes is 0.32, 0.49, and −0.24 K for atmPrf2010, atmPrf2013, and rishfsi2013, respectively. Similar comparisons of the lapse rate of the tropopause are showing negative bias for all GPS-RO retrievals.

Assimilation of GNSS-PWV data into a mesoscale weather prediction model has been found to be very useful in improving accuracy. Oigawa et al. (2018) studied the assimilation of high-resolution PWV data derived from a hyper-dense GNSS receiver network around Uji city, Kyoto, Japan, which had a mean inter-station distance of about 1.7 km. The observed characteristic length scale of water vapor distribution was small, i.e., 1.9–3.5 km, when it rained over the GNSS receiver network. The accuracy of the simulated 1-h rainfall amount was improved by assimilating the high-resolution PWV data with small localization radii over the rainfall area.

Ground-based remote-sensing techniques

The behavior of mesoscale atmospheric disturbances in the troposphere was studied by using various observation techniques, such as radiosonde, weather radar, wind profiling radar (WPR), lidar, and satellite images. Because local and mesoscale effects are more dominant than synoptic influences in the tropics, continuous observations with the ground-based remote-sensing techniques are useful. The equatorial atmosphere radar (EAR) was constructed in 2001 in Koto Tabang, West Sumatra under intensive collaboration between Japan and Indonesia (Fukao et al. 2003). EAR is equipped with an active phased-array antenna and can measure three components of wind velocity. In addition to winds, the observation of atmospheric temperature is vital for clarification of meteorological phenomena. The radio acoustic sounding system (RASS) (e.g., Matuura et al. 1986) was developed for continuous monitoring of atmospheric temperature profiles, which is a combination of a high-power sound transmitter and WPR.

Juaeni et al. (2018) conducted eight campaign observations in 2016 of RASS with EAR to measure the temperature in the tropical troposphere. The acoustic source location and acoustic frequency range affected the RASS echoes. The continuous measurement from August 29 to September 3, 2016, successfully retrieved the temperature profiles from RASS from 2 to 6–14 km, with time and height resolutions of about 10 min and 150 m, respectively.

Summary

Monitoring of the atmosphere and ionosphere with various remote-sensing techniques, from the ground and from satellites, is becoming increasingly important, not only for improving our understanding of the fundamental processes, but also for advancing prediction and mitigation systems for natural hazards. This special issue is devoted to the recent progress on application of SAR and GNSS for measurements of the atmosphere. An outline of the three meetings held through the bilateral collaboration between PoliMI and RISH was also reported. It is hoped that our joint research activities will be enhanced in the coming years.

Authors' contributions

TT, ER, YS, AS, MY, MF served as guest editors for this special issue. TT prepared this preface with the agreement of the other authors. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

Not applicable.

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FULL PAPER Open Access

Detections and simulations of tropospheric water vapor fluctuations due to trapped lee waves by ALOS-2/PALSAR-2 ScanSAR interferometry

Youhei Kinoshita*, Yu Morishita and Yukiko Hirabayashi

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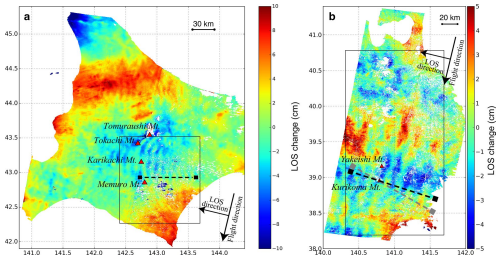
Abstract

Detailed wave-like spatial patterns of atmospheric propagation delay signals associated with mountain lee waves were detected in Hokkaido and Tohoku by synthetic aperture radar (SAR) interferometry (InSAR) with the ScanSAR mode observation data of a Phased Array-type L-band Synthetic Aperture Radar 2 on board the Advanced Land Observing Satellite 2. Both cases occurred under stable atmosphere conditions. The InSAR-observed peak-to-trough line of sight changes in the mountain wave signals was 4 and 5 cm with the horizontal wavelengths of 9 and 15 km in Hokkaido and Tohoku, respectively. Locations of positive phase maxima in the mountain wave signals coincides with locations of cloud streets observed by visible satellite imagery, indicating that crests of mountain waves contain relatively much water vapor compared with wave troughs. Numerical weather simulations with the horizontal grid spacing of 1 km were performed to reproduce InSAR phase variations, and as a result those simulations could reasonably reproduce observed wave amplitudes and wavelengths in both cases. On the other hand, numerical simulations tended to overestimate wave attenuation rates: simulated mountain waves decreased as the wave propagated faster than those of observed signals. Because the simulated wave attenuation rate is sensitive to physics in the planetary boundary layer (PBL), we investigated the reproducibility of five PBL schemes implemented in the WRF model. As a result, all the PBL schemes showed little attenuation except for the Yonsei University scheme (YSU), while the wavelength in the YSU was most close to the observation. Our study demonstrated the uniqueness and usefulness of InSAR for meteorological application as the ability to map the detailed water vapor distribution regardless of cloud cover. In addition, the reasonable reproducibility of the water vapor delay signal due to lee waves by the numerical weather model encourages researchers who tackle the correction of the tropospheric propagation delay, increasing the accuracy in detecting surface deformations.

Keywords: ALOS-2/PALSAR-2, Synthetic aperture radar (SAR), InSAR, ScanSAR interferometry, Mountain wave, Propagation delay, Water vapor, Numerical weather simulation



Graphical abstract

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FULL PAPER Open Access

Comparison of three retrievals of COSMIC GPS radio occultation results in the tropical upper troposphere and lower stratosphere

Noersomadi* and Toshitaka Tsuda

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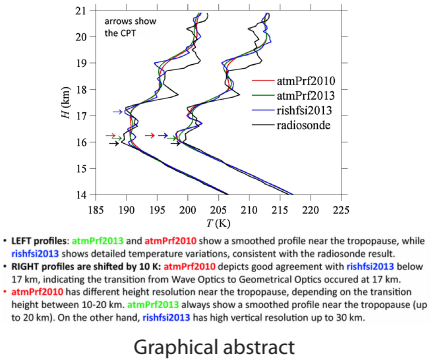
Abstract

Combining geometrical optics (GO) and wave optics (WO), the COSMIC data analysis and archive center (CDAAC) retrieved two sets of dry atmosphere temperatures (*T*) from COSMIC GPS radio occultation (GPS-RO), which are called atmPrf2010 and atmPrf2013. In atmPrf2010, the sewing height between WO and GO varies between 10 and 20 km, but is fixed at 20 km for atmPrf2013. The height resolution of the atmPrf2010 depends on the sewing height, while the *T* profiles by atmPrf2013 are smoothed over 500 m. We also derived *T* by applying WO throughout the troposphere and the stratosphere up to a 30-km altitude, which is called rishfsi2013. The three retrievals have different characteristics in the height resolution around the tropopause. Therefore, we aim to examine a possible discrepancy in the statistical results of the cold-point tropopause (CPT) and the lapse rate tropopause (LRT) among the three datasets, conducting their inter-comparisons as well as the comparison between GPS-RO and the simultaneous radiosonde dataset. We investigate the *T* variations in the upper troposphere and lower stratosphere (UTLS) over the tropics from October 1, 2011, to March 31, 2012, when radiosonde soundings were conducted as the CINDY-DYNAMO 2011 campaign. The mean *T* profiles are consistent between atmPrf2010 and atmPrf2013, but rishfsi2013 results are colder (warmer) than the CDAAC retrievals below (above) the tropopause. The mean *T* difference between atmPrf2013 and atmPrf2010 is 0.17 K at the cold-point tropopause (CPT) and −0.38 K at the lapse rate tropopause (LRT). On the other hand, rishfsi2013 shows a colder *T* at CPT by −0.77 and −0.59 K relative to atmPrf2013 and atmPrf2010, respectively, and the warmer *T* by 0.60 and 0.20 Kd at LRT. During CINDY-DYNAMO, we found 134 radiosonde soundings that coincide with GPS-RO within ±3 h and are collocated within 200 km from GPS-RO. The mean *T* difference at CPT from the radiosondes is 0.32, 0.49 and −0.24 K for atmPrf2010, atmPrf2013 and rishfsi2013, respectively. Both atmPrf2013 and atmPrf2010 have a positive bias at CPT, while rishfsi2013 has a negative one. Similar comparisons at LRT are −0.45, −0.69 and −0.41 K, respectively, showing a negative bias for all GPS-RO retrievals. The results show that rishfsi2013 is consistent with the retrievals at CDAAC and the radiosondes. Due to its good height resolution, rishfsi2013 is useful for studies on mesoscale *T* perturbations in the UTLS.

Keywords: COSMIC, GPS radio occultation (GPS-RO), Full spectrum inversion (FSI), Upper troposphere–lower stratosphere (UTLS), Retrieval algorithm



Graphical abstract

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FULL PAPER Open Access

Comparison of shipborne GNSS-derived precipitable water vapor with radiosonde in the western North Pacific and in the seas adjacent to Japan

Yoshinori Shoji*, Kazutoshi Sato, Masanori Yabuki and Toshitaka Tsuda

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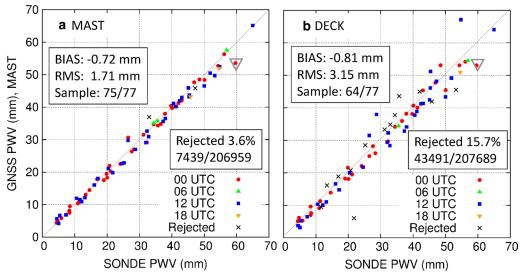
Abstract

We installed two global navigation satellite system (GNSS) antennas on a research vessel, the RYOFU MARU of the Japan Meteorological Agency, and conducted experimental observations to assess the GNSS-derived precipitable water vapor (PWV) from October 19, 2016, to August 6, 2017. One antenna was set on the mast (MAST), while another antenna was set on the upper deck (DECK). The GNSS analysis was conducted using the precise point positioning procedure with a real-time GNSS orbit. A quality control (QC) procedure based on the amount of zenith tropospheric delay (ZTD) time variation was proposed. After the QC was applied, the retrieved PWVs were compared to 77 radiosonde observations. The PWVs of MAST agreed with the radiosonde observations with a 1.7 mm root mean square (RMS) difference, a − 0.7-mm bias, and 3.6% rejection rate, while that of DECK showed a 3.2, − 0.8 mm, and 15.7%. The larger RMS and higher rejection rate of DECK imply a stronger multi-path effect on the deck. The differences in the GNSS PWV versus radiosonde observations were compared to the atmospheric delay, the estimated altitude of the GNSS antenna, the vessel's moving speed, the wind speed, and the wave height. The atmospheric delay and GNSS antenna altitude showed moderate correlation with the differences. The results suggest the kinematic PPP's potential for practical water vapor monitoring over oceans worldwide. At the same time, from the growing negative biases with the PWV value and with estimated antenna altitude, it could be inferred that the difficulty grows in separating the signal delay from the vertical coordinate under high-humidity conditions.

Keywords: GNSS meteorology, Precipitable water vapor, Kinematic precise point positioning, Real-time orbits



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Midlatitude sporadic-E episodes viewed by L-band split-spectrum InSAR

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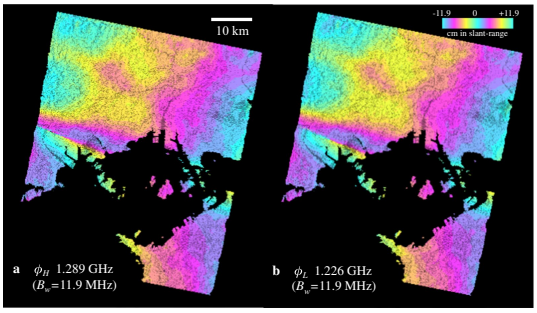
Abstract

Sporadic-E (Es) is a layer of ionization that irregularly appears within the E region of the ionosphere and is known to generate an unusual propagation of very high frequency waves over long distances. The detailed spatial structure of Es remains unclear due to the limited spatial resolution in the conventional ionosonde observations. We detect midlatitude Es by interferometric synthetic aperture radar (InSAR), which can clarify the spatial structure of Es with unprecedented resolution. Moreover, we use the range split-spectrum method (SSM) to separate dispersive and nondispersive components in the InSAR image. While InSAR SSM largely succeeds in decomposing into dispersive and nondispersive signals, our results indicate that small-scale dispersive signals due to the total electron content anomalies are accompanied by nondispersive signals with similar spatial scale at the same locations. We also examine the effects of higher-order terms in the refractive index for dispersive media. Both of these detected Es episodes indicate that smaller-scale dispersive effects originate from higher-order effects. We interpret that the smaller-scale nondispersive signals could indicate the emergence of nitric oxide (NO) generated by the reactions of metals, Mg and Fe, with nitric oxide ion (NO^+) during the Es.

Keywords: Ionosphere, Sporadic-E, Total electron content, Interferometric synthetic aperture radar, Split-spectrum method, Dispersive media, Higher-order refractive index, Nondispersive media



Graphical abstract

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FULL PAPER Open Access

Retrieval of temperature profiles using radio acoustic sounding system (RASS) with the equatorial atmosphere radar (EAR) in West Sumatra, Indonesia

Ina Juaeni, Hiraku Tabata, Noersomadi, Halimurrahman, Hiroyuki Hashiguchi and Toshitaka Tsuda*

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Abstract

The radio acoustic sounding system (RASS) with the equatorial atmosphere radar (EAR) at Koto Tabang, Indonesia was adapted to test the effects of the acoustic source location and acoustic frequency range on the continuous measurement of height profiles of temperature in the tropical troposphere. We installed the acoustic transmitting system by using six high-power horn speakers and four subwoofers. We developed a three-dimensional ray-tracing method of acoustic waves to predict the shape of acoustic wavefronts, accounting for the effects of the background winds on acoustic wave propagation. Then, we selected the appropriate antenna beam directions for EAR that satisfy the Bragg condition between the radar and acoustic wave propagation vectors. We carried out eight campaign observations in 2016, testing the performance of EAR–RASS. We found that the location and acoustic frequency range affected the RASS echoes. We also tested the compensation method of the background wind velocity with EAR to obtain the true sound speed. We intensively analyzed the RASS results from August 29 to September 3, 2016, when radiosondes were launched 12 times from the EAR site. We successfully retrieved the temperature profiles from RASS from 2 to 6–14 km with time and height resolutions of about 10 min and 150 m, respectively. Some temperature profiles were obtained up to about the tropopause at 17 km, although the observation period was short. During the RASS campaign, we detected a few interesting events regarding temperature variations as well as large perturbations in the three components of wind velocity.

Keywords: Virtual temperature profile, EAR, RASS, Three-dimensional ray tracing, Tropical troposphere, Cloud convection

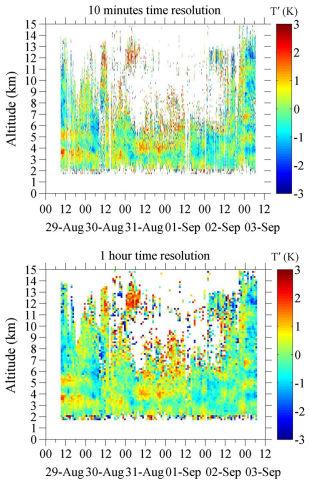

Fig. 16

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FULL PAPER Open Access

Detection of water vapor time variations associated with heavy rain in northern Italy by geodetic and low-cost GNSS receivers

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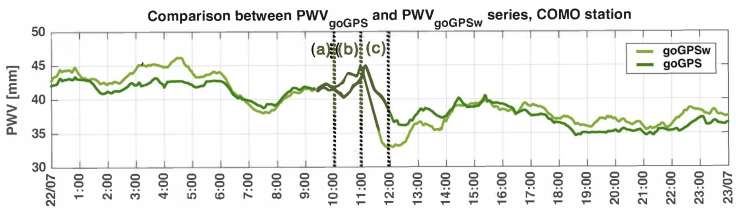
Abstract

GNSS atmospheric water vapor monitoring is not yet routinely performed in Italy, particularly at the regional scale. However, in order to support the activities of regional environmental protection agencies, there is a widespread need to improve forecasting of heavy rainfall events. Localized convective rain forecasts are often misplaced in space and/or time, causing inefficiencies in risk mitigation activities. Water vapor information can be used to improve these forecasts. In collaboration with the environmental protection agencies of the Lombardy and Piedmont regions in northern Italy, we have collected and processed GNSS and weather station datasets for two heavy rain events: one which was spatially widespread, and another which was limited to few square kilometers. The time variations in water vapor derived from a regional GNSS network with inter-station distances on the order of 50 km were analyzed, and the relationship between the time variations and the evolution of the rain events was evaluated. Results showed a signature associated with the passage of the widespread rain front over each GNSS station within the area of interest. There was a peak in the precipitable water vapor value when the heavier precipitation area surrounded the station, followed by a steep decrease (5–10 mm in about 1 h) as the rainclouds moved past the station. The smaller-scale event, a convective storm a few kilometers in extent, was not detected by the regional GNSS network, but strong fluctuations in water vapor were detected by a low-cost station located near the area of interest.

Keywords: GNSS meteorology, PWV variations, Intense rainfall



Graphical abstract

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FULL PAPER Open Access

3D tomography of midlatitude sporadic-E in Japan from GNSS-TEC data

Ihsan Naufal Muafiry*, Kosuke Heki and Jun Maeda

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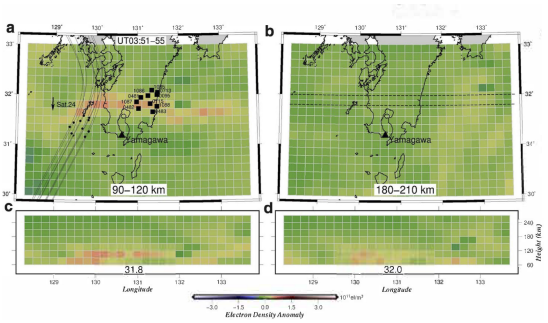
Abstract

We studied ionospheric irregularities caused by midlatitude sporadic-E (*Es*) in Japan using ionospheric total electron content (TEC) data from a dense GNSS array, GEONET, with a 3D (three-dimensional) tomography technique. *Es* is a thin layer of unusually high ionization that appears at altitudes of ~ 100 km. Here, we studied five cases of *Es* irregularities in 2010 and 2012, also reported in previous studies, over the Kanto and Kyushu Districts. We used slant TEC residuals as the input and estimated the number of electron density anomalies of more than 2000 small blocks with dimensions of 20–30 km covering a horizontal region of 300 × 500 km. We applied a continuity constraint to stabilize the solution and performed several different resolution tests with synthetic data to assess the accuracy of the results. The tomography results showed that positive electron density anomalies occurred at the E region height, and the morphology and dynamics were consistent with those reported by earlier studies.

Keywords: 3D tomography, Midlatitude sporadic-E, Global navigation satellite system, Total electron content



Graphical abstract

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FULL PAPER Open Access

2D PWV monitoring of a wide and orographically complex area with a low dense GNSS network

Ilaria Ferrando*, Bianca Federici and Domenico Sguerso

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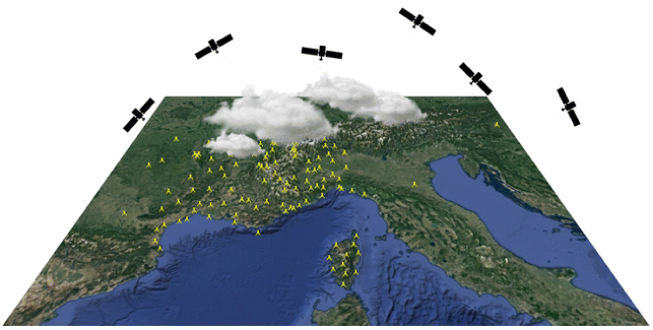
Abstract

This study presents an innovative procedure to monitor the precipitable water vapor (PWV) content of a wide and orographically complex area with low-density networks. The procedure, termed G4M (global navigation satellite system, GNSS, for Meteorology), has been developed in a geographic information system (GIS) environment using the free and open source GRASS GIS software (https://grass.osgeo.org). The G4M input data are zenith total delay estimates obtained from GNSS permanent stations network adjustment and pressure (*P*) and temperature (*T*) observations using existing infrastructure networks with different geographic distributions in the study area. In spite of the wide sensor distribution, the procedure produces 2D maps with high spatiotemporal resolution (up to 250 m and 6 min) based on a simplified mathematical model including data interpolation, which was conceived by the authors to describe the atmosphere's physics. In addition to PWV maps, the procedure provides ΔPWV and heterogeneity index maps: the former represents PWV variations with respect to a "calm" moment, which are useful for monitoring the PWV evolution; and the latter are promising indicators to localize severe meteorological events in time and space. This innovative procedure is compared with meteorological simulations in this paper; in addition, an application to a severe event that occurred in Genoa (Italy) is presented.

Keywords: Global navigation satellite system (GNSS), Zenith total delay (ZTD), Precipitable water vapor (PWV), Severe meteorological event monitoring, Meteorological simulation



Graphical abstract

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FULL PAPER Open Access

Data assimilation experiment of precipitable water vapor observed by a hyper-dense GNSS receiver network using a nested NHM-LETKF system

Masanori Oigawa*, Toshitaka Tsuda, Hiromu Seko, Yoshinori Shoji and Eugenio Realini

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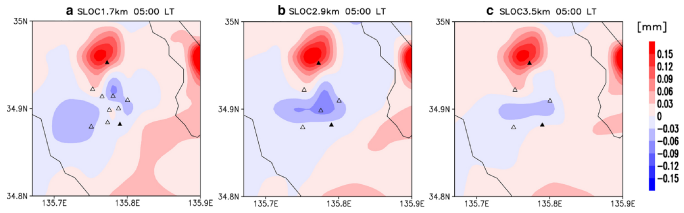
Abstract

We studied the assimilation of high-resolution precipitable water vapor (PWV) data derived from a hyper-dense global navigation satellite system network around Uji city, Kyoto, Japan, which had a mean inter-station distance of about 1.7 km. We focused on a heavy rainfall event that occurred on August 13–14, 2012, around Uji city. We employed a local ensemble transform Kalman filter as the data assimilation method. The inhomogeneity of the observed PWV increased on a scale of less than 10 km in advance of the actual rainfall detected by the rain gauge. Zenith wet delay data observed by the Uji network showed that the characteristic length scale of water vapor distribution during the rainfall ranged from 1.9 to 3.5 km. It is suggested that the assimilation of PWV data with high horizontal resolution (a few km) improves the forecast accuracy. We conducted the assimilation experiment of high-resolution PWV data, using both small horizontal localization radii and a conventional horizontal localization radius. We repeated the sensitivity experiment, changing the mean horizontal spacing of the PWV data from 1.7 to 8.0 km. When the horizontal spacing of assimilated PWV data was decreased from 8.0 to 3.5 km, the accuracy of the simulated hourly rainfall amount worsened in the experiment that used the conventional localization radius for the assimilation of PWV. In contrast, the accuracy of hourly rainfall amounts improved when we applied small horizontal localization radii. In the experiment that used the small horizontal localization radii, the accuracy of the hourly rainfall amount was most improved when the horizontal resolution of the assimilated PWV data was 3.5 km. The optimum spatial resolution of PWV data was related to the characteristic length scale of water vapor variability.

Keywords: Precipitable water vapor, Dense GNSS receiver network, Data assimilation



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Contents

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