Monitoring Air Pollution From Space: The Major urban areas of the Eastern Mediterranean Basin

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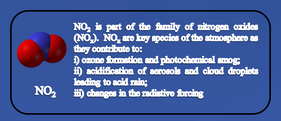
Abstract

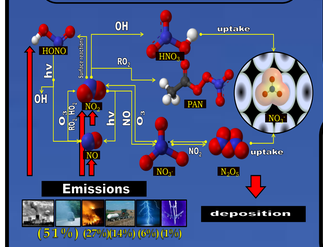
This study focuses on monitoring of key pollution precursors, namely nitrogen dioxide (NO_2), formaldehyde (HCHO) and glyoxal (CHOCHO). NO_2 is mainly produced by anthropogenic emissions linked to fossil fuel combustion and biomass burning. HCHO can be either directly emitted (e.g. from vehicles and industry) or secondarily formed via the oxidation of VOCs. CHOCHO is key intermediate product of the oxidation of volatile organic compounds (VOCs). Due to its short lifetime (~2-3hours), it is expected to provide valuable information on the identification of hot spots globally, which are linked to anthropogenic activities, biogenic emissions and biomass burning.

The scattered light spectra in the UV-VIS spectral range observed by the SCIAMACHY instrument, on board of the ENVISAT satellite has been used to derive NO_2, HCHO and CHOCHO by the differential optical absorption spectroscopy (DOAS) for the period 2003-2008. Monthly and annual means of these species were computed over the Eastern Mediterranean region (from 28.5°N to 42.5°N and from 18.5°E to 35.5°E). This region is characterised by enhanced air pollution due to long range transport and to high insolation under cloud-free conditions, leading to increased regional photochemical production. Special attention is given to the spatial and temporal changes of the vertical column densities over the most populated regions of the area. Satellite data are validated versus ground based measurements.

Sources and Sinks (NO_2)



NO_2 is part of the family of nitrogen oxides (NO_x). NO_x are key species of the atmosphere as they contribute to:
i) ozone formation and photochemical smog;
ii) acidification of aerosols and cloud droplets leading to acid rain;
iii) changes in the radiative forcing



Sources

In total around 45TgN y^{-1} are released in the atmosphere (Wang et al., JGR, 1996). From this number:

i) 51% is connected to fossil fuel combustion
ii) 27% to biomass burning
iii) 14% to soil emissions and/or NH_3 oxidation
iv) 3% from lightning
v) 1% from aircraft emissions

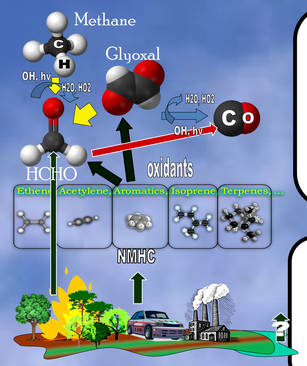
Sinks

The photolysis of NO_2 is considered to be the only source of ozone. NOx species are chemically transformed to other nitrogen species in the atmosphere either in gas phase (e.g. HNO_3, HONO, PAN, NO_3, N_2O_5) either in aqueous phase (e.g. NO_3^-). Ultimately, nitrogen is removed from the atmosphere via wet and dry deposition.

Sources and Sinks (HCHO and CHOCHO)

HCHO is the most abundant aldehyde, and the smallest carbonyl compound

Glyoxal is the smallest a-dicarbonyl compound



Sources

HCHO is mainly produced by the oxidation of methane (CH_4) and Non-Methane hydrocarbons (NMHC). It is also (to a lesser extend) primarily emitted by anthropogenic and biogenic sources.

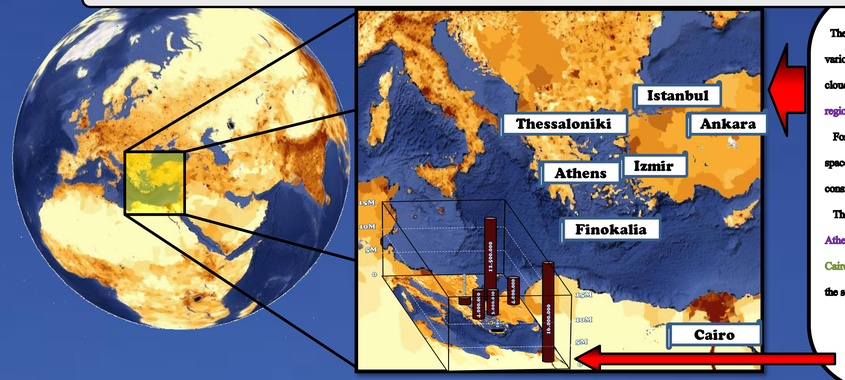
CHOCHO is formed by the oxidation of NMHC. Contrary to HCHO no direct sources are expected. This makes CHOCHO a unique indicator of the VOC oxidation.

Sinks

The main known sinks of HCHO and CHOCHO are:

a) reaction with OH radicals
b) photolysis leading to an estimated lifetime of 2h.
c) reversible, or irreversible uptake of CHO.CHO on/in aerosols and clouds (in the case of CHO.CHO).
d) wet and dry deposition.

Location (East Mediterranean) and Goal of the study

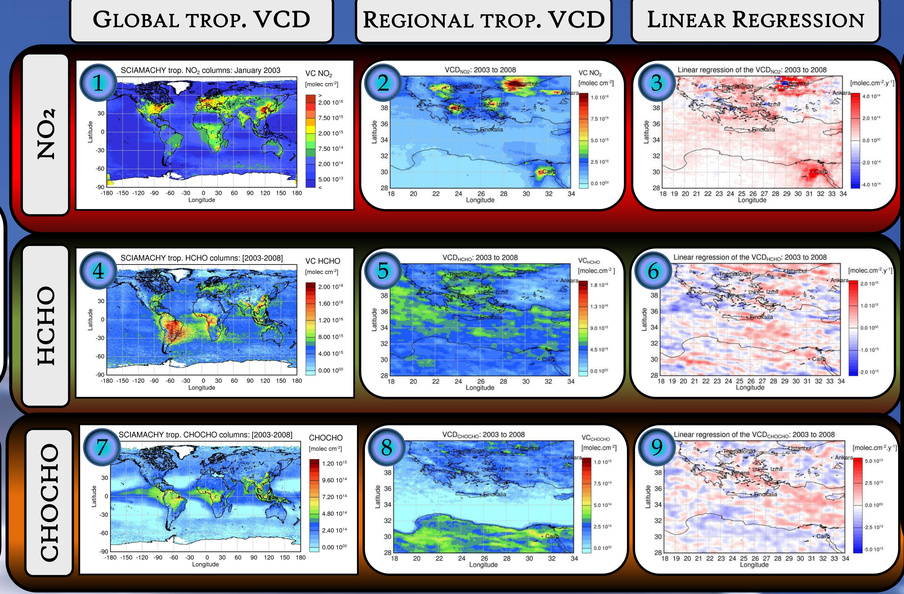


The East Mediterranean region is affected by the presence of air masses of various origins and chemical composition. Moreover due to the high frequency of cloud-free conditions, especially during summer, this area is sensitive to enhanced regional photochemical pollution.

For this reason, satellite and ground based measurements of NO_2, in addition to space based measurements of HCHO and CHOCHO are used to provide a consistent picture of the distribution of the pollution over the area.

The current analysis focused over large cities of the E. Mediterranean including Athens and Thessaloniki from Greece, Istanbul, Ankara and Izmir from Turkey and Cairo from Egypt. Istanbul and Cairo are the cities with the highest population for the selected region.

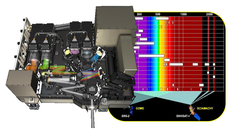
Global trop. VCD | Regional trop. VCD | Linear Regression



Global Vertical Column Densities (left figures) computed for the period 2003 to 2008: On a global scale the highest NO_2 values [1] are observed over the industrialized places (USA, Europe, Asia and S. Africa) and to a lesser extend above biomass burning areas. HCHO [4] and CHOCHO [7] show their highest levels in biogenic emissions (e.g. isoprene). High values are also observed above areas with intensive biomass burning as well as over places with enhanced anthropogenic activities. As their lifetime is short, high levels of these species point directly to the emissions sources (hot-spots).

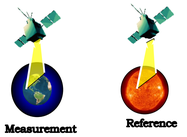
Regional VCDs (middle figures) and trends calculated from the linear regression analysis (2003 to 2008, right figure): As presented to [2], the highest VCD_{NO2} are computed for the most populated cities of the East Mediterranean region. The regression analysis [5] showed that for the VCD_{NO2} the largest increase per year is observed over Cairo and at the surroundings of Istanbul. A decrease is recorded for the cities of Athens, Thessaloniki, Izmir and at the center of Istanbul. Somehow elevated levels of HCHO [6] and CHOCHO [9] are found over the same cities. The respective trends of HCHO and CHOCHO emenating from the trend analysis [5], [8] is less profound in comparison to the NO_2 one due to their additional sources (e.g. biogenic emissions).

Instrumentation



SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY) is an imaging spectrometer whose primary mission objectives are global measurements of trace gases in the troposphere and in the stratosphere. The solar radiation transmitted, backscattered and reflected from the atmosphere is recorded at relatively high resolution (0.2 nm to 1.5 nm) over the range 240 nm to 1700 nm, and in selected regions within 2.0 μm and 2.4 μm. SCIAMACHY has a global coverage of 6 days with a spatial resolution of 60kmx30km.

DOAS Analysis



Measurement (Earthshine spectrum)

Reference (Solar Irradiance)

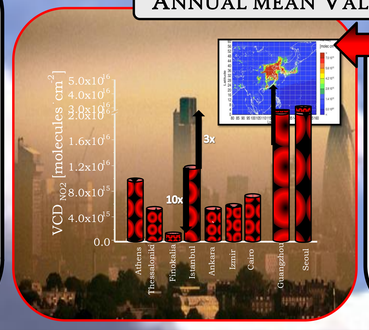
$\ln\left(\frac{\text{Measurement}}{\text{Reference}}\right)$

Radiative tranfer model (SCIATRAN) → Air Mass Factors (AMF)

Vertical Column Densities VCD_{CHOCHO}

The vertical columns (VC) of NO_2, HCHO and CHOCHO are calculated with the Differential Optical Absorption Spectroscopy (DOAS) by subsequently applying the air mass factor correction (AMF, calculated by the radiative transfer model SCIATRAN) to the slant columns (SC). The latter is the integrated amount of absorber averaged over all light paths. HCHO was retrieved in the UV region while NO_2 and CHOCHO in the blue spectral range. In specific, the spectral windows between 337 - 353nm, 425-250nm and 435 - 457 are chosen for the analysis. The absorption cross sections of O_3, BrO, NO_2, H_2O, O_4, phytoplankton, a ring spectrum which accounts for the rotational Raman scattering, and a polynomial are included in the fitting procedures.

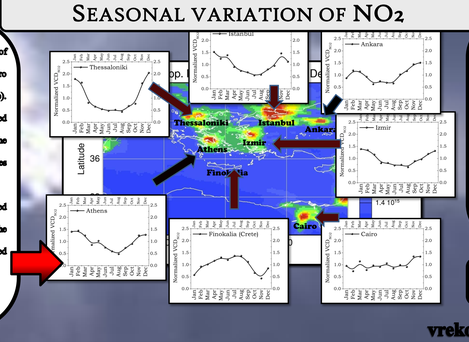
Annual mean Values of the VCD_{NO2}



LEFT FIGURE: Mean VCD_{NO2} (2003 – 2008) computed over a region of 0.5x0.5° for the cities of Athens, Thessaloniki, Ankara, Izmir, Istanbul, Cairo and for the remote measuring station Finokalia (Crete island, Greece). Istanbul and Athens are the most polluted cities in terms of NO_2 followed by a group of cities (Ankara, Izmir, Thessaloniki, Cairo) having about half the VCD_{NO2}. Istanbul's NO_2 is ten times greater than Finokalia's NO_2 and 3 times lower than the one retrieved for Seoul.

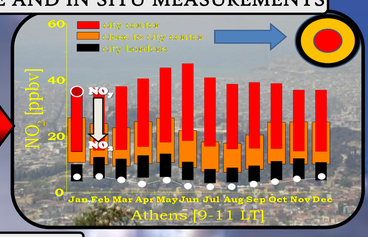
RIGHT FIGURE: Monthly normalized VCD_{NO2}. Most of the polluted cities follow a common behavior with the maxima observed during winter and the minima during summer. On the contrary, over Finokalia the observed seasonality is the opposite.

Seasonal variation of NO_2



Comparison of Satellite and in situ measurements

The converted VCD_{NO2}, assuming that most of the NO_2 is well mixed into the boundary layer, to mixing ratios (ppb$_v$)(white line) are compared with the ground based measurements performed in Athens. The ground stations were categorized into three groups: a) city center (red color), b) close to city center (orange) and c) city suburbs (black). As depicted in this figure, the SCIAMACHY values show better agreement with the observations at Athens suburbs. It should be noted that the in situ observations measure the total nitrogen oxides (NO_y). Depending on the prevailing conditions the "real" NO_2 is only a fraction of the measured NO_y values.



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