

File Revision Date:

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Data Set Description:

PI: Alkiviadis Bais
Instruments: Phaethon UV-Visible Spectrometer
Delta UV-Visible Spectrometer
Site(s): LAP.AUTH, 40.633° N, 22.956° E
Measurement Quantities: O3 and NO2

Contact Information:

Name: Alkiviadis Bais
Dimitris Karagkiozidis
Address: Laboratory of Atmospheric Physics
Aristotle University of Thessaloniki
54124 Thessaloniki, Greece
Phone: +30 2310 998 088
Email: abais@auth.gr/dkaragki@auth.gr

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Instrument Description:

Since 2018, two UV/Vis spectrometers (type Phaethon) have been operating at the Laboratory of Atmospheric Physics (LAP), Thessaloniki, Greece for the retrieval of NO₂ and O₃ columns. In June 2022, LAP was equipped with a new research-grade spectrometer system (namely Delta), which represents a significant enhancement of the existing instrumentation as it is designed to provide higher quality spectral measurements and is characterized by increased accuracy and sensitivity. The technical characteristics and specifications of all instruments are described below.

Instrument identification number: Phaethon (007) [2018 – 2022]:

Spectrometer: AvaSpec-ULS2048LTEC (f=75 mm)

Entrance slit: 50 microns

Grating: 1800 grooves/mm

Wavelength range: 297 – 458 nm

Spectral resolution: 0.45 nm FWHM

Detector: Sony ILX511

Temperature: 5° C

Input optic: 8 m Quartz fiber

Field of view: 1°

Instrument automatic control: Custom-made

Instrument identification number: Phaethon (008) [2020 – present]:

Spectrometer: AvaSpec-ULS2048x64-EVO (f=75 mm)

Entrance slit: 50 microns

Grating: 1200 grooves/mm

Wavelength range: 275 – 539 nm

Spectral resolution: 0.55 nm FWHM

Detector: Hamamatsu Hams11071-2048x64

Temperature: 10° C

Input optic: 8 m Quartz fiber

Field of view: 1°

Instrument automatic control: Custom-made

Instrument identification number: Delta (009) [2022 – present]:

Spectrograph: Kymera 193i

Detector: PIXIS 2KBUV

Grating: 600 grooves/mm

Wavelength range: 305 – 523 nm

Spectral resolution: 0.85 nm FWHM

Temperature: -50° C

Pointing accuracy: < 0.01°

Input optic: 8 m Quartz fiber

Tracker: EKO STR-22G

Field of view: 0.8°

Instrument automatic control: Custom-made

Phaethon is a mini custom-built system, developed at the Laboratory of Atmospheric Physics (LAP) that consists of an outdoor telescope, mounted on a two-axis sun-tracker, and an indoor unit (spectrometer). Both systems, operating at LAP, perform spectral measurements from sunrise to sunset up to a solar zenith angle (SZA) of 95°, with acquisition integration times that range between 1 and 3 min depending on the light intensity conditions. They operate in three different measurement modes: Zenith-sky, Off-axis, and Direct-sun. In order to achieve higher signal-to-noise and to avoid saturated spectra, the number of scans of each individual measurement and the exposure time of the CCD are automatically adjusted by the operating software according to the light intensity received by the detector. Dark spectra are measured on a daily basis (after each sequence of scans) and they are subtracted from the radiation spectra. The measured raw data are transferred to a local server in near-real-time through the Internet for spectral analysis and storage.

Delta is a scientific-grade instrument developed in collaboration with the Royal Belgian Institute for Space Aeronomy (BIRA-IASB) that consists of an outdoor optical head, mounted on a two-axis sun-tracker, and an indoor acquisition unit. The system is configured to perform spectral measurements of scattered radiation at 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 30 and 90° elevation angles, with the latter viewing direction (zenith) serving as a reference spectrum in the DOAS analysis. Elevation scans are performed at 4 different azimuth directions. The integration time per viewing angle is set to 30 s. Dark spectra are measured during nighttime and they are subtracted from the measured solar spectra prior to the DOAS analysis.

Algorithm Description:

Both NO₂ and O₃ slant column densities are retrieved by the differential optical absorption spectroscopy (DOAS) analysis of the measured radiance spectra using the QDOAS software that is developed by IASB-BIRA. NO₂ is analyzed in the 411-445 nm spectral window for Phaethon 7 and in the 425-490 nm window for Phaethon 8 and Delta. O₃ is retrieved for the Phaethon 8 system in the window 450 - 540 nm (in the Chappuis band), and for Delta in a slightly smaller window (450 – 520 nm). The vertical columns are derived from measured slant columns using look-up tables of air mass factors (AMFs), following the new NDACC recommendations available at <http://uv-vis.aeronomie.be/groundbased/>. For NO₂, these are based on a harmonic climatology of stratospheric NO₂ profiles, while for ozone the TOMS V8 O₃ profile climatology is being used. Mean twilight vertical columns are obtained by averaging individual measurements between 86 and 91° SZA.

Expected Precision/Accuracy of Instrument:

The error budget of the measurements is obtained by considering error sources affecting the determination of the slant column densities (SCD), the residual amount in the reference spectrum (R), and the air mass factor (AMF). Fitting errors derived from the least-squares analysis typically give small uncertainties of the order of 3E14 molec/cm² for NO₂ SCDs and 5 DU for O₃ SCDs. However, results from intercomparisons exercises (e.g., Van Roozendaal et al., 1998; Vandaele et al., 2005; Roscoe et al., 2010) show that state-of-the-art instruments hardly agree to better than a few percent, even using standardized analysis procedures, which indicates that the actual accuracy on SCDs is limited by uncontrolled instrumental and/or analysis factors. More conservatively and including uncertainties of absorption cross-sections and their temperature dependencies, we quote an uncertainty of the order

5% for NO₂ SCDs, and 2% for O₃ SCDs. The accuracy on R is mostly limited by the method used to derive the vertical column at the time of the reference spectrum acquisition (we use a Langley-plot approach). The contribution from this error source to the total error budget is generally small (typically 1-2%), although it may become significantly larger for NO₂ when very low abundances are to be monitored. In most conditions, the major contribution to the error budget of both NO₂ and O₃ total columns is the AMF calculation which requires appropriate modelling of the diffuse radiance in the nadir direction. Published studies indicate that the sensitivity of the AMF to stratospheric profiles of pressure, temperature and the constituent itself, accounts for an uncertainty of 10 % maximum for NO₂, and 4 % for O₃. In the case of NO₂, much larger errors can be obtained when tropospheric NO₂ is produced or transported above the station. Such pollution events are usually easily detected by inspection of the SZA dependency of the NO₂ SCDs and are filtered out in the analysis process. In summary we estimate the total accuracy on vertical columns to be in most cases better than 15% for NO₂, and better than 5% for O₃.

Instruments History:

Phaethon (007)

starting date: 2018/01/01

ending date: 2022/06/22

spectrometer 1:

AvaSpec-ULS2048LTEC, grating 1800 grooves/mm, 297-458 nm, FWHM 0.45 nm

Entrance slit 50 microns, Sony ILX511 detector (5° C)

Phaethon (008)

starting date: 2020/05/28

ending date: present

spectrometer 1:

AvaSpec-ULS2048x64-EVO, grating 1200 grooves/mm, 275-539 nm, FWHM 0.55 nm

Entrance slit 50 microns, Hamamatsu Hams11071-2048x64 detector (10° C)

Delta (009)

starting date: 2022/06/15

ending date: present

spectrometer 1:

Kymera 193i spectrograph, PIXIS 2KBUV detector (-50° C), grating 600 grooves/mm, 305-523 nm,

FWHM 0.85 nm, tracker EKO STR-22G, pointing accuracy < 0.01°

The Phaethon 7 system has been tested and validated during the Cabauw Intercomparison of Nitrogen Dioxide Measuring Instruments 2 (CINDI-2) campaign in 2016 in Cabauw, the Netherlands.

The Phaethon 8 and Delta systems have been tested and validated during the CINDI-3 campaign in 2024.