Estimating average Nitrogen Oxide emissions from inland waterway vessels using MAX-DOAS measurements

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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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Abstract

EGU General Assembly 2022

Picture: courtesy of Steffen Dörner

Introduction

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Why NO_x?

- NO_x = (NO + **NO_2**) are one of the main trace species in the urban air pollution

Why inland waterway vessels (IWVs)?

- Diesel engines of IWVs operate at high temperatures → emit NO_x
- Emissions could significantly contribute to the local air quality (e.g. along intensively used Rhine River)

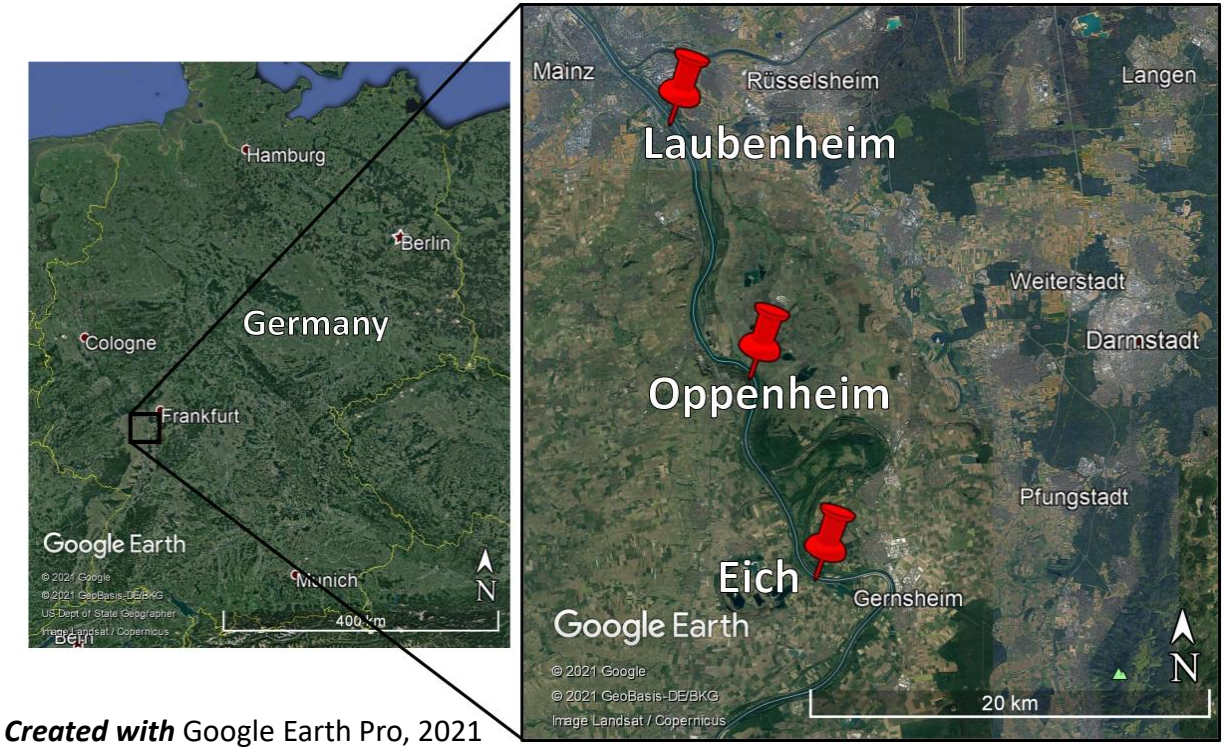
Motivation

- Knowledge about IWVs' contribution to the local air quality
- Scarce data on IWVs' emissions

- Ground-based **Multi-AXis Differential Optical Absorption Spectroscopy (MAX-DOAS)**:
  - Sensitive to NO_2 emitted by IWVs
  - Spatial and temporal ship plume distribution

MPIC Tube MAX-DOAS in Eich on 23rd of July 2020.
Courtesy of Steffen Dörner

Measurement site and method



Created with Google Earth Pro, 2021

- **Measurement site: Rhine River** between Mainz and Gernsheim cities in western Germany
- MAX-DOAS method was used to measure NO_2

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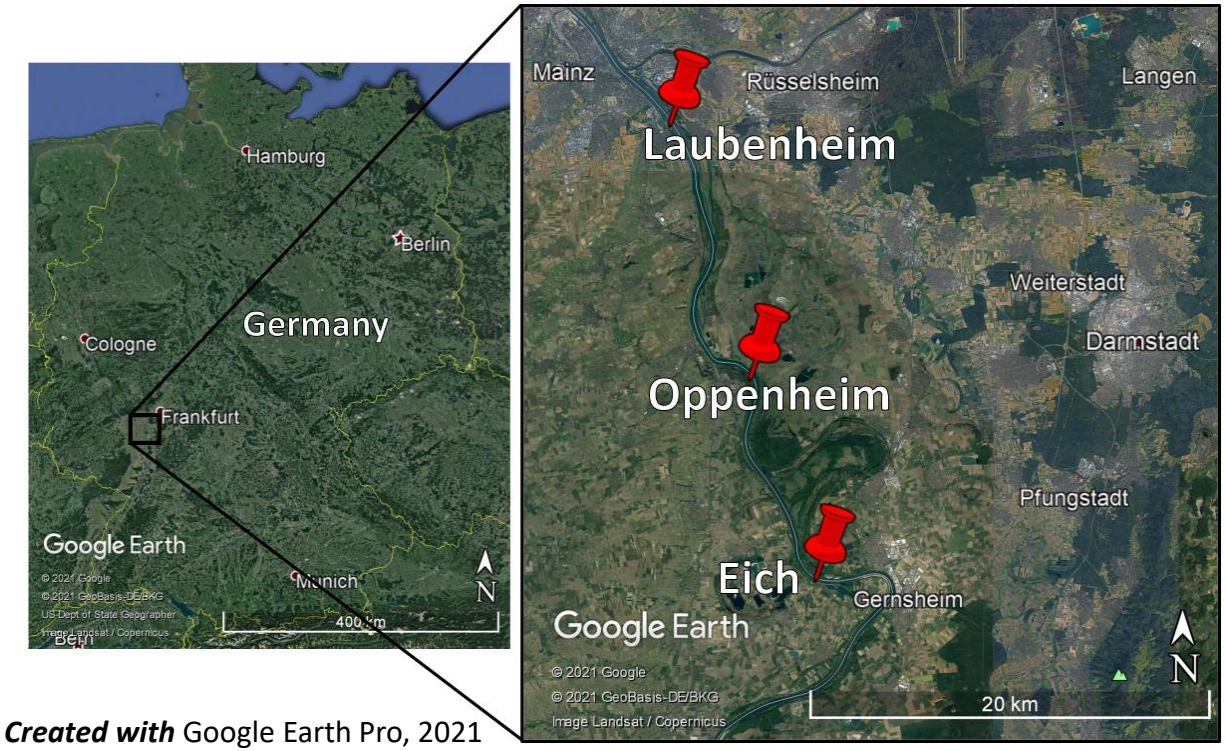

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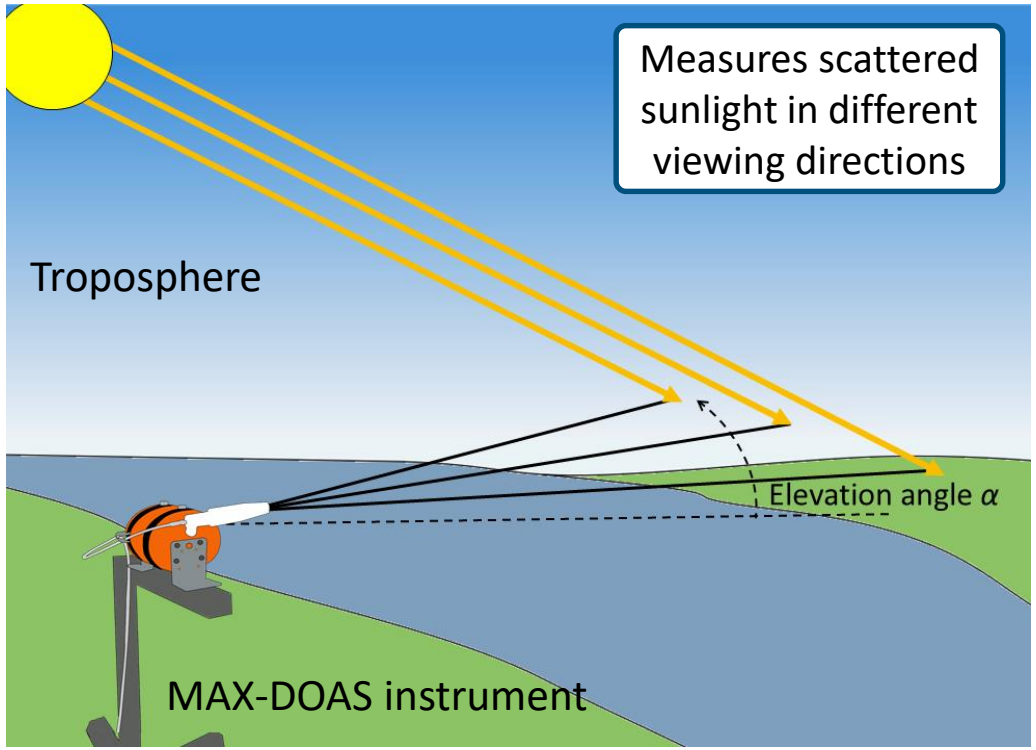
MAX-DOAS geometry for ship emission measurements



Adapted from Platt and Stutz, 2008

Retrieves **Differential Slant Column Density DSCD (molec/cm²):**

$$\mathrm{DSCD} = \mathrm{SCD}_{meas} - \mathrm{SCD}_{ref}, \qquad \text{with SCD} = \int_0^L c(s)ds$$

L = light path and c = concentration

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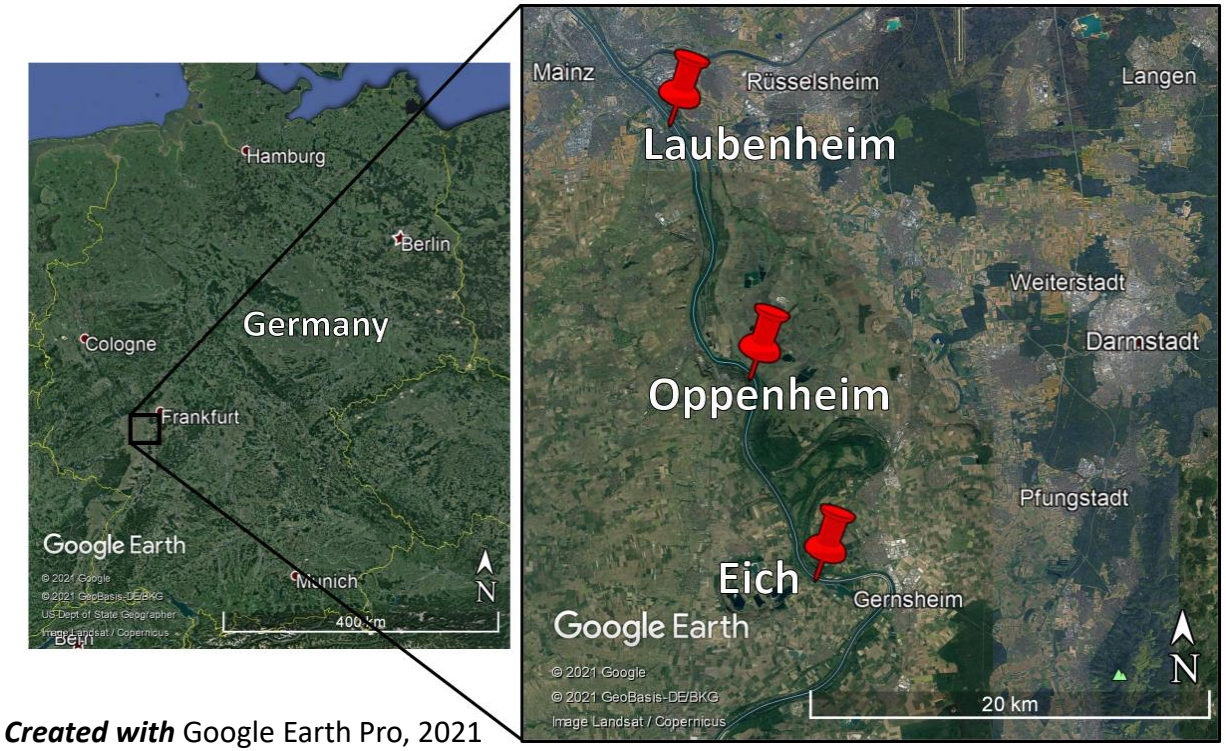

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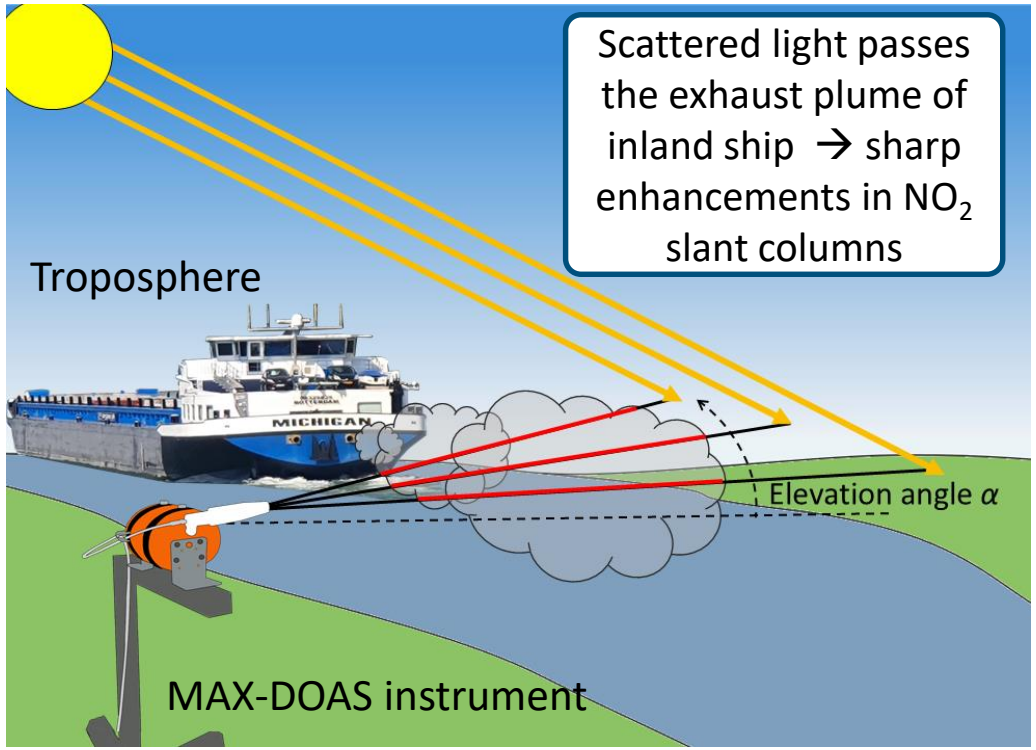

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Estimation of NO_x emissions

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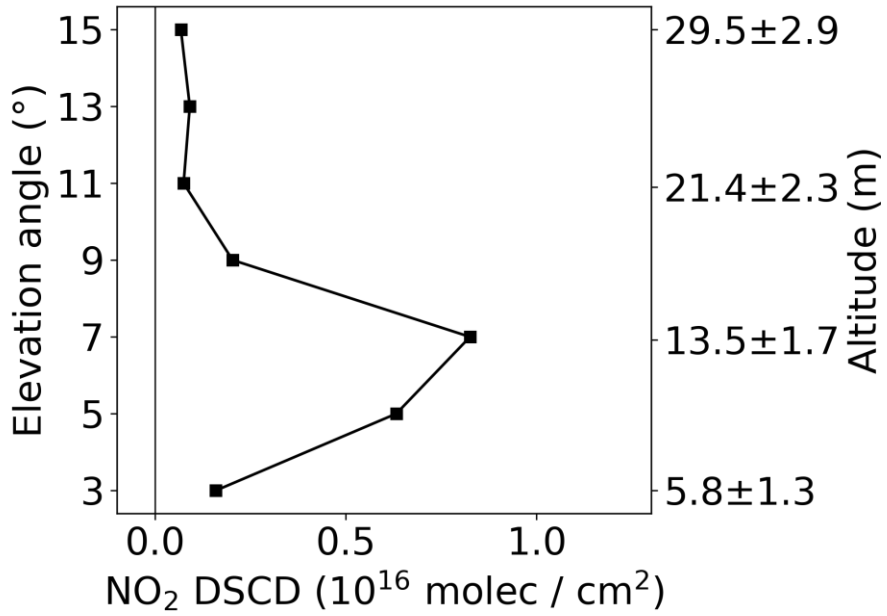
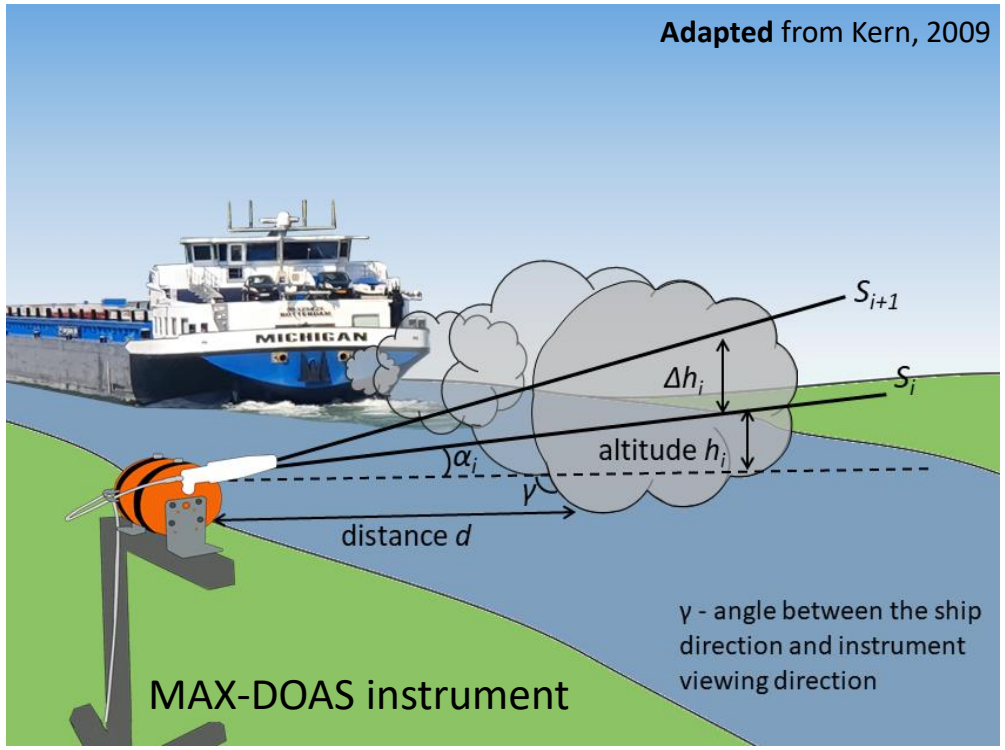
MAX-DOAS measurements:
NO_2 DSCDs (molec/cm²)

Total NO_x emission flux through the plume slice (molec/s)



Plume cross-section in Eich, 23rd of July 2020 13:07 UTC

Integration of NO_2 amount in a ship emission plume



Adapted from: Kern, 2009

Estimation of NO_x emissions

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NO_2 emission flux through the plume slice (molec/s)

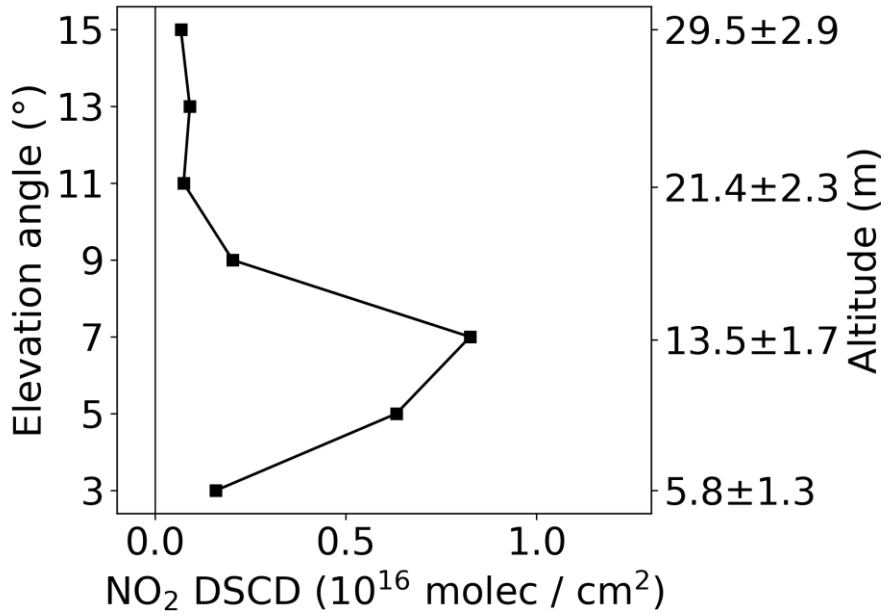
$$\phi_{NO_2} = X_{NO_2} \cdot v_{plume}$$

Integrated amount of NO_2 (molec/cm) in the cross-section of plume

$$X_{NO_2} = \sum_{i \in Plume} \left(S_i \cdot \Delta h_i \right) \cdot \sin\gamma$$

Plume transport velocity (cm/s)

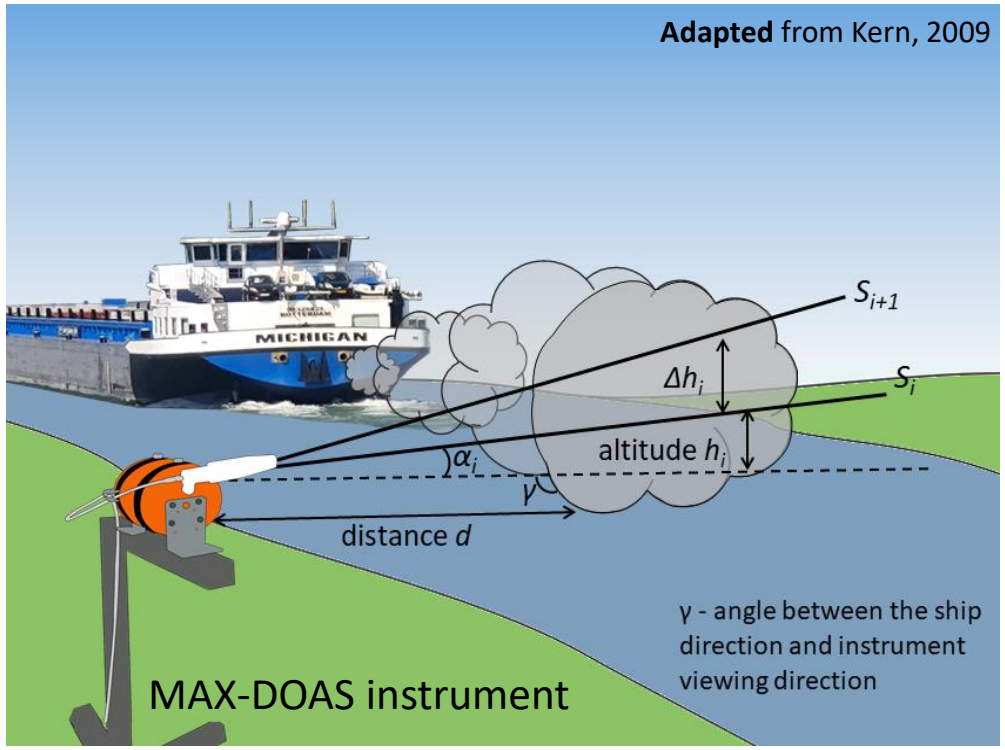
$$v_{plume} = v_{ship} - v_{wind,\ \parallel}$$



Plume cross-section in Eich, 23rd of July 2020 13:07 UTC

S_i = average slant column density between two viewing directions
Δh_i = distance between two viewing directions
v_{ship} = ship velocity
$v_{wind,\ \parallel}$ = wind velocity parallel to ship sailing direction

Integration of NO_2 amount in a ship emission plume



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Estimation of NO_x emissions

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Integrated amount of NO_2 (molec/cm) in the cross-section of plume

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$$\phi_{NO_2} = X_{NO_2} \cdot v_{plume}$$

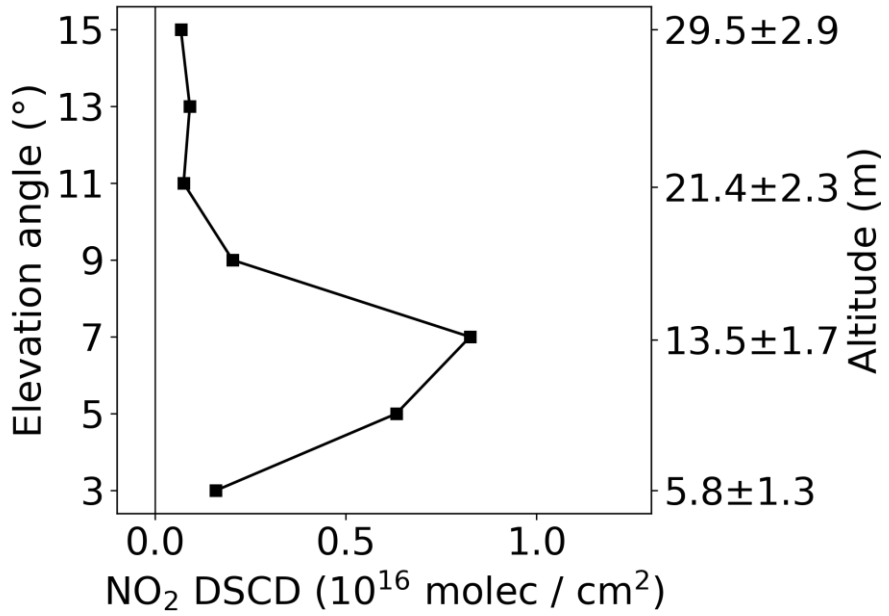
Plume transport velocity (cm/s)

$$v_{plume} = v_{ship} - v_{wind,\ \parallel}$$

Total NO_x emission flux (molec/s)

$$\phi_{NO_x} = f \cdot \phi_{NO_2}$$

Conversion factor
f = 1.32 (*Beirle et al., 2011*)



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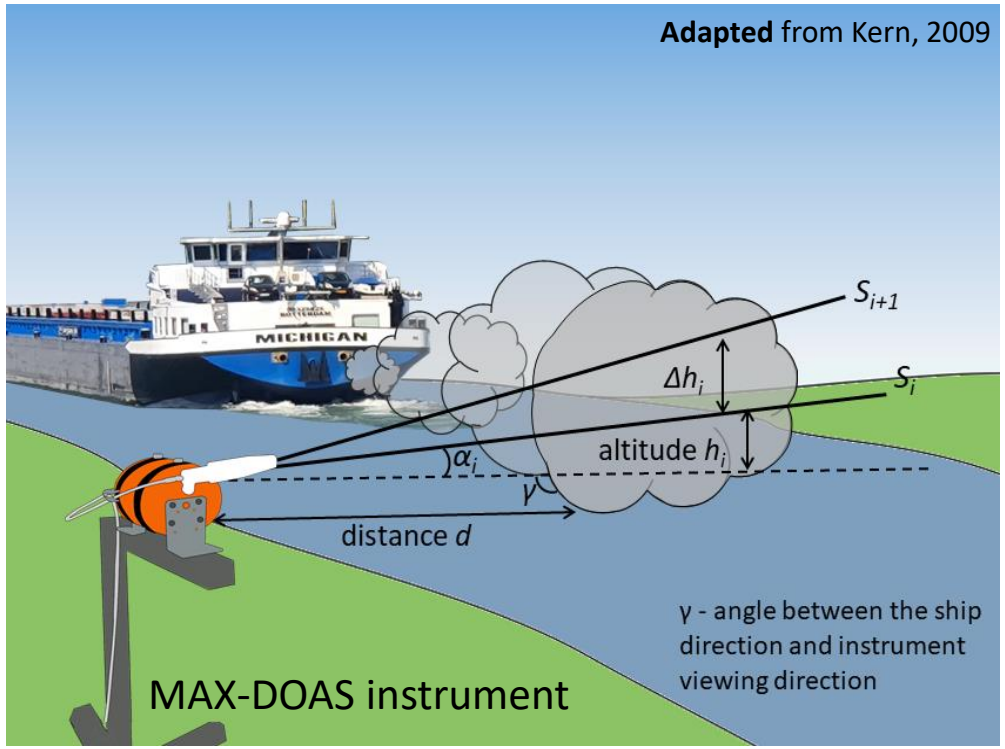

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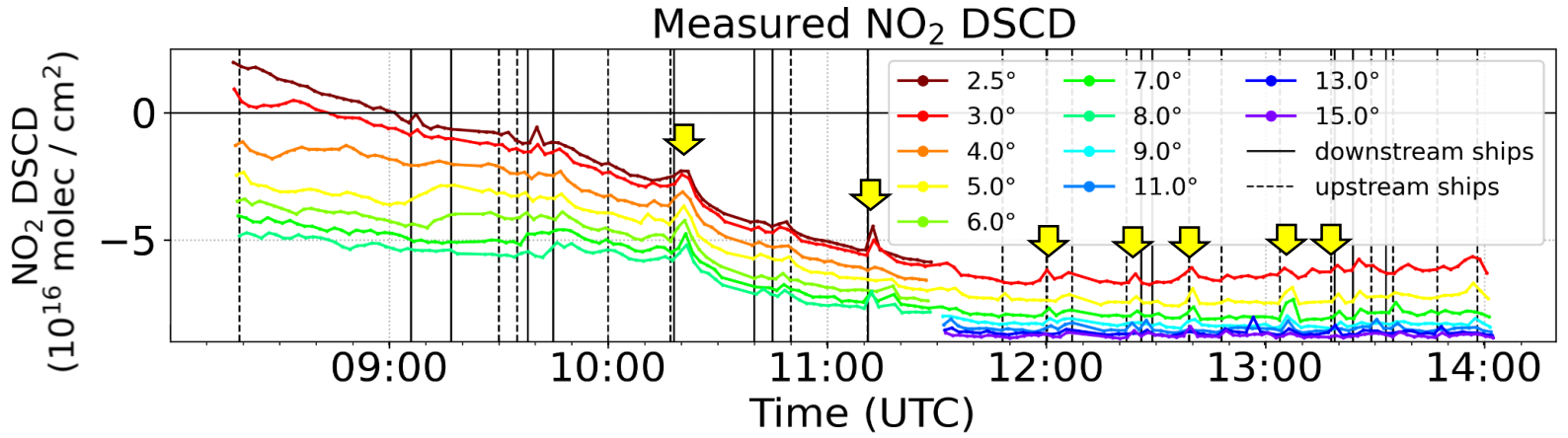
Background correction

Eich, 23rd of July 2020



NO_2 DSCDs = **background** + **ship emissions**

Background correction

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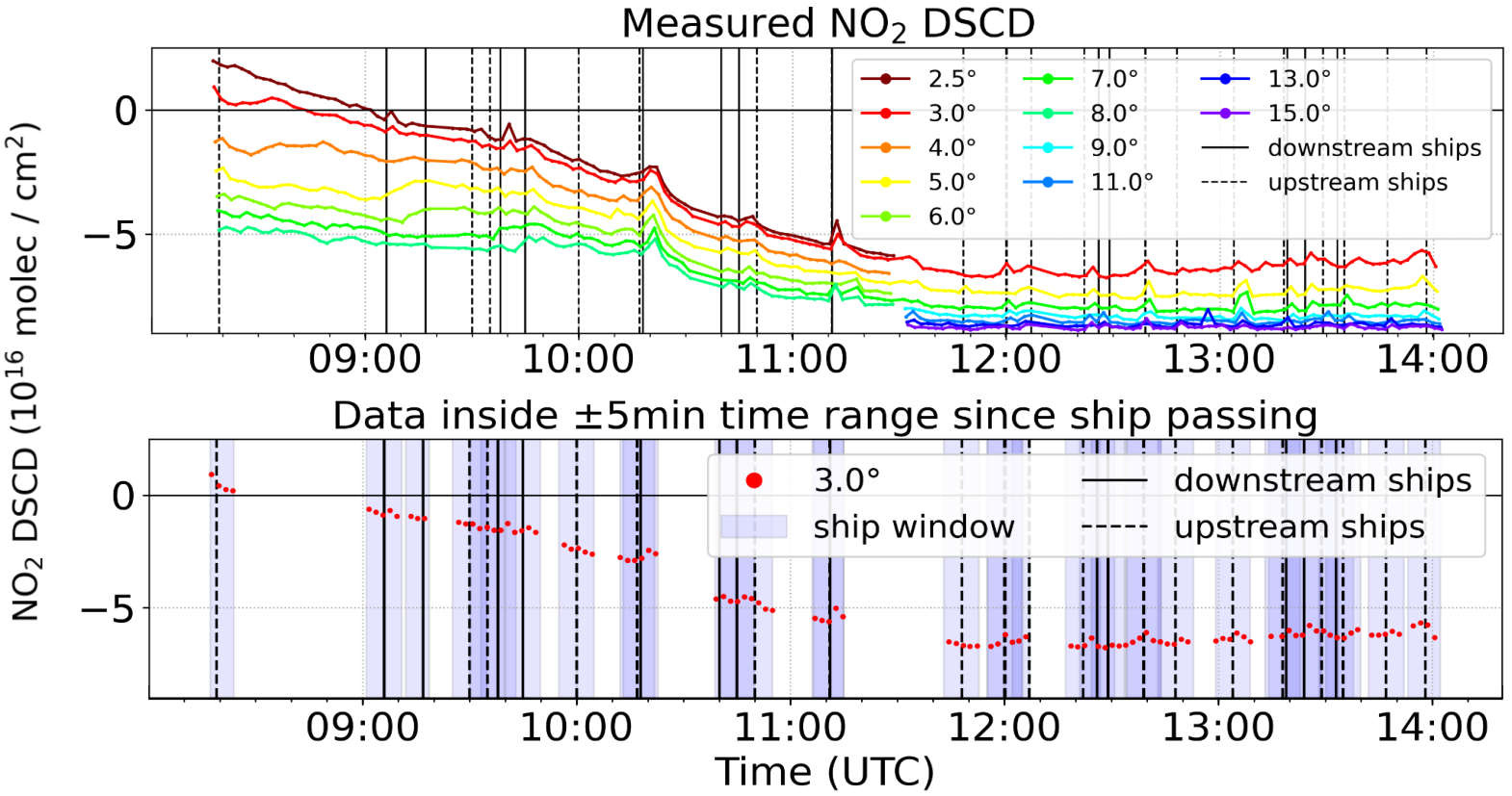

NO_2 DSCDs = **background** + **ship emissions**

values affected by ship emissions

Background correction

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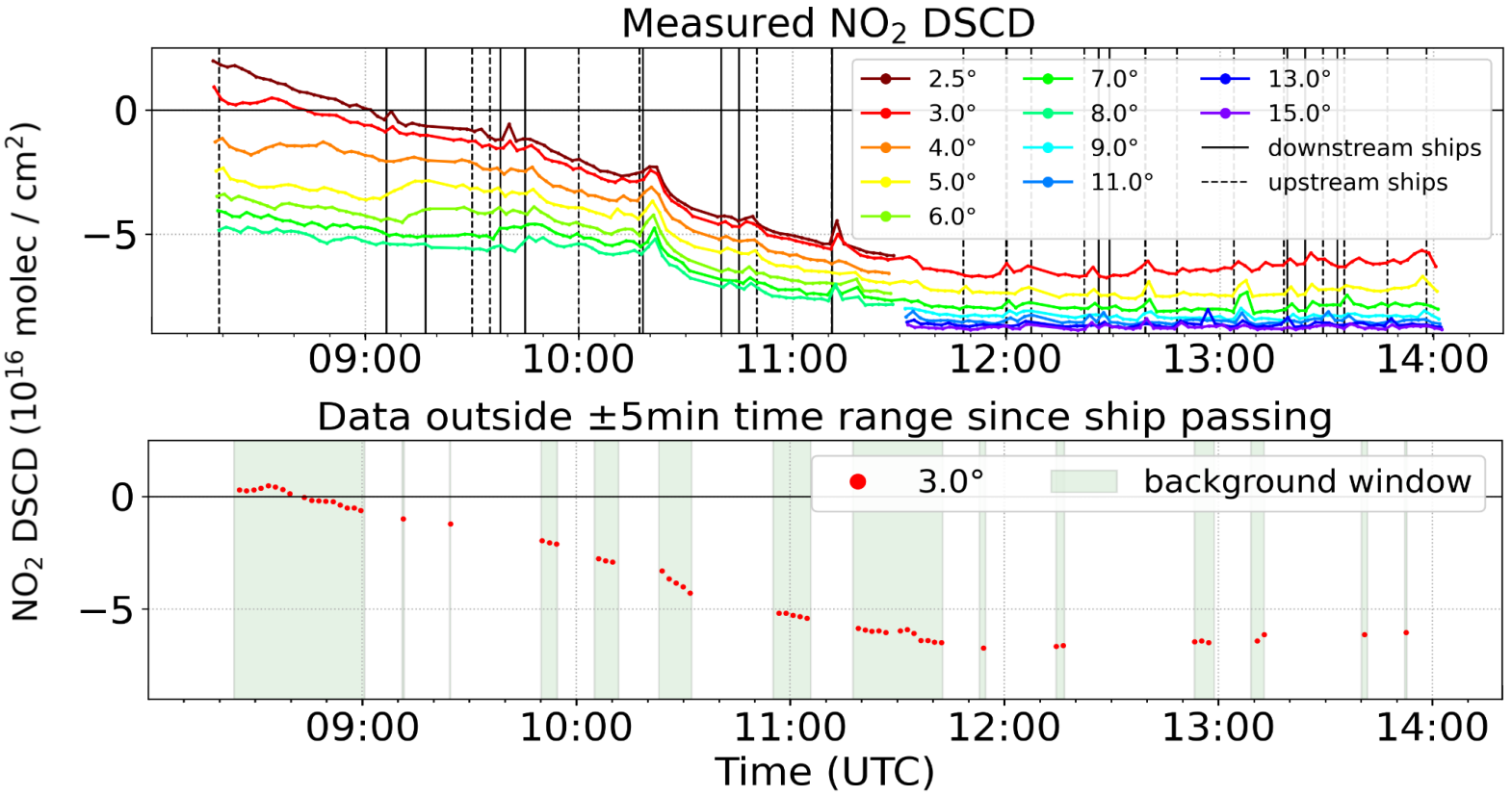

NO_2 DSCDs = **background** + **ship emissions**

values not affected by ship emissions

Background correction

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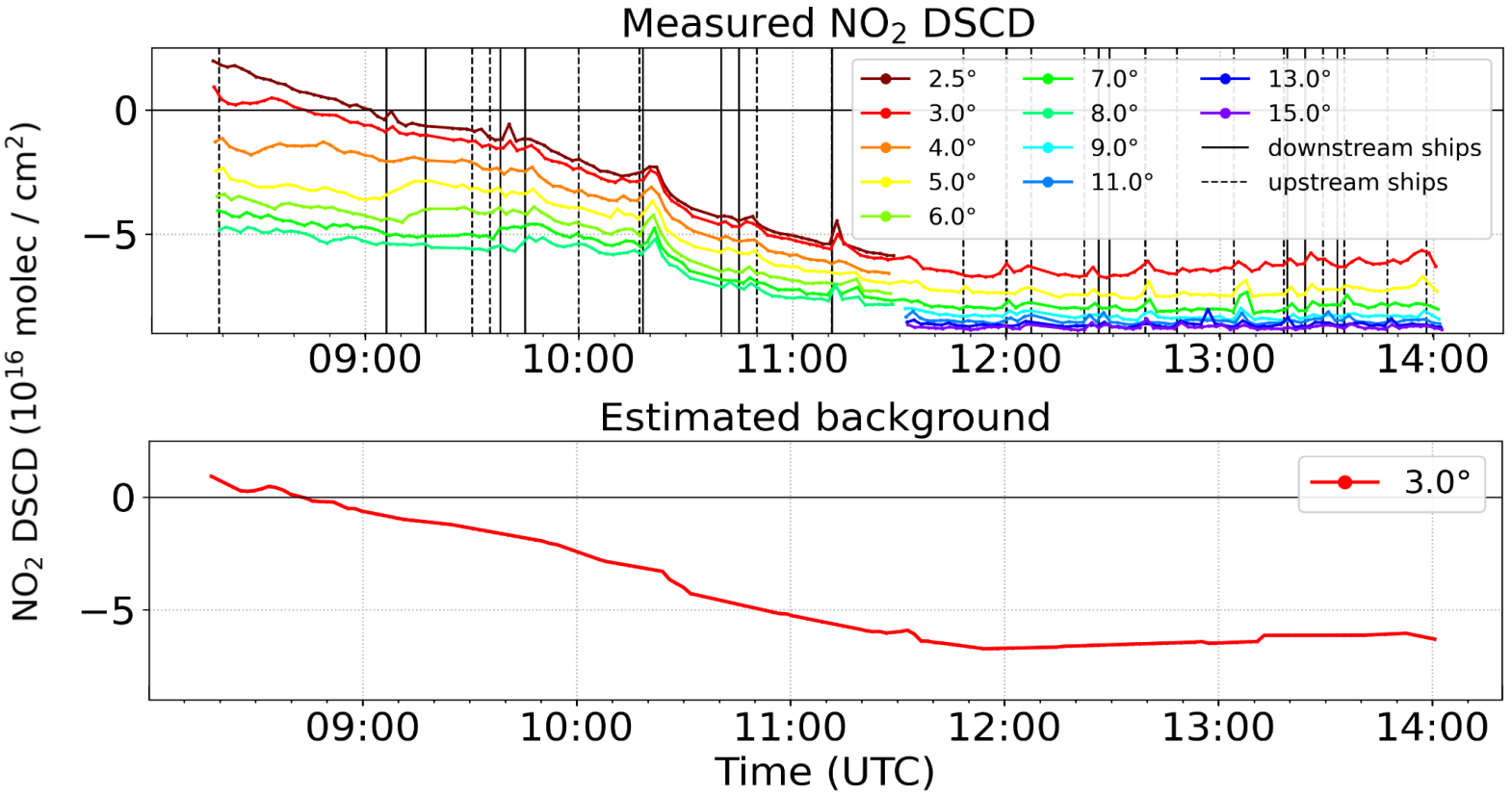

NO_2 DSCDs = **background** + **ship emissions**

Linear interpolation between “background windows” → $DSCD_{backgr}$

Background correction

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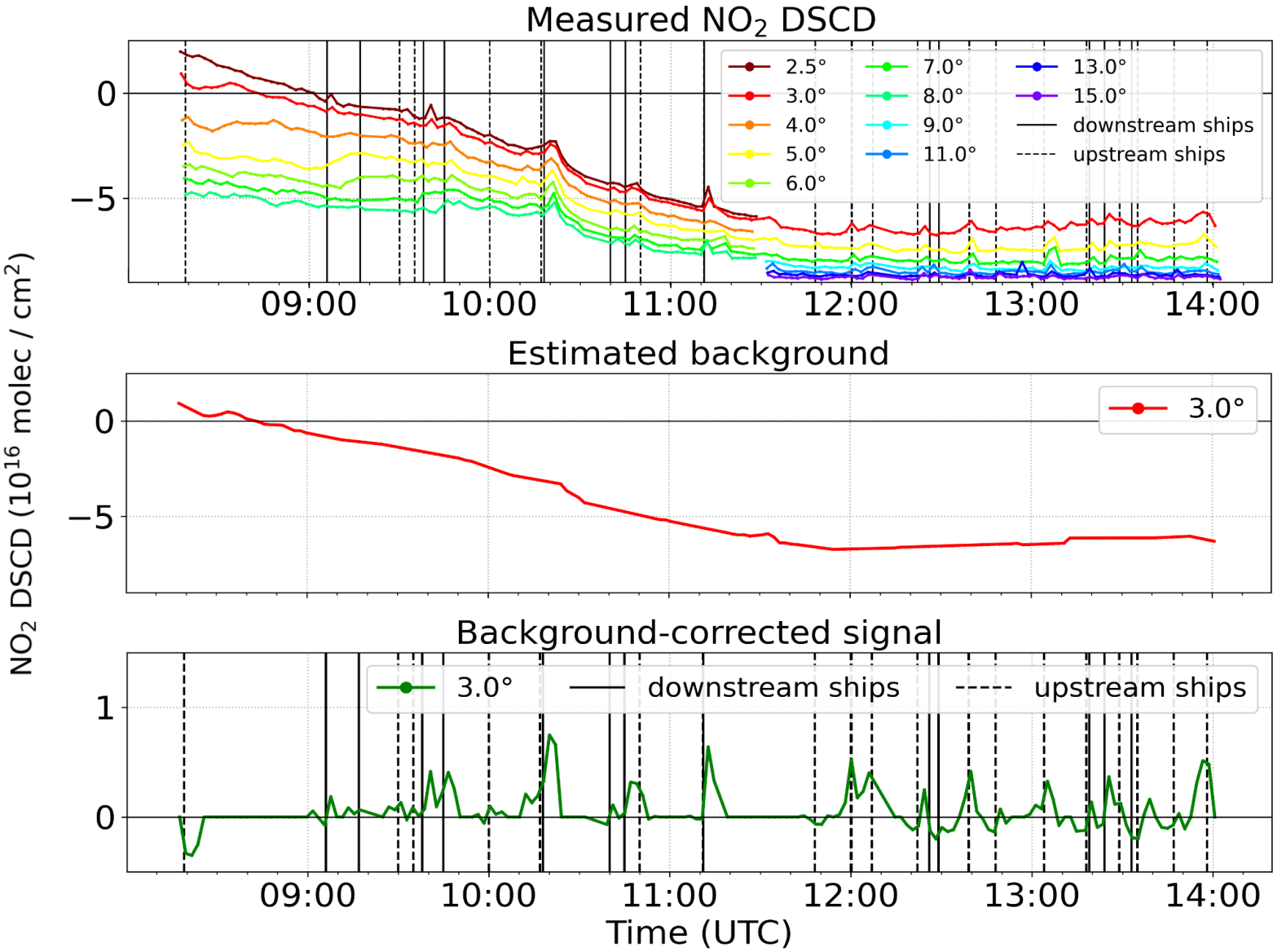


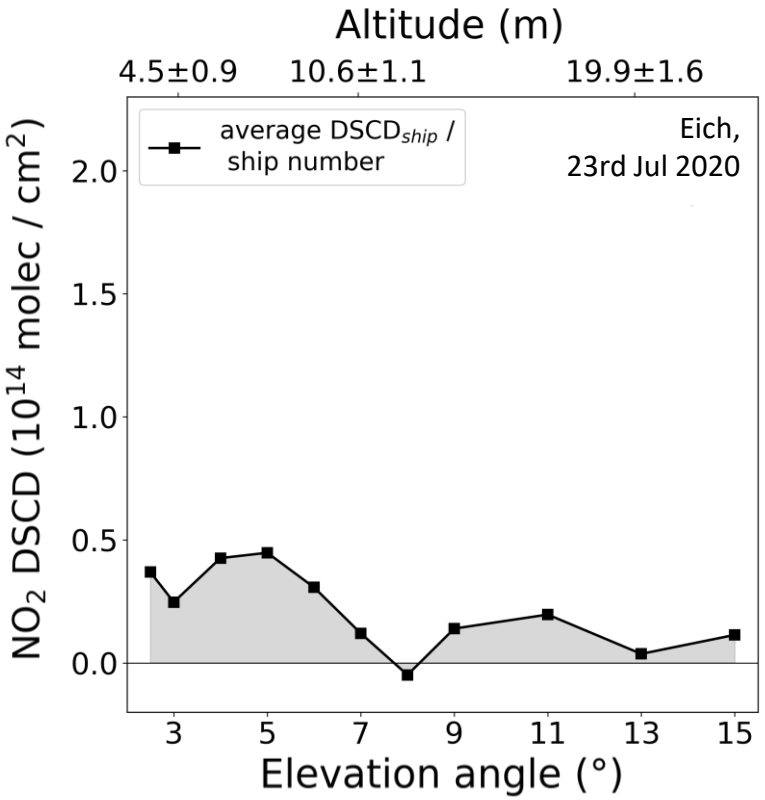
NO_2 DSCDs = **background** + **ship emissions**

Linear interpolation between "background windows" → $DSCD_{backgr}$

Ship related signal $DSCD_{ship}$ for every elevation angle:

$$\mathrm{DSCD}_{\mathrm{ship},\,i} = \mathrm{DSCD}_i - \mathrm{DSCD}_{\mathrm{backgr},\,i}$$

Average NO_x emissions
Eich, 23rd of July 2020



Average ship emission plume

- $DSCD_{ship}$ averaged for every elevation angle
- Divided by number of ships that passed the instrument
- Only values within ±5 min “ship window”

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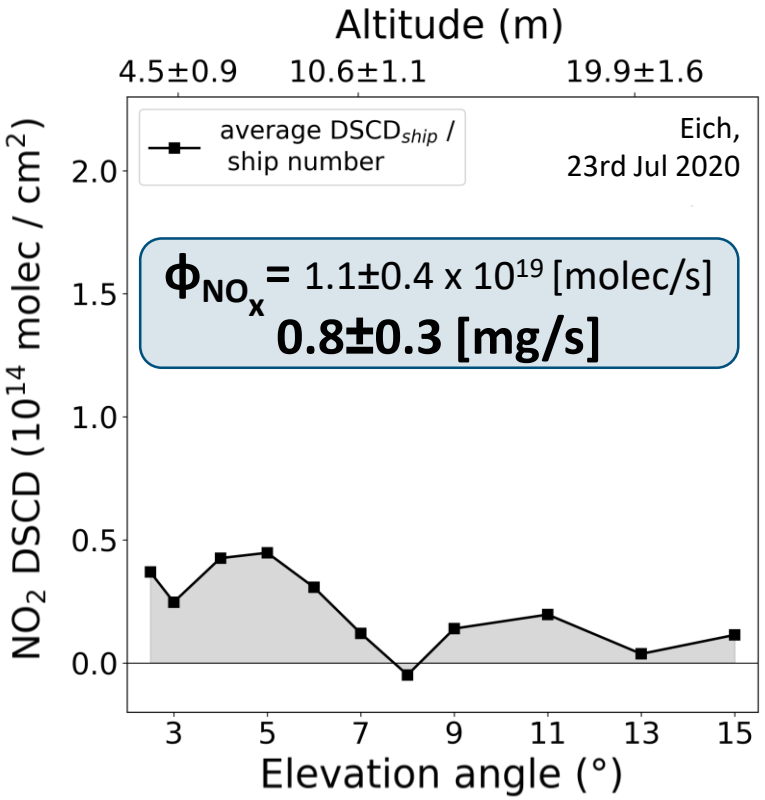

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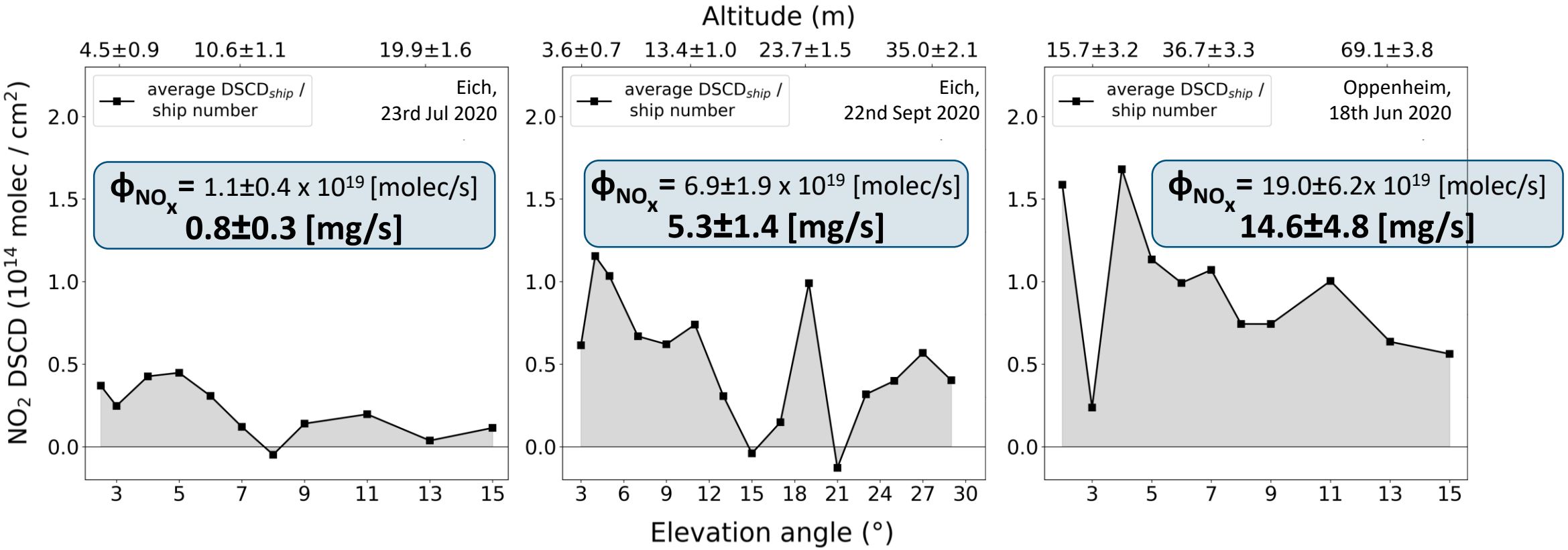

Conclusions

- **MAX-DOAS** technique **can detect NO_2** signals originating **from IWVs**
- For an unambiguous plume detection, measured NO_2 DSCDs were background corrected
- Average background-corrected NO_2 signals were used to estimate average NO_x emissions from inland ships
- Average values vary between 0.8 and 14.6 mg/s for shown measurement days

Abstract

Thanks for your attention!

For questions, comments and suggestions please contact:
Simona Ripperger-Lukošiūnaitė: s.lukosiunaite@mpic.de

Picture: Courtesy **of** Steffen Dörner

References

- Google Earth Pro V 7.3.4.8248 (Google Earth Pro), 2021. Rhine River between Mainz and Gernsheim, Germany. 49°54’15.59” N, 8°19’09.86” E, eye altitude 5100 km. Google 2021, GeoBais-DE/BKG 2021, Image Landsat/Copernicus, US Dept of State Geographer

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