Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

MEASUREMENT OF VERTICAL IN-SITU NITROGEN DIOXIDE PROFILES NEAR NANJING USING A QUADCOPTER.

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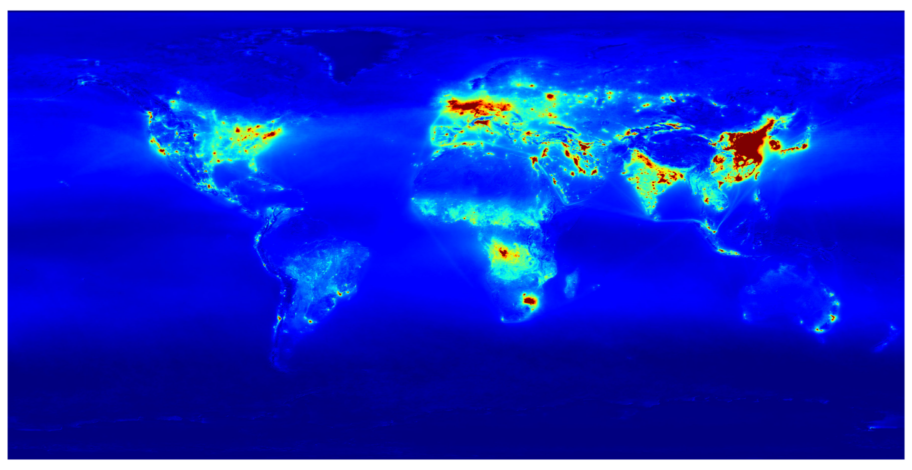
Abstract

During the Research on the Simulation and Mechanism of the impacts of Black Carbon on Climate and Environment atmospheric measurement campaign carried out near Nanjing, China in June 2018, a lightweight, accurate nitrogen dioxide (NO_2) sensor was attached to a quadcopter to measure vertical profiles of NO_2. Between 1 and 14 June 2018, ~50 vertical NO_2 profiles were measured inside the planetary boundary layer up to an altitude of 900-1300 meters during 13 subsequent measurement days. Six NO2 soundings were conducted on a daily basis at approximately 8 AM (morning), 12 & 4 PM (afternoon), 8 PM (evening) and 12 & 4 AM (night). The NO_2 measurements were calibrated using a scaling factor derived from a side-by-side inter comparison with a commercial NO2 analyzer operated by NUIST prior to the start of the campaign. These measurements clearly demonstrate the diurnal cycle of NO2, including the emergence of elevated concentrations close to the surface during the night and early morning and the mixing of the boundary layer from sunrise onward resulting in flat NO2 vertical profile shapes with lower concentrations. As a result, this type of measurement could play an important role in the validation of future geostationary satellites since the diurnal cycle of NO_2 will have an impact on the accuracy of the satellite retrievals.

Introduction

Nitrogen dioxide (NO_2) is a key component of air pollution worldwide.
The KNMI Research & Development Satellite Observations department monitors trace gases such as NO_2 from space using satellite instruments such as the TROPOspheric Monitoring Instrument (TROPOMI).



Global distribution of tropospheric NO_2 as observed in 2019-2021 by TROPOMI. Figure by Henk Eskes and Bas Mijling, KNMI.

The amount of NO_2 in the atmosphere derived from TROPOMI observations is often divided in a tropospheric and a stratospheric amount.

Large uncertainty in satellite derivations:
about 30-40% of the tropospheric amount.

One of the major sources of uncertainty:
the assumed vertical NO_2 profile shape in the troposphere.

Next to satellite validation, measurement of the vertical distribution of NO_2 is essential to:

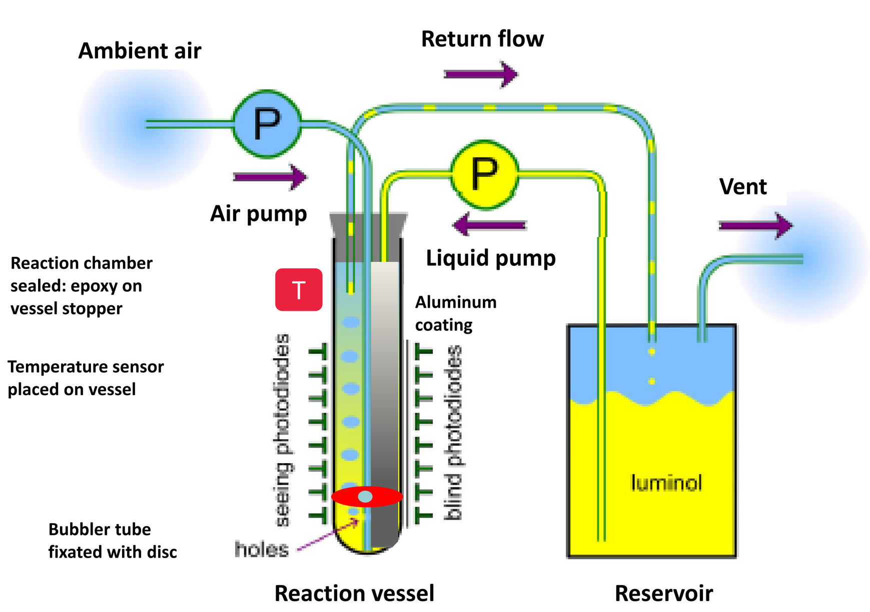
- Study NO_x (NO_2 + nitrous oxide (NO)) photochemistry and (aerosol) dynamics
- Validate results from chemical models
- Understand effects of regional transport
- Identify emitting sources and sinks[1]

Objective

- **Who:** Royal Netherlands Meteorological Institute (KNMI) and Nanjing University of Information Science & Technology (NUIST).
- **What:** Repetitive, high-resolution soundings of the planetary boundary layer (PBL).
- **Where:** Nanjing, China. Rural spot in the Pukou district.
- **When:** 1-14 June 2018.
- **Why:** Study the vertical distribution of NO_2 inside the PBL and gain better insight into local NO_x photochemistry.
- **How:** Deployment of a self-developed, accurate in-situ NO_2 sensor mounted on a drone.

Methods

Schematic overview of KNMI NO_2-sonde design[2].



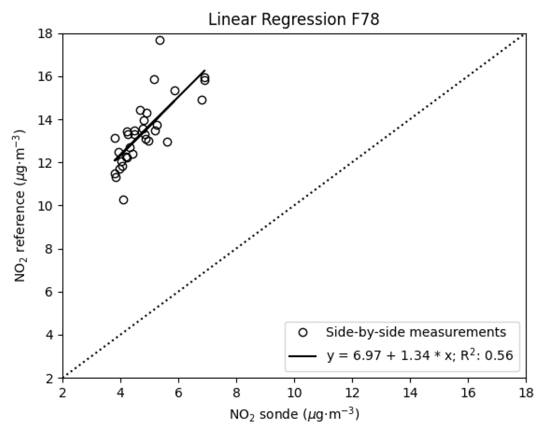
Drone (quadcopter) close to measurement site.

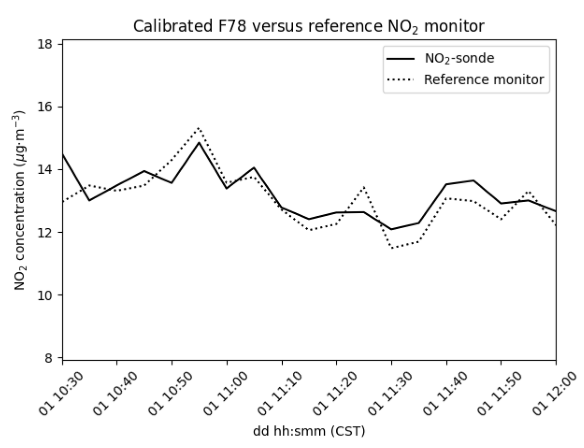
- **Sampling rate:** every second
- **Accuracy:** +/- 1 ppbv
- **Weight:** < 1 kg
- **Measurement duration:** 3-4 hours
- **Range:** 1-200 ppbv
- **Method:** Wet Luminol Chemiluminescence

- **Price:** < € 1000 per instrument
- **Power consumption:** < 2 Watt
- **Weather conditions:** -10-45 °C; 0-100% RH
- **User-friendly. Not harmful to user or finder!**

Results

Calibration of the NO_2 sensor:
Side-by-side comparison with NO_x analyzer Thermo Environmental Instruments (TEI) 42 at NUIST.

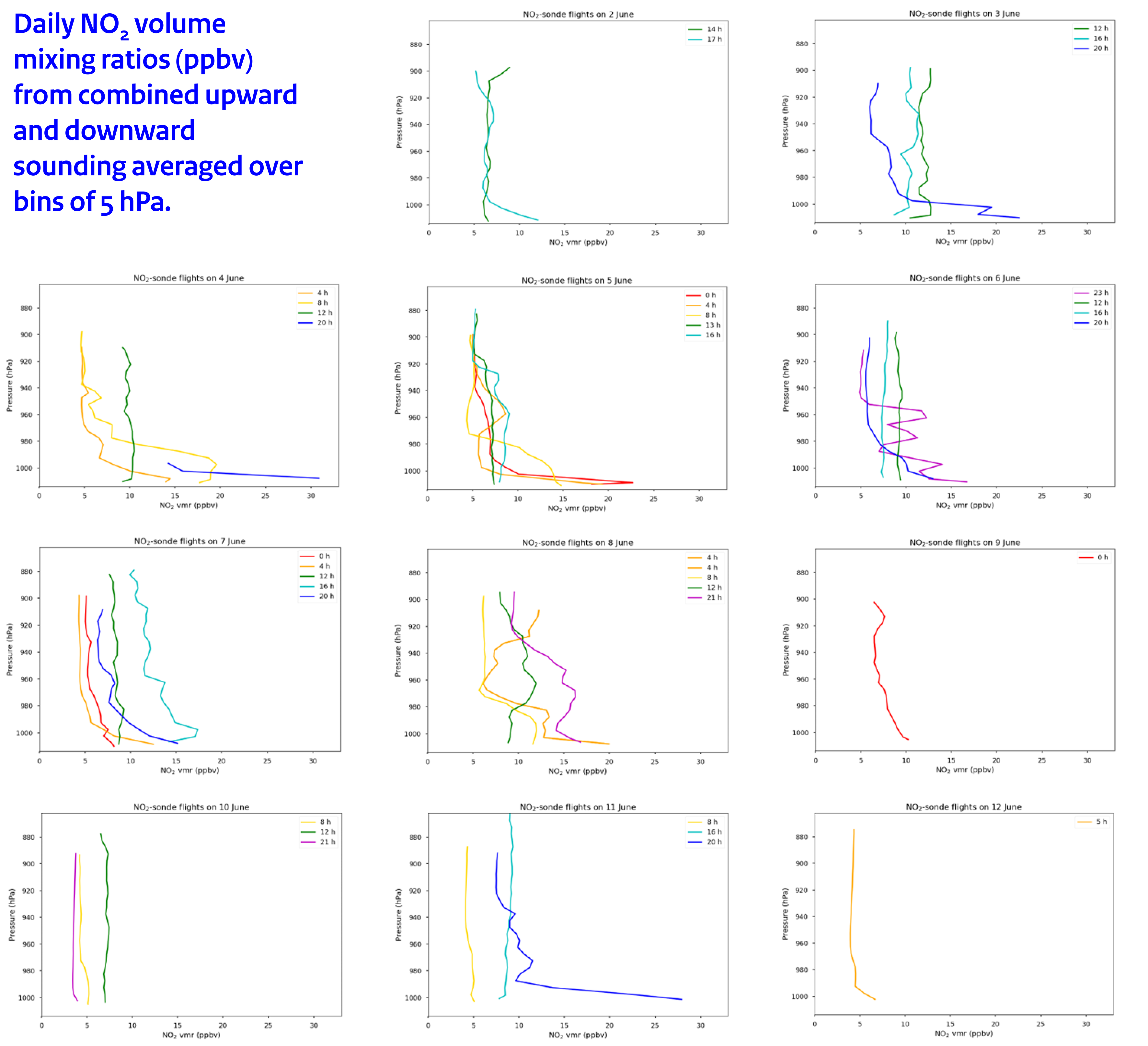




36 calibrated NO_2 vertical profiles measured between 2-12 June 2018
Diurnal cycle of NO_2 clearly visible:

- Elevated NO_2 concentrations close to the surface during the night and early morning.
- Development of PBL/rise of PBL height from sunrise onward .
- Well mixed PBL/flat NO_2 vertical profile shapes with lower concentrations during afternoon.

Daily NO_2 volume mixing ratios (ppbv) from combined upward and downward sounding averaged over bins of 5 hPa.



Discussion & Conclusion

NO_2 vertical profiles:

- **More accurate flight telemetry data** from the UAV could improve vertical profile accuracy and resolution. Now, pressure data from the NUIST O_3-sensor is used that measured simultaneously
- **Saturation issues:** NO2-sensor could not always capture full night-time NO_2 peak concentration. If available, a surface NO_2 dataset could be used to determine a possible correction factor.
- Supplementary surface NO_2 data should also be used to investigate cases where the **upward and downward soundings differ** substantially and cases where measured **vmrs seem too low**.

Reference monitor:

- Measures ambient concentrations of NO and NO_x simultaneaously using chemiluminescence.
- NO_2 is determined indirectly by converting NO_2 to NO by means of a heated molybdenum converter to measure NO_x and subsequently calculate de NO_2 concentration as NO_x-NO.
- The determined offset of 6.97 $\mu g{\cdot}m^{-3}$ probably results from the NO_2 to NO conversion since other NO_x oxidation products are converted to NO as well[3].

Conclusion: with the KNMI NO_2-sonde mounted on the NUIST quadcopter a unique dataset of ~40 vertical in-situ NO_2 profiles was collected that demonstrates the (local) NO_2 diurnal cycle.

Mayor References

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2. Sluis, W. W., Allaart, M. A. F., Piters, A. J. M., and Gast, L. F. L.: The development of a nitrogen dioxide sonde, Atmos. Meas. Tech., 3, 1753–1762, https://doi.org/10.5194/amt-3-1753-2010, 2010.
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