remote sensing

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Editorial

Editorial for the Special Issue "Remote Sensing of Atmospheric Components and Water Vapor"

Victoria E. Cachorro [1,*] and Manuel Antón [2]

1 Department of Experimental Sciences Teaching (feyts), "Atmospheric Optics Group", University of Valladolid, Paseo de Belén, 7. Campus Miguel Delibes, 47011 Valladolid, Spain

2 Department of Physics, University of Extremadura, Avenida de Elvas s/n, 06006 Badajoz, Spain; mananton@unex.es

* Correspondence: chiqui@goa.uva.es

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Abstract: The observation/monitoring of atmospheric components and water vapor in the atmosphere is today open to very different remote sensing techniques, most of them based on the radiation-matter interaction covering the full electromagnetic spectrum. This SI collects some papers regarding the retrieval, calibration, validation, analysis of data and uncertainties, as well as comparative studies on atmospheric gases and water vapor by remote sensing techniques, where different types of sensors, instruments, and algorithms are used or developed.

Keywords: remote sensing; atmosphere; atmospheric gases; ozone; water vapor; pollutant; radiometry; spectroscopy; sensor satellite; LIDAR

Increasingly, the last few decades have shown the importance of GHGs, pollutants, and trace gases in general, due to the continuous deterioration of our environment and the warming of the climate system and therefore the need of its surveillance [1,2]. Atmospheric components refer here to atmospheric gases: greenhouse gases (GHGs) (CO_2, CH_4, N_2O, O_3, CFCs), pollutants (NO_2, CO, SO_2, HCHO, VOCs, etc.), and trace gases (OCl, OClO, OBr, etc.), which may belong to one or another group according to the classification criteria. Additionally, the gases that normally make up the atmosphere or the air we breathe as main components (oxygen, nitrogen, noble gases) are also included, with water vapor being one of the most important and abundant. The observation/monitoring of atmospheric components and water vapor in the atmosphere is today open to very different remote sensing techniques, such as radiometry, the wide variety of spectroscopic techniques (Differential Optical Absorption Spectroscopy (DOAS); Fourier Transform spectroscopy (FTS), etc.), interferometry, LIDAR, and other techniques, most of them based on the interaction of radiation with the atmospheric components and covering the whole electromagnetic spectrum, from UV to microwaves. They are developed on instruments located at ground level but are also collocated across different platforms in the space, satellite being the most common of them, although airplanes, helicopters, balloons, unmanned aerial vehicles, etc., are also used. These techniques are continuously developing with new instruments, together with new theoretical algorithms, for a better retrieval of atmospheric components, their properties and associated processes, which allows for the acquisition of knowledge of atmospheric composition, air quality, long range transport of pollutants, weather forecasting, climate, climate change, and other atmospheric studies.

Water vapor requires an explicit reference in this Special Issue (SI) because of its great relevance. Water vapor is the main natural GHG that plays a key role in the energy balance of the Earth [3,4], and its participation in the different elements of the climate system by means of the hydrological cycle make it a special and differential component which is not equalized by any other component of the atmosphere. This is due to its capacity to be present in the Earth's system in a solid–liquid–vapour state, in a very short range of temperatures, precisely the range in which humans live on Earth. The role of water vapor in general atmospheric circulation brings into play the most important climate processes; as clouds are gathered and distributed, water vapor condensation releases latent heat and causes the corresponding transport of this heat flux from the surface to the upper layers and from low to high latitudes, and it is therefore relevant for the thermodynamic properties of the entire atmosphere. Therefore, water vapor presents a high temporal and spatial variability within the atmosphere, making it necessary to monitor it in a more regular and accurate way than other gases.

Although there are other important components of the atmosphere, such as aerosols and clouds, they are not considered here because they are mainly composed of particles. However, in many cases, it is difficult to separate particles and gases due to their common interactions and processes (e.g., gas-to-particle conversion) within the climate system [5]. Clouds, aerosols, and gases in the atmosphere share many techniques, and their amounts and properties are very often measured with the same instruments. Furthermore, most of the trace gases, due to their low concentrations in the atmosphere, require very sensitive techniques for their determination, being masked or suffering interferences from other components, mainly by water vapor.

Much of the atmospheric components are supported from a local to a global scale by regional, national, and global ground-based networks, such as NDACC, TCCON, SAOZ, Brewer network, AERONET, EMEP, GAW, EARLINET, SAOZ, EUREF/GNSS, SUOMI-GPS, GRUAN, and others, as the main base element for their monitoring. On the other hand, adding the large family of Earth-observing satellite programs, we dispense with the powerful infrastructure used to obtain long-term data series on atmospheric gases and water vapor in the atmosphere, as part of the climate system.

Radiosounding (RS) is considered the most traditional technique for humidity measurements in the atmosphere, being a mix between "in situ" and remote sensing techniques. Although it is expensive in manpower and it provides low temporal and spatial sampling, RS remains the reference technique for temperature and water vapor measurement and the profiling of water vapor in the atmosphere (https://www.gruan.org). LIDAR-RAMAN-DIAL is also a powerful technique for water vapor profile retrieval, with a higher temporal resolution, mainly with ground-based sparse stations (EARLINET network) but also onboard different aerial or spatial platforms (WALES, CALIOPE). Most recent of all the above mentioned techniques for column integrated water vapor (IWV) retrieval is the Global Navigation Satellite System (GNSS), which, due to its high accuracy and spatial resolution (thanks to the low cost of ground-based stations), has become the best technique for IWV determination. Hence, GNSS has been taken as a reference for validation studies relating to other techniques, mainly satellite radiometric sensor validation. As mentioned, techniques based on multispectral, hyperspectral radiometers, spectroradiometers, and other optical systems, covering UV to far infrared, have been developed based on the absorption bands of direct or reflected solar radiation and supported by the ground-networks and satellite platforms, to retrieve water vapor and other absorbing gases (ozone, NO_2, etc.). The most sophisticated algorithms are necessary when solar or atmospheric radiances are measured, allowing researchers to determine the water vapor profile (AIRS; IASI, ANSU, HIRS sensors) or those of other pollutant gases such as CO or NO_2. Microwave radiometry/spectroradiometry has particular features but it also has an enormous potential for probing the atmosphere as solar/infrared techniques, since it is not perturbed by clouds or weather [6].

It is very difficult in this short abstract to name all the different programs which have been developed and are carried out today by the different world space agencies or institutions working on Earth observation focused on atmospheric/climate studies. New and advanced sensors with higher spatial and temporal resolutions, such as visible and infrared imager radiometers onboard the new generation of international geostationary (GEO) and polar weather satellites (National Polar-orbiting Operational Environmental Satellite System (NPOESS), EUMETSAT Polar System (EPS)), can retrieve a major number of atmospheric components or their profiles or the field of moisture in the atmosphere, in this case of special applications for helping Numerical Weather Prediction (NWP). Therefore, only a few examples are mentioned here: water vapor by MODIS/TERRA/AQUA [7,8], ozone by TOMS, OMI/AURA, (https://ozonewatch.gsfc.nasa.gov; http://rammb.cira.colostate.edu/dev/hillger/ozone-monitoring.htm); GOME-2/METOPs, [9,10], MOPPIT/TERRA (CO, columnar and profile; [11]), or sensors that retrieve a set of different components: SCIAMACHY/ENVISAT (O_3, NO_2, OClO, HCHO, SO_2, BrO, H_2O, CO, CO_2, CH_4; [12–14]), AIRS/AQUA (H_2O, O_3, CO, CH_4 profiles, https://airs.jpl.nasa.gov; [15,16]), IASI/METOP_A (columnar data of H_2O, O_3, CO, SO_2, N_2O, CH_4, CO_2, and profile of some of them; [17,18]), TROPOMI/SENTINEL5P/SENTINEL5 (O_3, SO_2, NO_2, CO, CH_4, CH_2O, HCHO, CHOCHO; [19,20]), GOSAT/Ibuki and OCO-2/NASA/JPL for CO_2 monitoring [21].

This SI collects some papers regarding the retrieval, calibration, validation, analysis of data and uncertainties, as well as comparative studies on atmospheric gases and water vapor by remote sensing techniques, where different types of sensors, instruments, and algorithms are used or developed, as mentioned above. The SI offers 11 different contributions. Obviously, we can group the papers into two categories: those about water vapor (seven papers) and those relative to other atmospheric gases (four papers), such as ozone, carbon monoxide CO, glioxal, etc.

The seven papers related to water vapor are very different, making use of practically all the above-mentioned retrieval/monitoring techniques and different satellite sensors, but most of them include GNSS data as their reference. Two of these papers [22,23] deal with the analysis/comparison of data retrieved by different instruments/techniques; [22] focuses on the comparison of IWV data of radiosonde, GNSS, and microwaves in two ground-based stations in Arctic areas; [23] compares IWV satellite products of MIRS/ANSU/MHS, MODIS, and IASI, analyzing the impact of sampling on the climatologies and frequency distributions of these data, taking the extended network of German GNSS data as a reference. In [24], the researchers evaluate three bias correction methods of systematic biases in the column-averaged dry-air mole fraction of water vapor (XH_2O) data retrieved from greenhouse gases observing satellite (GOSAT) short-wavelength infrared (SWIR) observations compared with three ground-based data from the Total Carbon Column Observing Network (TCCON). The water vapor field in the atmosphere and its spatial–temporal variability is a fundamental element in weather storm forecasting/evolution. Water vapor absorption band radiance measurements from the advanced imagers onboard the new generation of geostationary weather satellites allow us to quantitatively evaluate the environmental moisture fields from NWP models. Paper [25] focuses on this issue, analyzing the behavior and uncertainty of the moisture fields of three different NWP models under different weather conditions for better understanding and enhancing storm prediction.

Two papers are concerned with water vapor from a more instrumental perspective: the work of Almansa et al. [26] shows the first results of the column-integrated water vapor retrieved by a new radiometer (ZEN-R52) that is specifically designed to monitor aerosols and atmospheric water vapor (940 nm) with a high degree of autonomy and robustness. IWV is extracted by zenith radiance measurements using a new Look-up-tables technique based on an Radiative Transfer model and for validation is compared with the quasi-simultaneous Fourier transform infrared (FTIR) and Cimel photometers (AERONET) at the Izaña Observatory (Tenerife Island, Spain). In Kula and Ritter's paper [27], the difficult problem of LIDAR water vapor calibration is faced, and different strategies are developed in order to obtain reliable calibration that supports water vapor profile measurements, which are of major importance in Arctic areas (Svalbard Island) for climate studies.

The papers related to atmospheric gases are also very diverse: one of the papers [28] is concerned with an extended study about the spatial–temporal variations and trends of columnar CO over Asia, retrieved by the MOPPIT and AIRS satellite sensors and where a comparative study is carried out. The study also analyzes the sensibilities of the interannual variation of CO with biomass burning fires [X], showing a high correlation over this extended country. Paper [29] presents a study of a simulation that assesses the measurement errors and their impacts on the retrievals of the Atmospheric Limb Sounder (TALIS), a Chinese sub-millimeter limb sounder designed by the National Space Science Center of the Chinese Academy of Sciences. TALIS measures the temperature and chemical constituents vertically in the middle and upper atmosphere, with good precision and vertical resolution. Paper [30] presents an algorithm for glyoxal (CHOCHO) retrieval using the ozone monitoring instrument (OMI) based on the DOAS methodology and accounts for the interference of the tropospheric nitrogen dioxide's (NO_2) spatial–temporal distribution on glyoxal retrieval. The retrieval is applied over different regions of China, where a comparative study with other glyoxal datasets are carried out, analyzing the agreement or discrepancies according to different regions and seasons.

Finally, two papers are focused on the study of the radiative effects of ozone [31] and water vapor [32]. The first of them provides a worldwide and long-term analysis (1979–2014) of ozone radiative forcing in the UVB range, using the total ozone column from the ERA interim reanalysis data collection and radiative transfer simulations. This work reported that the midlatitude areas of both hemispheres exhibited a notable decrease in the ozone column, which sparked an increase in net UVB radiation at the tropopause. Another paper [32] analyzes water vapor's radiative effects (WVRE) at the surface in the long-wave (LW) and short-wave (SW) spectral ranges in Spain over the period of 2007–2015. For this goal, GNSS water vapor data and radiative transfer simulations were used. The positive trends for LW and total WVRE found in this work could partially explain the well-known increase in surface air temperature in the study region.

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