

Ship-based MAX-DOAS measurements of nitrogen dioxide in the South China and Sulu Sea

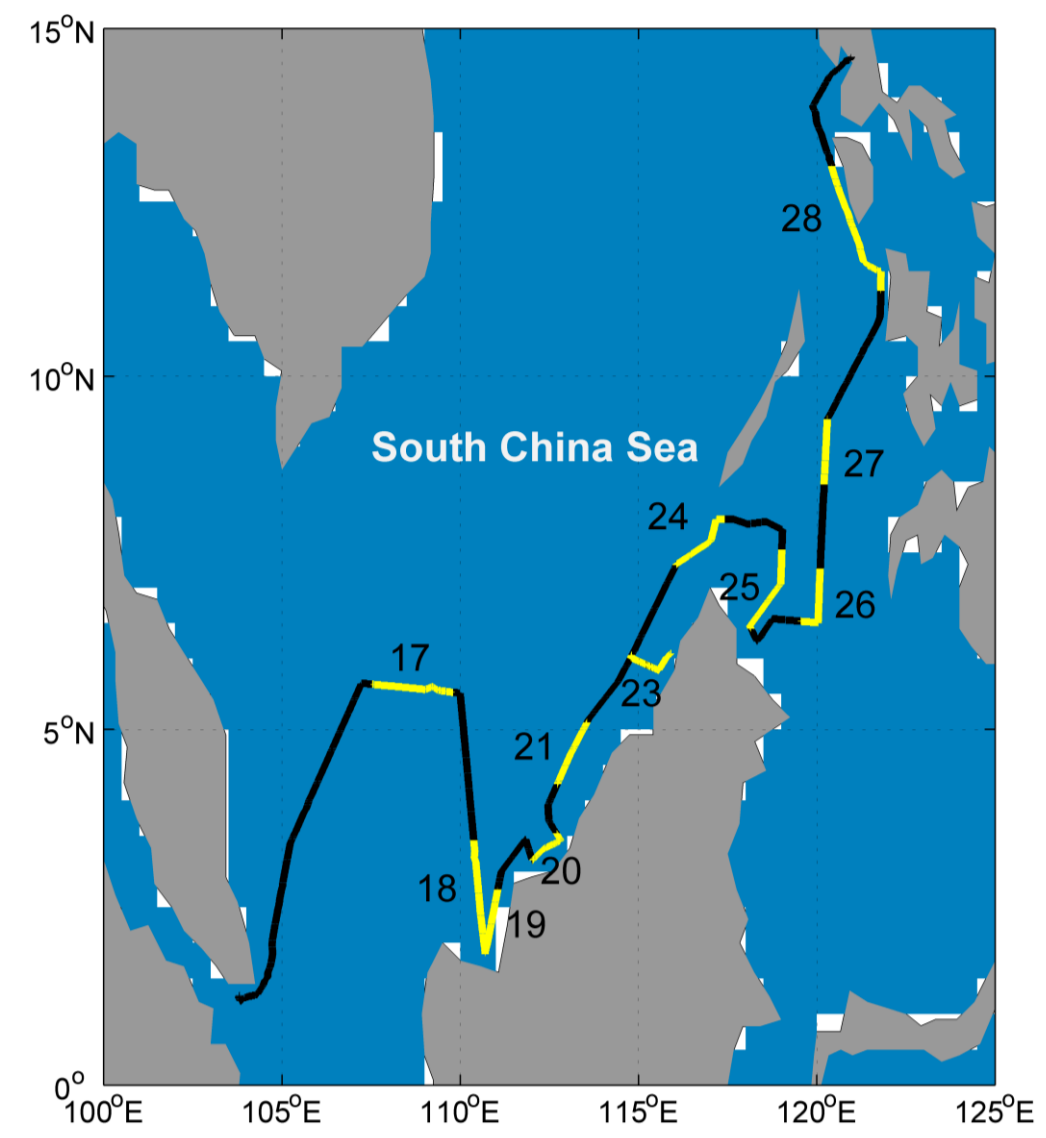
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1 Ship cruise within SHIVA



The ship cruise was carried out with the German research vessel (RV) Sonne as a part of the SHIVA campaign between 15 November and 29 November 2011 in the South China and Sulu Sea.

The IUP Bremen MAX-DOAS instrument was part of the RV Sonne instrumentation during SHIVA to measure atmospheric trace gases.

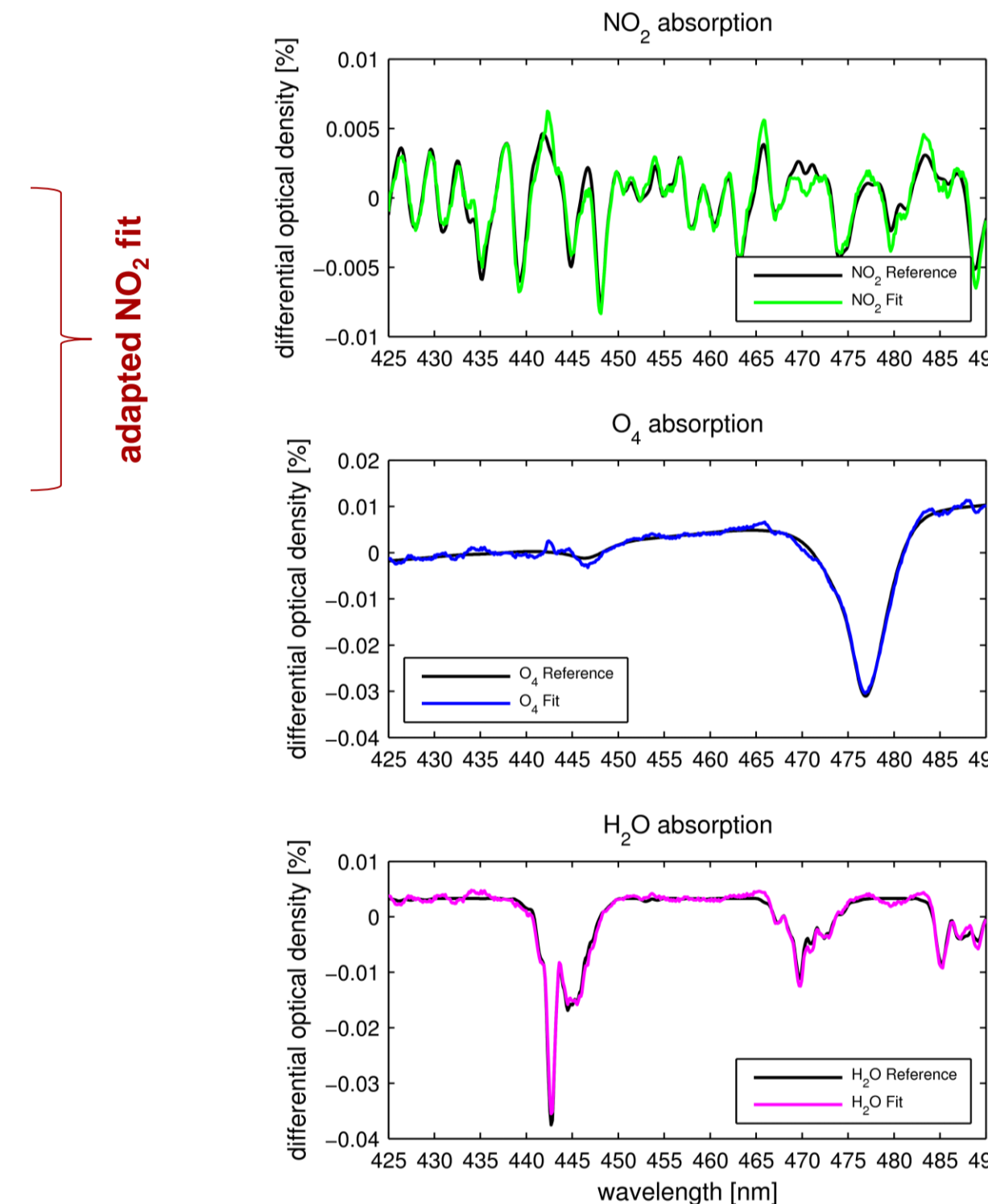
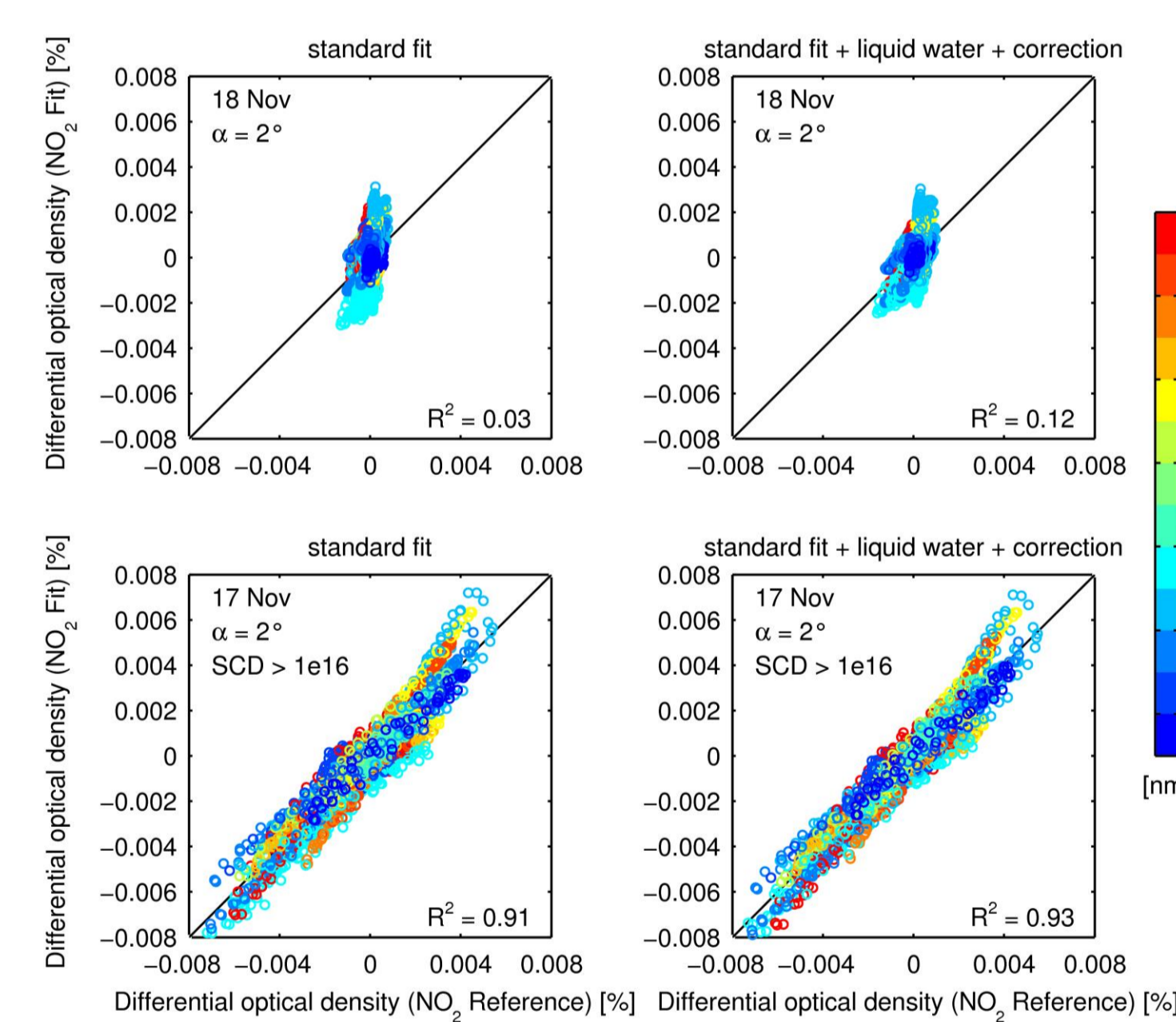
Overall, spectral measurements have been performed on eleven days during SHIVA, which provides a good basis for the analysis of NO₂ vertical columns and profiles in the coastal waters of South China and Sulu Sea.

The ship track (black) and daytime stages (yellow), indicating the period between the first and last MAX-DOAS measurements, are shown in the figure.

4 Retrieval of NO₂ columns

The NO₂ retrieval is performed in the visible spectrum:

- fitting window: 425-490 nm
- cross sections
 - O₃ (Bogumil et al., 2003)
 - NO₂ (Vandaele et al., 1996)
 - O₄ (Greenblatt et al., 1990)
 - H₂O (Rothmann et al., 2003)
 - Ring (SCIATRAN)
 - H₂O_{liq} (Pope and Fry, 1997; Peters et al. (2014))
 - polynomial degree: 5



We have compared the standard NO₂ fit with the NO₂ fit adapted for the ship-based SHIVA campaign for a clear day (18.11.) and a polluted case on 17.11. for 2° elevation angle (left Figure).

- slight improvement (indicated by R² values)
- especially when NO₂ is lower (18.11.)

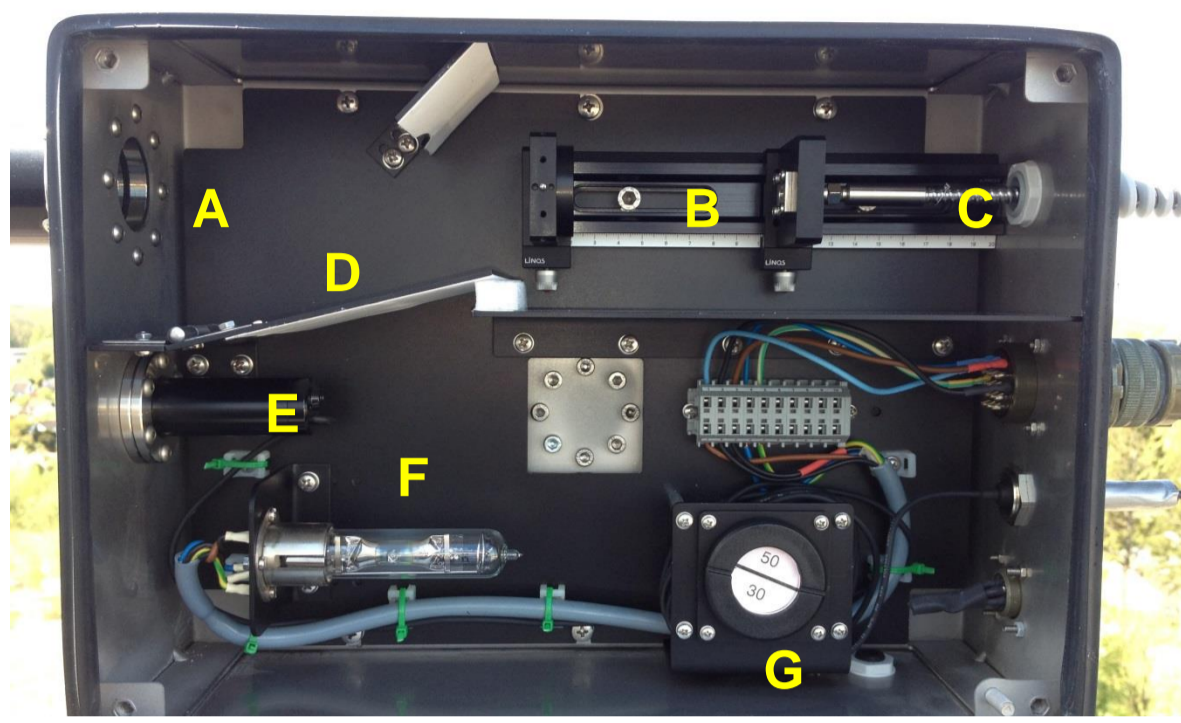
Acknowledgements

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Selected References

Peters E et al.: Formaldehyde and nitrogen dioxide over the remote western Pacific Ocean: SCIAMACHY and GOME-2 validation using ship-based MAX-DOAS observations, Atmos. Chem. Phys., 12, 11179–11197, 2012
 Wittrock F: The retrieval of oxygenated VOCs by remote sensing techniques, PhD thesis, 2006
 Roscoe HK et al.: Intercomparison of slant column measurements of NO₂ and O₄ by MAX-DOAS and zenith-sky UV and visible spectrometers Atmos. Meas. Tech., 3, 1629-1646, 2010

2 MAX-DOAS instrument

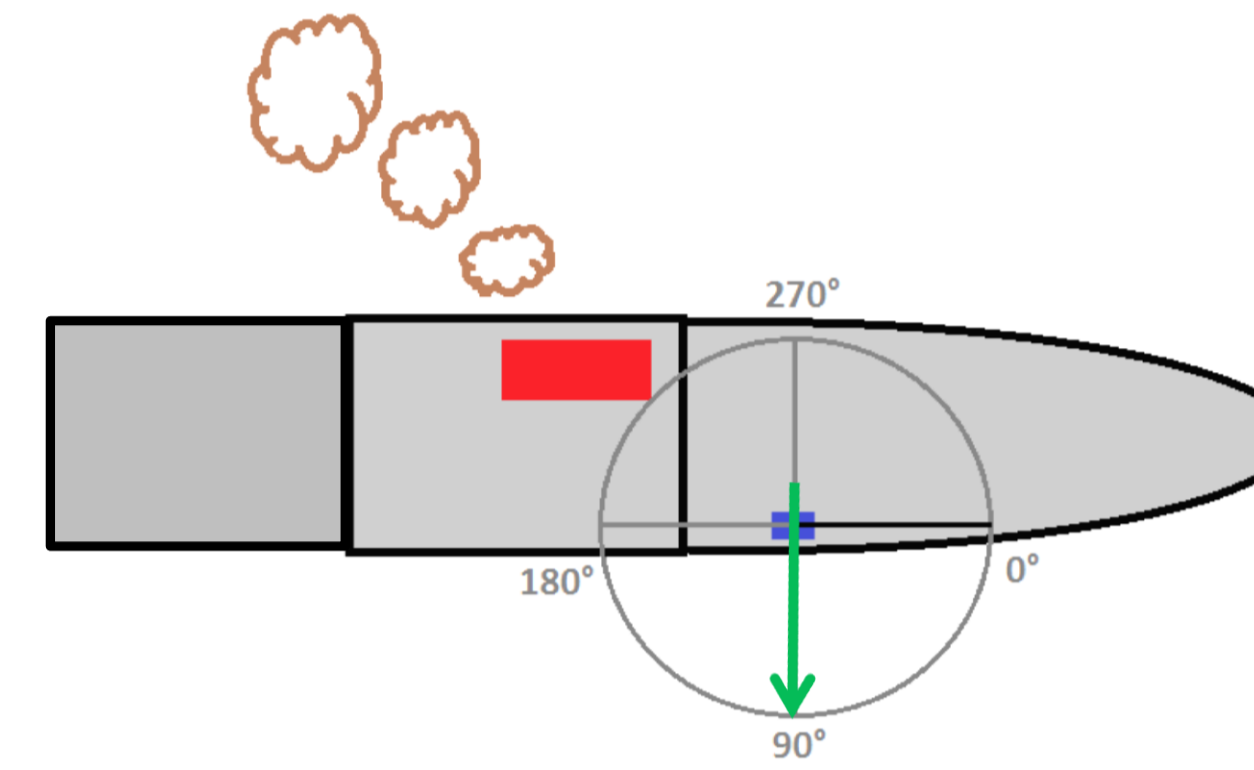


- A ... entrance window
- B ... optical bank with lens
- C ... fibre mount
- D ... gravity-driven shutter
- E ... video camera
- F ... HgCd line lamp
- G ... drying agent

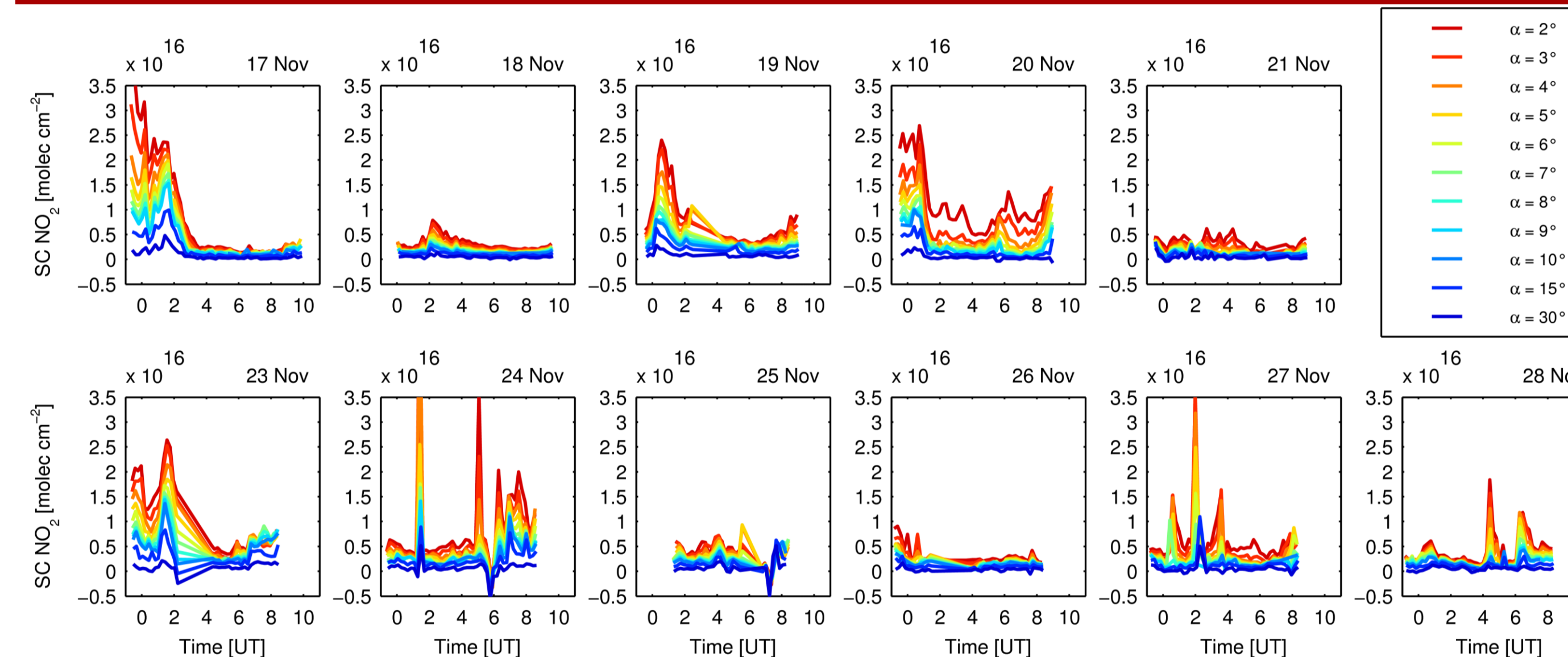
The telescope unit is connected with two spectrometers. The UV (315-384 nm) and visible (400-570 nm) spectrometers are both equipped with a CCD camera with 512 x 2048 (UV) and 100 x 1340 (visible) pixels.

The azimuthal angle of the telescope unit (green arrow) was kept at 90° relative to the ship's heading.

Elevations angles (α) of 1°, 2°, 3°, 4°, 5°, 6°, 7°, 8°, 9°, 10°, 15°, 30°, and 90° were included in the scanning sequence designed for the NO₂ retrieval.



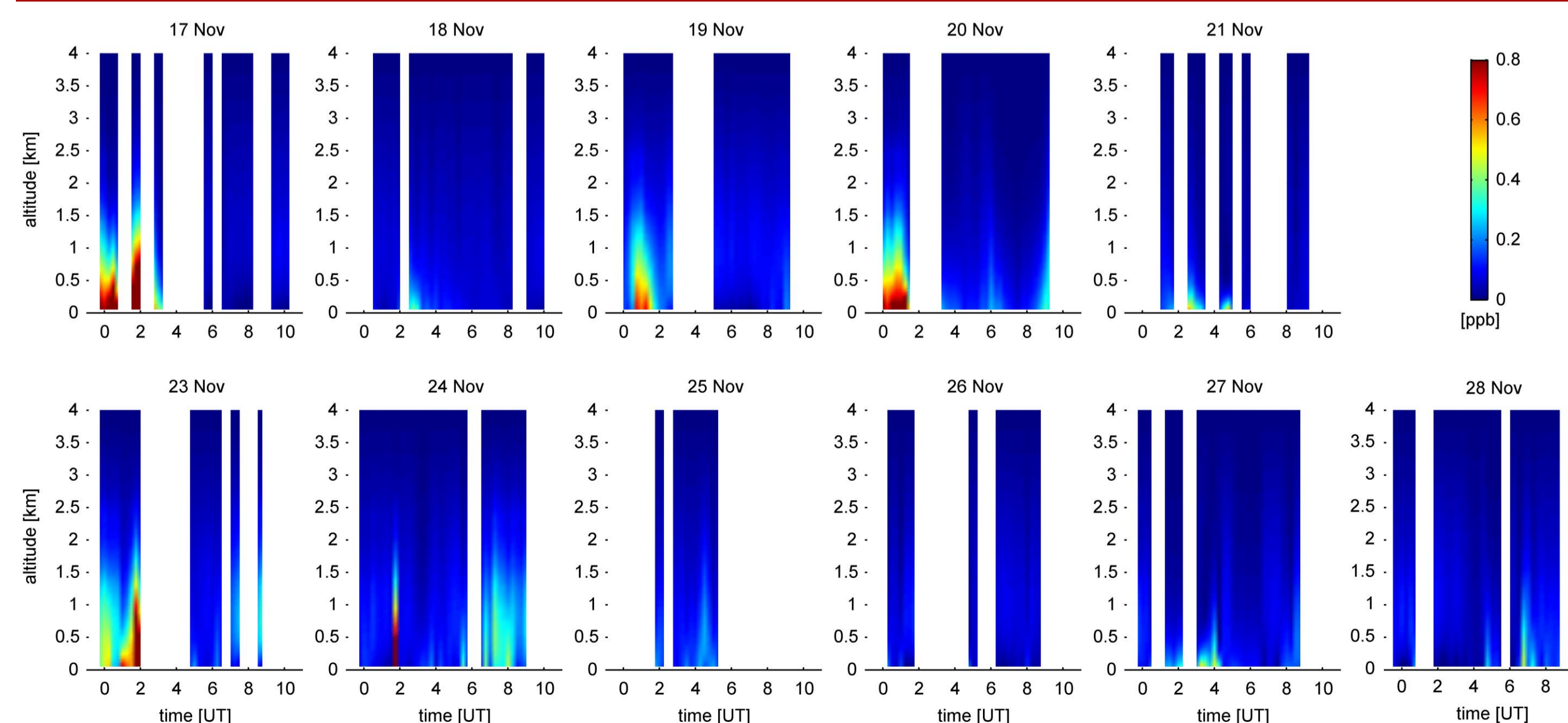
5 NO₂ slant column densities



For the retrieval of SCDs, spectra have been divided by a contemporary zenith measurement. The highest values are observed for the lowest elevation angles, whereas the lowest values are found at the highest elevation angles.

The lowest NO₂ SCDs are observed when the ship was far away from the coast and in a sufficiently large distance to other ships. Higher values are found, when the ship was either in proximity to the coast or close to other vessels.

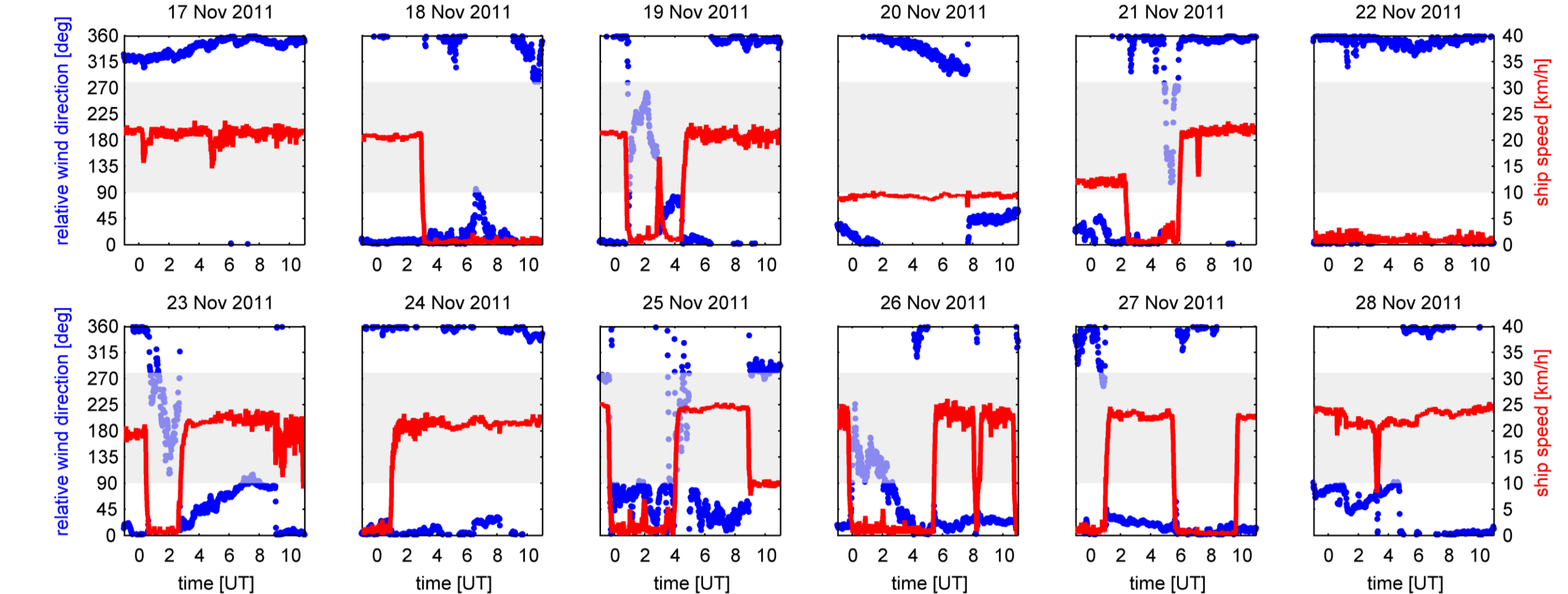
7 Tropospheric NO₂ profiles



It is again obvious that the higher NO₂ mixing ratios occurred in the morning hours when the ship moved along the Coast of Borneo Island.

The highest NO₂ mixing ratios exceeding 0.6 ppm are generally found within the first 500 m.

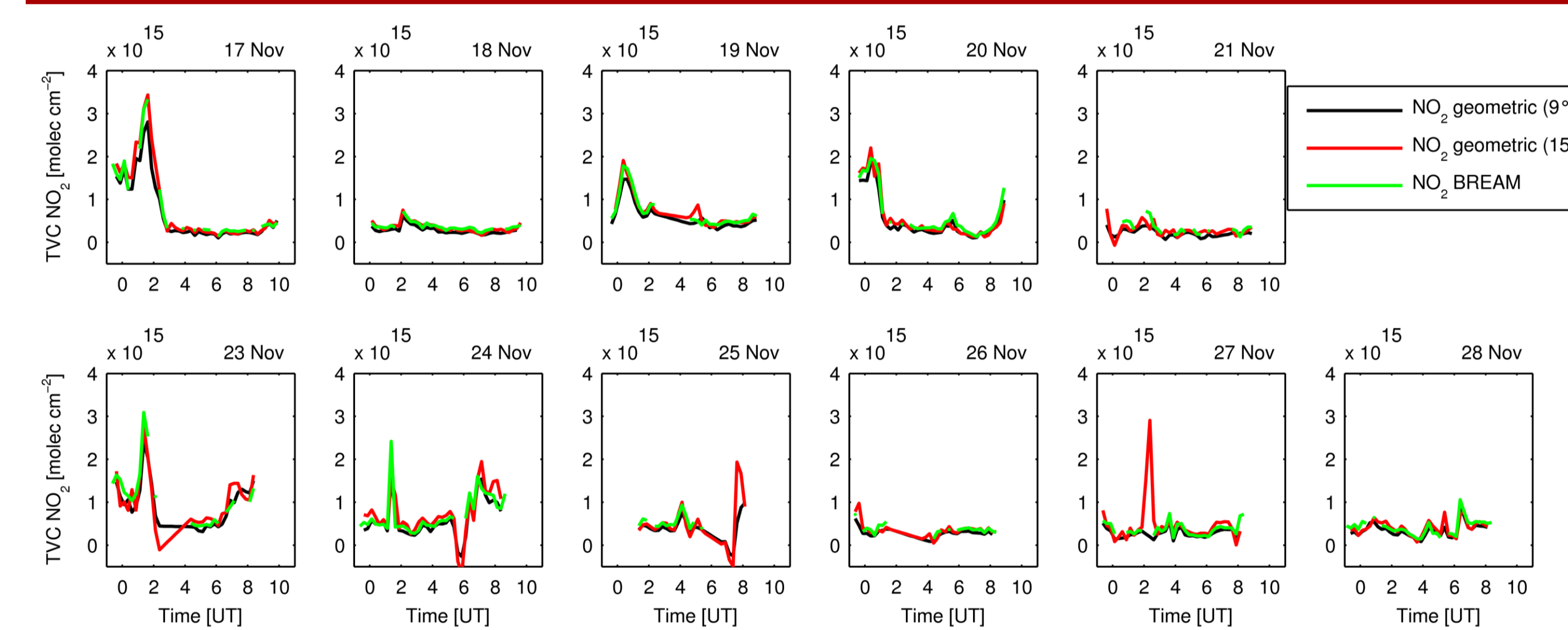
3 Data preparation and filtering



Besides the correction for pitch and roll motions of the ship, we have removed spectra collected under unfavorable wind directions (between 90° and 280°).

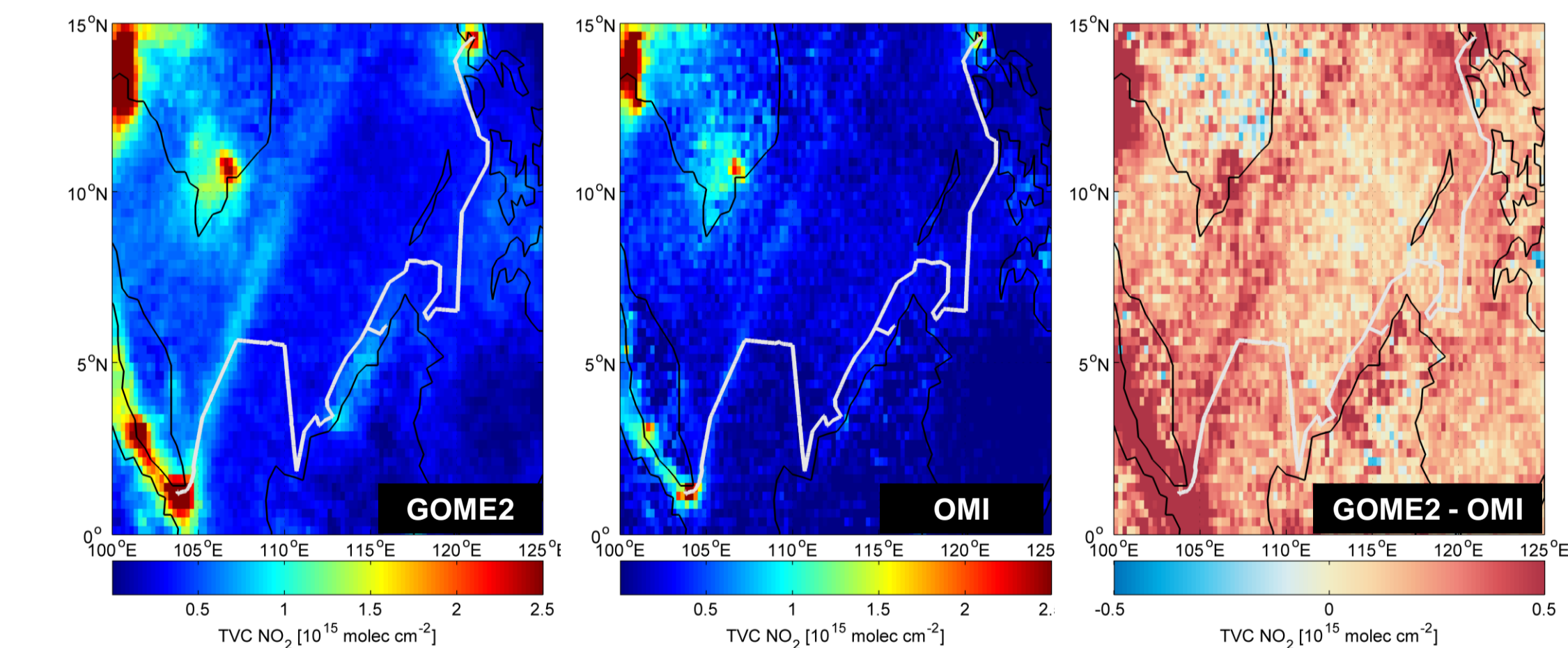
When the ship was running at full speed (red), the recorded relative wind direction (blue) was between 0-90° and 280-360° most of the time.

6 Tropospheric NO₂ vertical columns



TVC NO₂ as obtained from the geometric approach using the 15° (red) and 9° (black) elevation angles and from BREAM profile inversion (green) are shown.

On 17, 19, 20, 23, and 24 November, TVC NO₂ amounts of about 2 x 10¹⁵ molec cm⁻² were observed in the morning hours.



TVC NO₂ from GOME2 (left) and OMI (middle) for November (2007-2011).

The difference between GOME2 and OMI shows higher values for the morning measurements (~9:30 LT) along the coast of Borneo.

This is in good agreement with the ship-based MAX-DOAS observations.

8 Summary and conclusions

- 11 days of ship-based MAX-DOAS measurements in the marine environment of Southeast Asia
- Adapted NO₂ fit for ship-based measurements accounting for H₂O_{liq} and VRS
- The conversion of slant columns into vertical columns is performed with the Bremen Advanced MAX-DOAS Retrieval Algorithm (BREAM) and compared to the geometric approach → 15° and 9° elevation angles are suitable for the geometric approach in this region
- Interesting insights into spatio-temporal patterns of tropospheric NO₂ vertical columns → e.g. increased NO₂ levels in the morning in proximity to the coast