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Near Real-Time Air Quality Modeling: Comparing NO_2 Remote Sensing Data with Interpolated Measurements

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Abstract

Nitrogen dioxide (NO_2) is one of the most important air pollutants in the troposphere. It is toxic by inhalation and creates many problems to human health. Therefore, it is much needed to regularly monitor and validate tropospheric NO_2 columns with ground based in situ measurements. NO_2 columns can be retrieved from SCIAMACHY spectra with high accuracy. The objective of this research paper is to compare the satellite measurements (SCIAMACHY) of tropospheric NO_2 vertical column with ground based in situ measurements. The study area has been selected as North Rhine-Westphalia (NRW) of Germany. The research has been designed to compare remote sensing data of NO_2 with interpolated in situ ground measurement at the same time. This research shows a weak correlation between the satellite observation and the in situ ground measurements of NO_2 concentrations in near real time.

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1. INTRODUCTION

Nitrogen dioxide (NO_2) is a chemical compound. It is a part of group of gaseous compounds produced as a result of road traffic, biomass burning, fossil fuel combustions, lightning and microbiological processes in soil.

Nitrogen dioxide (NO_2) plays an important role in the troposphere for air quality and climate change [1]. Tropospheric NO_2 is important for the oxidization circulation of the atmosphere. As part of NO_x (= NO_2 + NO) it forms photochemical smog during pollution episodes and contributes to acid rain. Nitrogen dioxide (NO_2) is one of the most important air pollutants in the troposphere [2].

2. ADVERSE IMPACTS OF NITROGEN DIOXIDE (NO_2) ON HUMAN HEALTH

Nitrogen dioxide is toxic by inhalation and creates many problems for human being. Long-term exposure to NO_2 at concentrations above 40– 100 µg/m^3 causes adverse health effects. The current WHO guideline values for NO_2 are a 1-hour level of 200µg/m^3 and an annual average of 40µg/m^3 [3].

The long term exposure to NO_2 can do the following adverse health effects [4]:

a) Decrease lung function

b) Cause bronchitis, cold, flu, cough and other respiratory problems

c) People with asthma and children are much vulnerable and so on.

3. TROPOSPHERIC NO_2 FROM SCIAMACHY

SCIAMACHY (SCanning Imaging Absorption SpectroMeter for Atmospheric CartograpHY) is one of the ten instruments of ESA's (European Space Agency) Environmental Satellite (ENVISAT). It is an imaging spectrometer whose primary mission objective is to perform global measurements of trace gases in the troposphere and in the stratosphere (Source: ESA). SCIAMACHY provides detailed information on the nitrogen dioxide content in the planetary boundary layer.

SCIAMACHY, aboard the ENVISAT satellite, was launched by ESA (European Space Agency) from Kourou, French Guiana, in 1st March 2002.

The solar radiation transmitted, backscattered and reflected from the atmosphere is recorded at relatively high resolution (0.2 nm to 0.5 nm) over the range 240 nm to 1700 nm, and in selected regions between 2000 nm and 2400 nm. SCIAMACHY alternately makes limb and nadir measurements.

The high resolution and the wide wavelength range make it possible to detect different trace gases, clouds and aerosols (Figure 1).

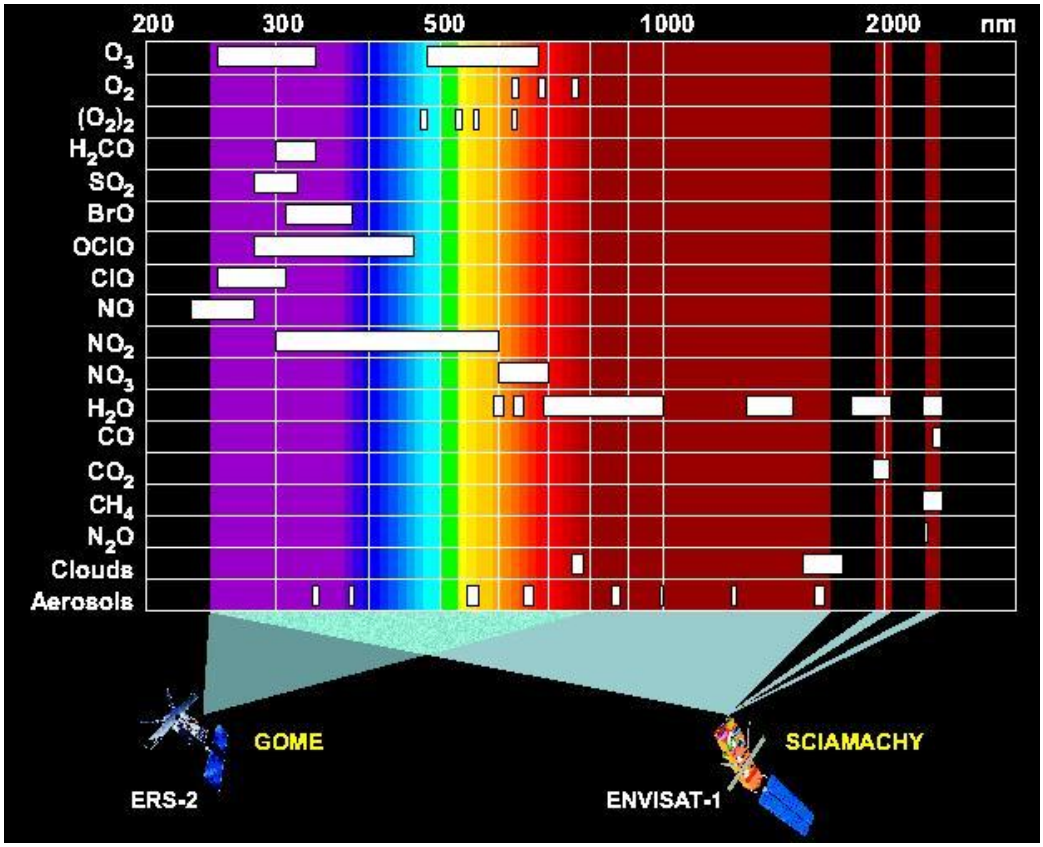


Figure 1: SCIAMACHY Coverage Range

Source: Official webpage of European Space Agency and the Differential Optical Absorption Spectroscopy-Method (DOAS) group, Institute of Environmental Physics (IUP) and Institute of Environmental Physics, University of Bremen, Germany.

NO_2 columns can be retrieved from SCIAMACHY spectra with high accuracy in the 425-450 nm regions using the DOAS method. Tropospheric NO_2 columns from SCIAMACHY

measurements are available from August 2002 onwards. The spatial resolution of SCIAMACHY depends on the wavelength region and also on the solar zenith angle. For most NO_2, the pixel size is 60 x 30 km^2. A sample is depicted in Figure 2.

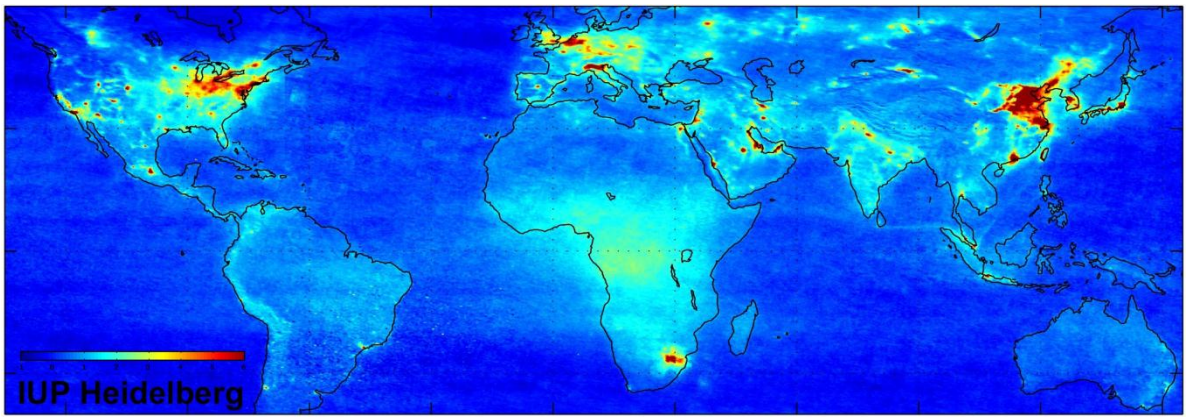


Figure 2: The image shows the global mean tropospheric nitrogen dioxide (NO_2) vertical column density (VCD) between January 2003 and June 2004, as measured by the SCIAMACHY instrument on ESA's Envisat.

The scale is in 10^{15} molecules/cm^2.

Source: University of Heidelberg.

3.1. ERRORS IN SCIAMACHY

SCIAMACHY is alternating between limb and nadir measurements. During limb observations, stratospheric profiles are measured and the corresponding nadir pixels are missing. Therefore there are some gaps along the orbits are found (Figure 3).

Data distribution of SCIAMACHY products still has problems, and only a fraction of all orbits are available for analysis. Therefore some days/orbits are missing.

Source: University of Bremen IUP DOAS.

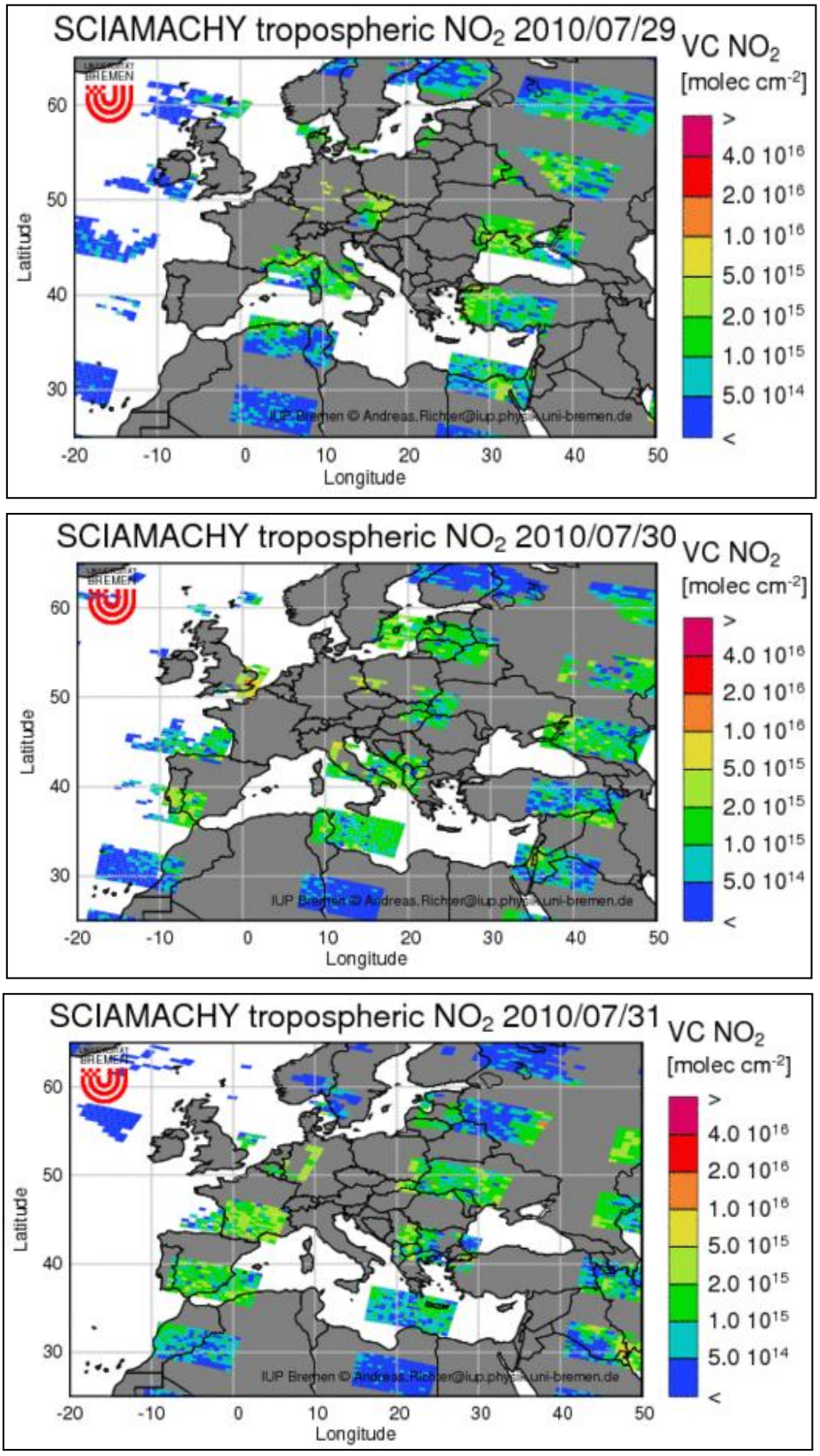


Figure 3: View of European Tropospheric Column of NO_2 from SCIAMACHY

(From 29-31 July, 2010)

Source: The Institute of Environmental Physics, University of Bremen, Germany

4. OBJECTIVE

The objective of this research paper is to compare the satellite measurements (SCIAMACHY) of tropospheric NO_2 vertical column with ground based in situ measurements.

5. DATA SOURCE

The SCIAMACHY images and the data of the tropospheric column (ASCII file format) have been collected from the Tropospheric Emission Monitoring Internet Service (TEMIS).

The ground-based station data for Germany have been retrieved from the European Air Quality data base (Airbase). Source: The European Environment Agency (EEA).

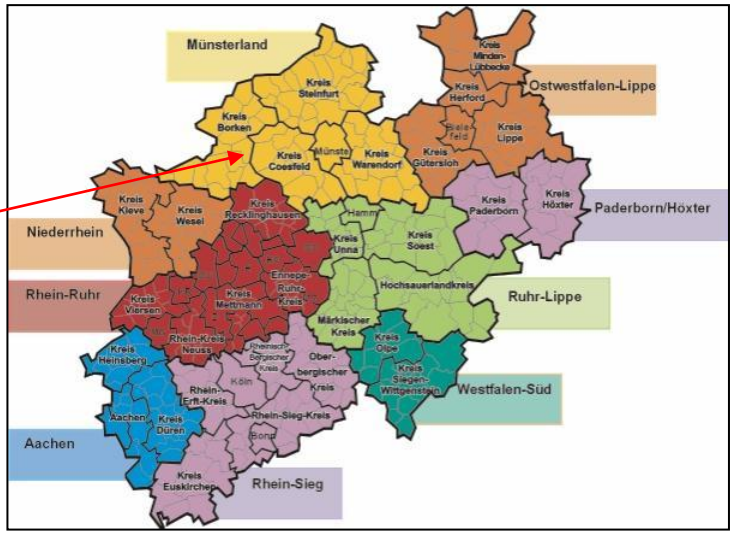
6. STUDY AREA PROFILE

The study area for this research has been selected as North Rhine-Westphalia (NRW) (Figure 4). It is the westernmost, the most populous, and the most economically powerful state of Germany. The capital city is Düsseldorf.

For selecting the study area, at first, the stations that are collecting the NO_2 measurements for Germany have been identified (Figure 5). Then it is found that most of the stations are located in NRW region (Figure 5).

There are in total 1326 ground stations but only 91 stations collect NO_2 measurements. Among the 91 stations 84 stations are located in North Rhine-Westphalia (NRW) region. Considering the distribution of ground stations locations in Germany, NRW region has been considered as the study area.

Map of Germany, showing the 16 German States and their State Capitals



Map of North Rhine-Westphalia State (Study Area), Germany

Figure 4: Location of the Study Area (North Rhine-Westphalia), Germany

Source: Institute for Geoinformatics, Münster, Germany and German Travel-Info

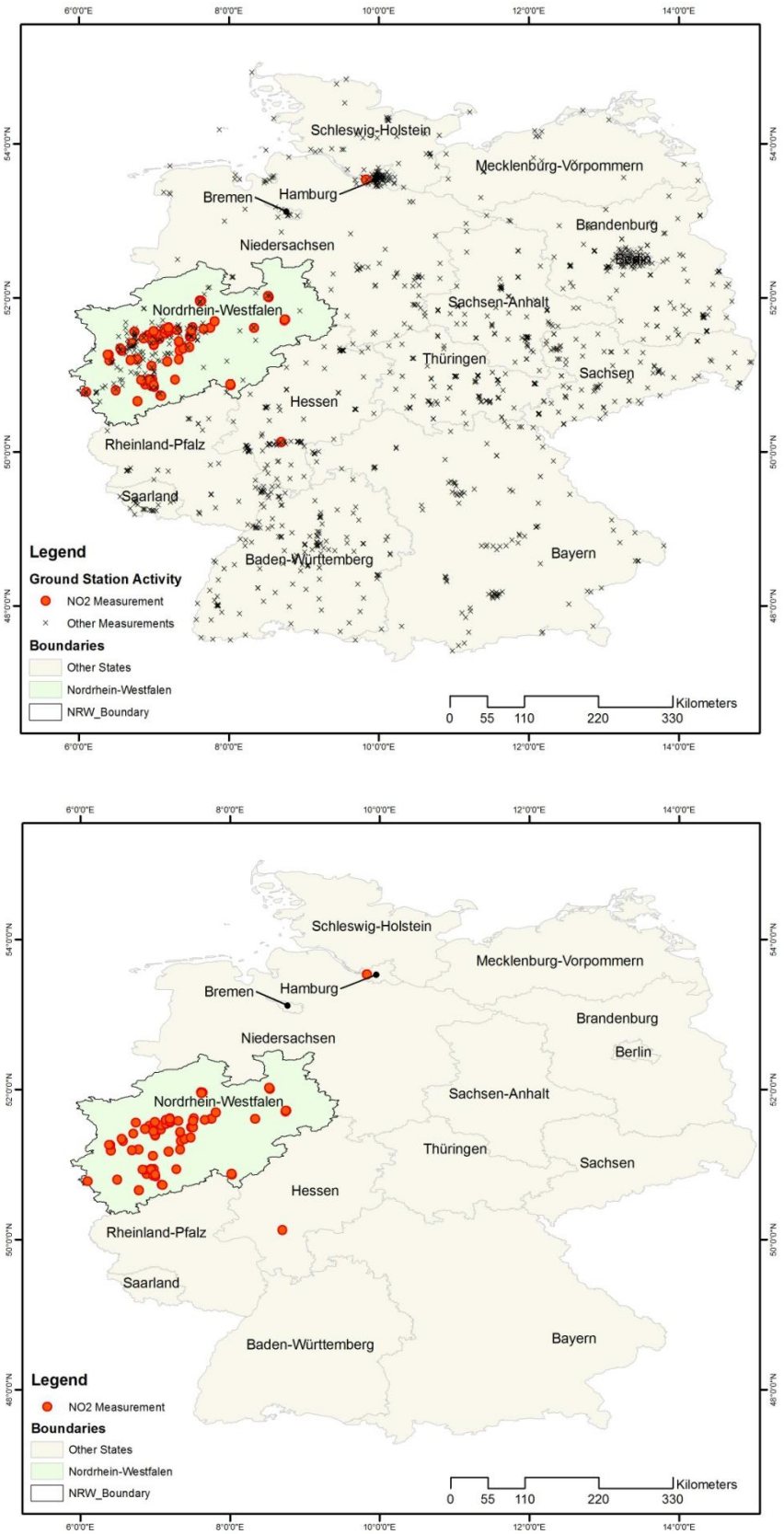


Figure 5: Location of NO_2 Measurement Stations within NRW

(Station point source Airbase and maps have been prepared by the author)

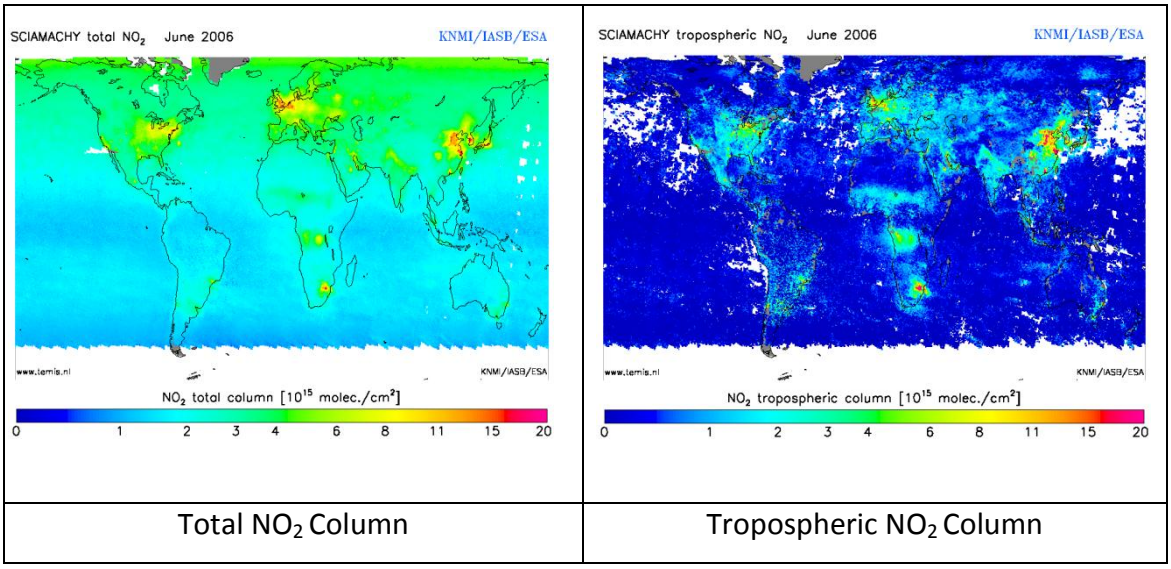
7. METHODOLOGY

The research has been designed to compare remote sensing data of NO_2 with interpolated in situ ground measurement at similar time.

7.1. SCIAMACHY DATA PROCESSING

Tropospheric NO_2 columns have been derived from satellite observations based on slant column NO_2 retrievals with the DOAS technique, and the KNMI combined modelling/retrieval/assimilation approach. The slant columns from SCIAMACHY observations are derived by BIRA-IASB, the slant columns from OMI by KNMI/NASA. The Vertical Column Data (vcd) was used in the analysis which retrieved total vertical column density at the unit of 10^{15} molec. cm^{-2}.

TEMIS Server publishes Near-real time regional and global SCIAMACHY data products daily and monthly average basis in different file format. But daily data product character is quite random in terms of spatial coverage and temporal frequency (Figure 3). Considering the in situ ground measurement data availability, the research has been conducted of June 2006 monthly average SCIAMACHY NO_2 vcd data (Figure 6).



Total NO_2 Column	Tropospheric NO_2 Column

Figure 6: SCIAMACHY Data of June 2006 (Global Monthly Mean)

Source: Boersma, K.F., H.J. Eskes and E.J. Brinksma, Error Analysis for Tropospheric NO_2 Retrieval from Space, J. Geophys.

The Data has been downloaded in ESRI grid (ascii) format and converted to Idrisi format for image analysis.

7.2. GROUND BASED IN SITU DATA

NO_2 ground measurement has been retrieved from the European air quality database for Germany. Station location data was retrieved from "AirBase_DE_v4_stations.csv" file. The field terminology was retrieved from "AirBase_DE_v4_measurement_configurations.csv" and monthly mean NO_2 measurement was retrieved from "AirBase_DE_v4_rawdata" folder after trials and observations. Based on the availability of in situ monthly average NO_2 measurement stations were filtered in few stages (Figure 5). Finally 27 stations were connected with the NO_2 measurement database for June 2006.

7.3. INTERPOLATION AND COMPARISON

Station location data was interpolated by Inverse Distance Weighted method maintaining same cell size and parameters like SCIAMACHY image data. Both SCIAMACHY image and Interpolated grid data was analysed in IDRISI software after unit conversion for deriving correlation coefficient to measure the relationship between two distributed NO_2 measurement. Few maps have been produced to display distribution NO_2 values from two data sources.

8. RESULTS AND ANALYSIS

Figure 7 and figure 8 represent the interpolated results after performing the methodological steps as mentioned above.

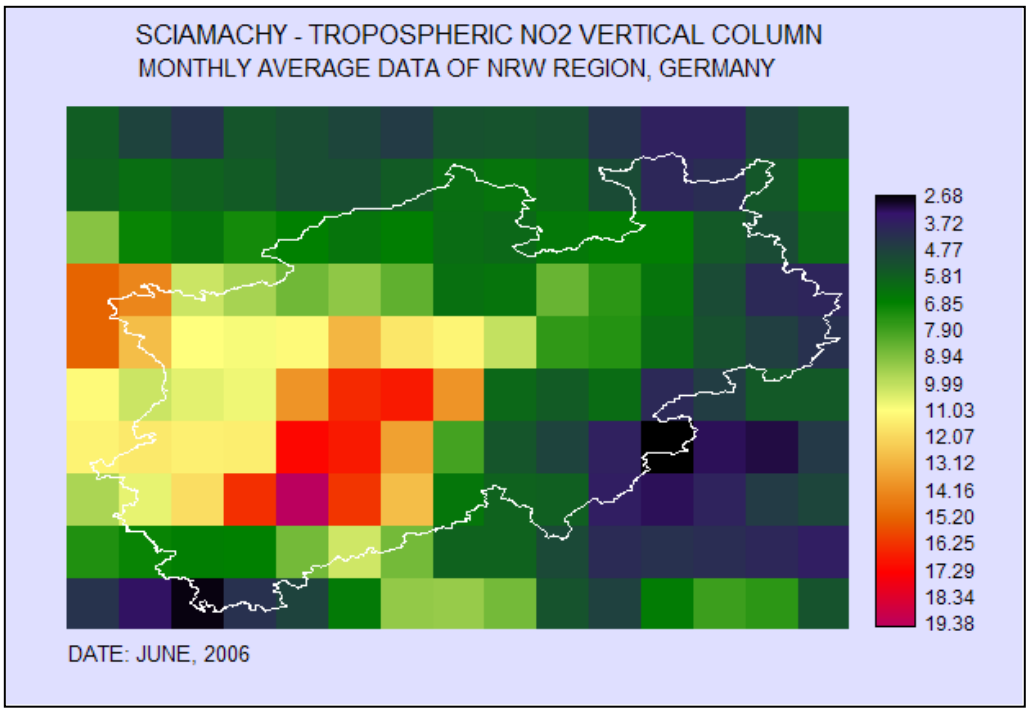


Figure 7: Interpolated SCIAMACHY Tropospheric NO_2 Column of NRW [Scale Unit: 10^{15} molecules/cm^2]

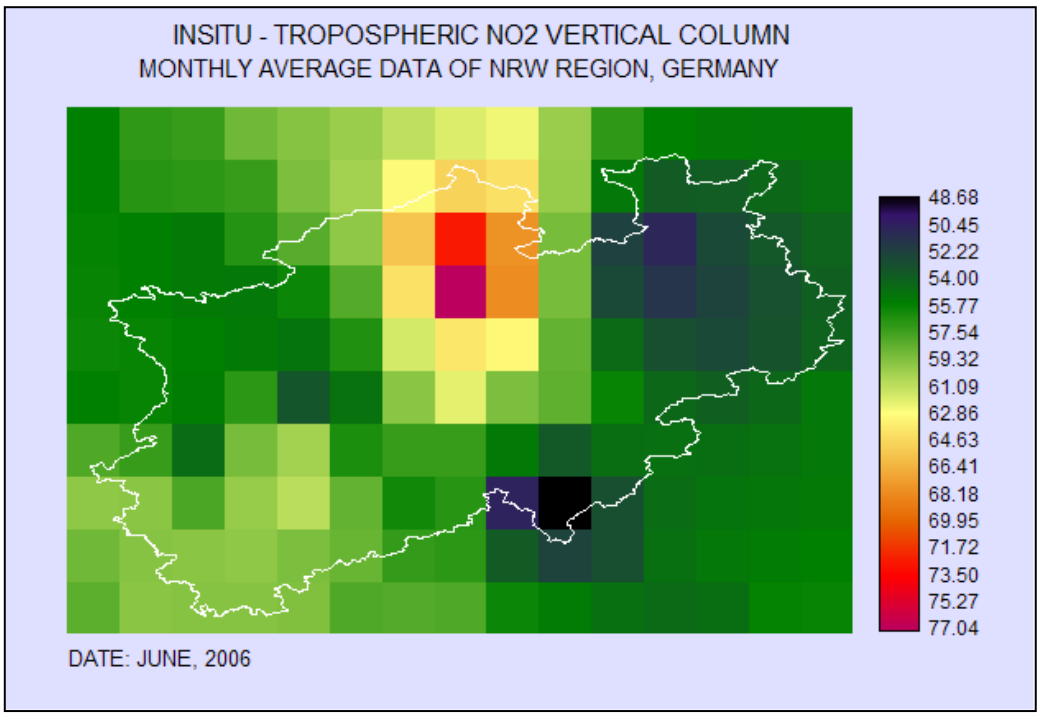


Figure 8: Interpolated in situ Ground Based Tropospheric NO_2 Column of NRW

[Scale Unit: µg/m^3]

After visually analyzing figure 7 and 8, it is clear that there is huge differences between the satellite and ground measurement pixel values. In the next step, statistical analysis has been performed to compare much more accurately.

In order to examine how representative the satellite estimations to local surface emissions, based on in situ ground measurements of the stations, we have compared them with all available in situ surface NO_2 observation in the area. Figure 9 presents a scatter plot of concurrent monthly mean satellite measurements (SCIAMACHY) versus ground based in situ measurements.

The correlation coefficient is R=0.143901 that indicates that there is a relatively weak correlation agreement between the two kinds of measurements.

Achieving this kind of low value of correlation coefficient is due to the limitations of data collection and errors in SCIAMACHY.

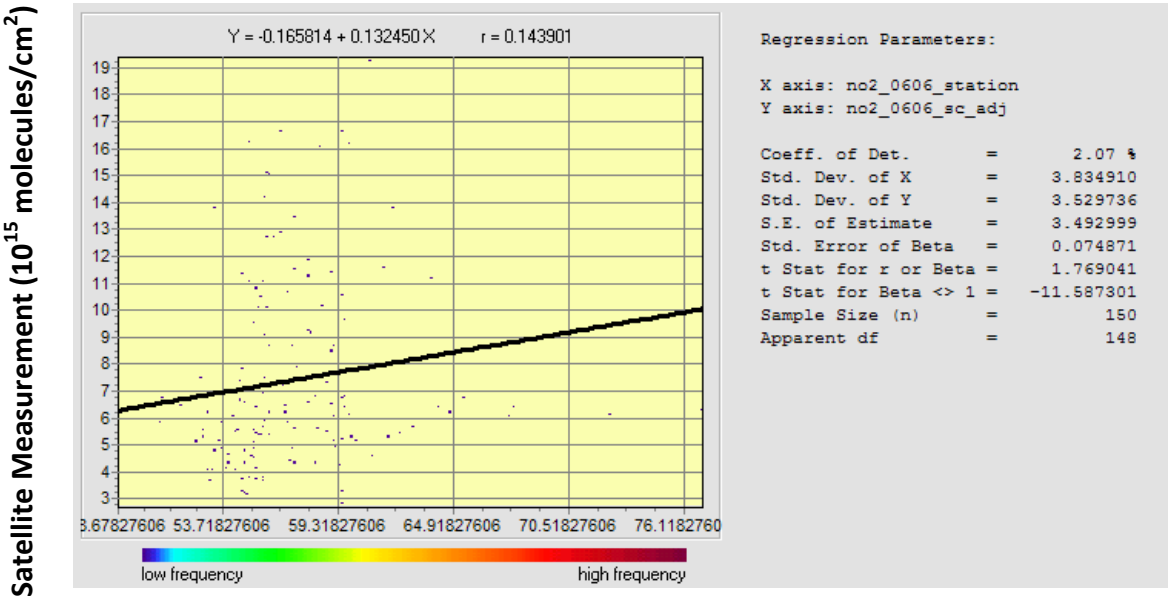


Figure 9: Scatter plot of concurrent monthly mean satellite measurements (SCIAMACHY) versus ground measurements that are available through the European Air Quality database.

9. LIMITATIONS OF THE RESEARCH

Following shortfalls have been identified to carry out comparing SCIAMACHY NO_2 columns with interpolated near real time situ measurements data:

- The fundamental problem when comparing in situ measurements with column quantities arises from the fact that the latter integrate both horizontally and vertically, where as in situ measurements provide point information only and those are not well distributes throughout the region.
- The European Air Quality data base (Airbase) had NO_2 measurements until 2008. Many station stopped their activity long time ago and NO_2 measurement capturing stations are limited within NRW state only.
- The haphazard distributions of Ground measurement stations are highly concentrated in certain areas while some areas having no stations.
- The spatial resolution of SCIAMACHY depends on the wavelength region and also on the solar zenith angle. For most NO_2 image resolution is around 60 x 30 km^2.
- SCIAMACHY is alternating between limb and nadir measurements. During limb observations, stratospheric profiles are measured and the corresponding nadir pixels are missing.
- Data distribution of SCIAMACHY products still has problems, and only a fraction of all orbits are available for analysis.
- Monthly mean global or regional NO_2 data has many missing areas which affects the result of comparison analysis with the interpolated measurements.
- It is very difficult to retrieve for monthly mean or daily NO_2 in situ ground measurement by introducing automation from the European Air Quality database. The available database is quite old (latest data is 2008 also available for only few stations) and there are many missing data (both inside station data file and station file is missing in the raw database).
- Current data arrangement of all sources restricted the study to carry out with only small spatial (NRW State) and temporal segment (June 2006).

10. RECOMMENDATIONS

Following important aspects have been realised throughout this research to get better comparison between satellite and ground based NO_2 measurements outcomes:

- Both in situ ground and satellite measurements should be consistently available for the same time period for a particular location.
- The SCIAMACHY vertical column measurement for NO_2 should be captured consistently at a regular spatial and temporal interval.
- The ground stations should be evenly distributed by maintaining a regular distance.
- This research requires cross matched data for a longer period (average 3-5 years) for minimizing data disparity.

11. CONCLUSION

This research shows a weak correlation between the satellite observation and the in situ ground measurements of NO_2 concentrations in near real time. Validation of tropospheric NO_2 columns should be done in as homogeneous situations as possible using only clear sky data. The time of measurement is critical as is the distance between validation measurement and satellite overpass. Further analyses or research works can be performed to get much better results based on the shortcomings and recommendations of this article.

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