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PREFACE

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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 stripmap-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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