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Radiative Effects of Carbon Oxides (Co_x) and Nitrogen Oxides (No_x) on Radiative Transfer in the Lower Atmosphere of Dakar In 2013

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Abstract

Dakar, like most African capitals, is characterized by a high human density, a dense transport network where motor vehicles are old and a high concentration of industries. Significant quantities of hydrocarbons are consumed daily to meet the energy needs of the economy; the combustion of hydrocarbons in engines and boilers in the presence of oxygen in the air produces various pollutants including carbon oxides (CO_x) and nitrogen oxides (No_x) found in the lower atmosphere. This work investigates the radiative forcing by Modtran6 following the concentrations of these two types of pollutants measured in the city of Dakar. Thus, this study has shown slight changes in the total radiance and a no less negligible place of ozone (especially in the dry season) whose peak absorption is 1040 cm^{-1} in the infrared. Atmospheric transmittance decreases throughout the width of the spectral band used during the rainy season; the most important jumps of this transmittance are observed around the wave numbers 800 cm^{-1} and 1050 cm^{-1}.

Keywords: Transport; Industries; Hydrocarbons; Carbon oxides; Nitrogen oxides; Radiative forcing; Modtran6

Introduction

Fossil fuels (oil, natural gas, and coal) account for about 80% of global energy demand; the use of these fuels in transport and industry is the main source of emissions of chemical pollutants such as carbon oxides (CO_x=CO+CO_2), nffitrogen oxffides (No_x=NO+NO_2), oxides of sulfur (SO_x=SO_2+SO_3) and hydrocarbons (HC) in the atmosphere [1]. These anthropogenic pollutants, through interaction with solar radiation, are precursors of ozone and other organic compounds in the lower troposphere [2]. Chemical Composition of the Atmosphere largely determines its radiative behavior. Indeed, the interaction between solar radiation and the chemical constituents of the atmosphere involves the phenomena of absorption, emission, and diffusion of more or less energetic radiations but also other chemical compounds [3]. Because of its properties, secondary pollutant ozone absorbs ultraviolet radiation at the stratosphere but contributes to an increase in temperature in the lower stratosphere. An increase in anthropogenic gaseous pollutant emissions can have adverse effects on the environment and on the health of populations [1].

The objective of this study is to estimate the anthropogenic contributions of carbon oxides CO_x and nitrogen oxides No_x mainly due to transport and industries on the radiative budget of the lower atmosphere of Dakar, given the importance of emissions of pollutants by car traffic and industries. For this, we will study the variations of atmospheric transmittance and radiance in the spectral range between 800 cm^{-1} and 1300cm^{-1} belonging to the infrared which only takes into account the phenomena of absorption and re-emission.

Sources of Co_x and No_x Emissions

The automobile transport of dakar

The region of Dakar (Senegal), located on the seaboard of West Africa, concentrates a quarter of the population of the country; it has the following geographic coordinates:

- Latitude: 14.73°

- Longitude: - 17.5°

The Dakar region, which covers an area of 550 km^2, concentrates 72.8% of the Senegalese car fleet in 2013 (Directorate of Land Transport). Motor vehicles with an average age of around 12 years (12 years) increased from 7.3% in 2012 to 7.4% in 2013; however, the number of new vehicles purchased increased from 25.1% in 2011 to 27.2% in 2013. The mass transport that ensures human mobility and goods with 1751900 trips per day is made diesel type cars.

Car traffic in Dakar is marked by the almost continuous presence of traffic jams causing engines to idle and consequently significant emissions of pollutants. The motor transport sector is the largest source of urban pollution, especially for cities where the park is dilapidated [4]. The major chemical pollutants resulting from the transport of hydrocarbon fuels are carbon oxides CO_x and oxides of nitrogen (No_x). In addition, a train (the Little Blue Train) running on a diesel engine ensures regular movement of people between the suburbs and the city center.

By way of comparison, in European countries where the car fleet is less old than in Africa, automobile transport is responsible for 55% of CO emissions and 36% of No_x emissions, the other chemical pollutants emitted are hydrocarbons up to 21%, plus 12% consisting of PM [1].

Industries

The industry is considered as the engine of economic development, but it has negative effects related to atmospheric pollution. Dakar is the most industrialized city in the country, it alone accounts for 90% of the

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country's industrial fabric. Among the industries present, there are three thermal power plants (Cap de Biches, Bel-Air and Kounoune), a cement plant (Sococim) and a refinery (African Refining Company). The new coal-fired power plant located in Bargny (32 km from Dakar) may contribute more to increasing the level of pollution because, for illustrative purposes, coal is responsible for 60% of No_x emissions in 2010 in China [5].

Study of the Impact of No_x and Co_x Emissions on Radiative Transfer

Methodology

With the Atmospheric Model, the Moderate Resolution Atmospheric Transmission Version 6 (Modtran6) developed by US Air Force Phillips Laboratory, we have represented the radiative influence of carbon oxides CO_x (CO_2 and CO) and oxides of nitrogen No_x (NO_2 and NO) following the modification of their concentrations in the lower atmosphere of Dakar [6,7].

The carbon dioxide concentrations were estimated from the total hydrocarbon consumption in the city of Dakar, carbon monoxide (CO) and nitrogen oxides (NO and NO_2) were determined from the measurements in real time by the five measurement stations of the Center for Air Quality Management (CAQM) [8]. The atmospheric model (Modtran6) was configured in a tropical atmosphere on a 5 km observation scale from the ground. Measurements of transmittance and radiance are made at 12 H taking into account the meteorological parameters (wind, relative humidity, and precipitation) of the Dakar region and its geographical coordinates (latitude: 14°41' and longitude-west: 17°26') [9]. This study is made on the wavenumber interval corresponding to the wavelengths λ of 8 μm to 12 μm of the infrared.

This method is used to evaluate the radiative impact of the concentrations of chemical pollutants generally emitted by transport for the year. The transmittances and radiances (obtained from the in situ data) thus determined are compared with the real curves. This study covers two days of the year 2013 corresponding to the two seasons: February 10 and the rainy season on August 10 at 12H (UT).

Results and Discussion

Analysis of transmittance and radiance from February 10, 2013, to 12h

The results of Figure 1 are obtained from the following parameterization of the modtran6:

-Standard model: 800-1300cm^{-1}- Tropical ATM h=5km: T=300K at 12h

-Forcing: CO_2: 538ppm /CO: 0.96ppm /NO_2: 0.018 ppm; Relative Humidity 70%. Wind: 4m.s^{-1}

The standard and experimental transmittance curves of February 10, 2013, is shown slightly different in amplitudes for wave numbers between 800 cm^{-1} and 1300 cm^{-1} (curve b) (Figure 1). A slight decrease in transmittance is observed in the vicinity of the wave numbers 800cm^{-1}, 895 cm^{-1} and around 1050 cm^{-1} as shown in curve (c).

The decrease of transmittance observed is due to an increase in the absorption of solar radiation from the infrared, which can be explained by the presence of ozone molecules that absorb the infrared around 9.6 μm (corresponding to a number of waves of the order of 1040 cm^{-1}). The pollutant molecules No_x nitrogen oxides and CO_x carbon oxides following atmospheric oxidation by hydroxyl radicals (OH) generate tropospheric ozone which strongly absorbs in the spectral band studied [9].

The results obtained show that chemical pollutants can influence the radiative transfer directly by infrared absorption or indirectly by the production of secondary pollutants such as ozone. In dry period when the relative humidity of the air is low and the maximum sunlight, the production of tropospheric ozone catalyzed by carbon oxides (CO_x) and nitrogen oxides (No_x) leads to a decrease in atmospheric transmittance which may be associated with an increase in the greenhouse effect due to the phenomenon absorption and re-emission of the infrared in the lower layers.

Regarding radiance, the concentrations of No_x and CO_x measured at Dakar did not change the standard values as shown in curve (d) where there is almost perfect overlap. Radiance as a spectral quantity, depending on the geometric characteristics of the light source and the medium, is not modified by the variations in the concentrations of the atmospheric constituents.

Analysis of the transmittance and the radiance of August 10, 2013, at 12Th (UT)

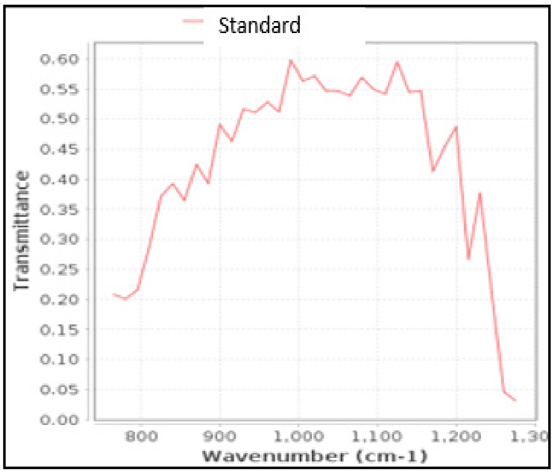
The standard curve of the transmittance (curve (a)) of two peaks marked with wave numbers of 995 cm^{-1} and 1130 cm^{-1} and a particular irregularity (appearing as a hollow) around these two maxima where the transmittance takes a minimum value of 4,1692.10^{-1} W.cm^{-2}.sr^{-1} at 1040 cm^{-1} (Figure 2).

Curves (a) and (b) show a reduction of the transmittance at the atmospheric low level of the order of 82% over the standard value of 2.3127.10^{-1} W.cm^{-2}.sr^{-1} at the value of 800^{-1} cm of the wavenumber. , corresponding to a wavelength of 8 μm. The deviation of the transmittance remains almost constant of 3.10^{-1} W.cm^{2}.sr^{1} in the range 810 cm^{-1} to 1000 cm^{-1} in both cases; this difference decreases sharply beyond 1200 cm^{-1}.

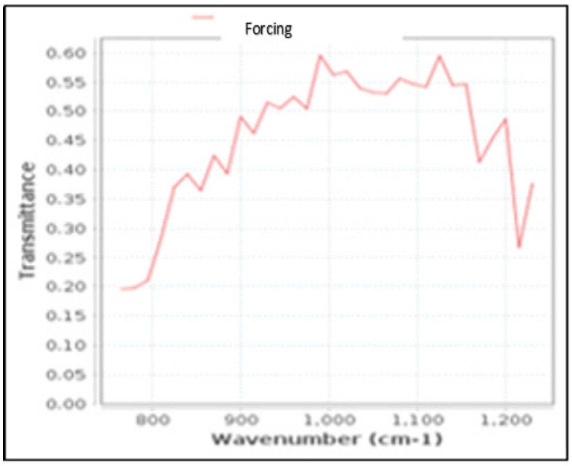
The decreases in transmittance over the entire spectral band used may be related to the increase in pollutant concentrations combined with a high relative humidity of the air. The additional effect of the molecules of carbon dioxide (CO_2), water (H_2O) and tropospheric ozone (O_3) during the rainy season can explain in this spectral domain the decrease of the transmittance; this phenomenon can come from an enlargement of the molecular absorption bands. The "hollow" observed around 1040 cm^{-1} (wavelength of 9.6 μm) on the curve of variations in transmittance shows the role of ozone molecules in energy exchanges in the lower troposphere; this ozone whose peak of absorption in infrared is 9,6 μm is not emitted directly by the anthropic sources but its presence in the atmospheric layer studied can be explained by the physicochemical transformations of the pollutants which are a source of it.

The strong presence of water molecules (related to a relative humidity of about 80% and rain) associated with chemical pollutants may explain the changes in radiative transfer during the rainy season; indeed, water vapor, carbon dioxide, and tropospheric ozone absorb almost all the infrared radiation they receive and emit it in all directions of space [10]. The increase of the absorption in the lower atmosphere is greater during the rainy season in a tropical zone; this is manifested by an increase in the greenhouse effect so a warming that can at a certain local result in an increase in temperature.

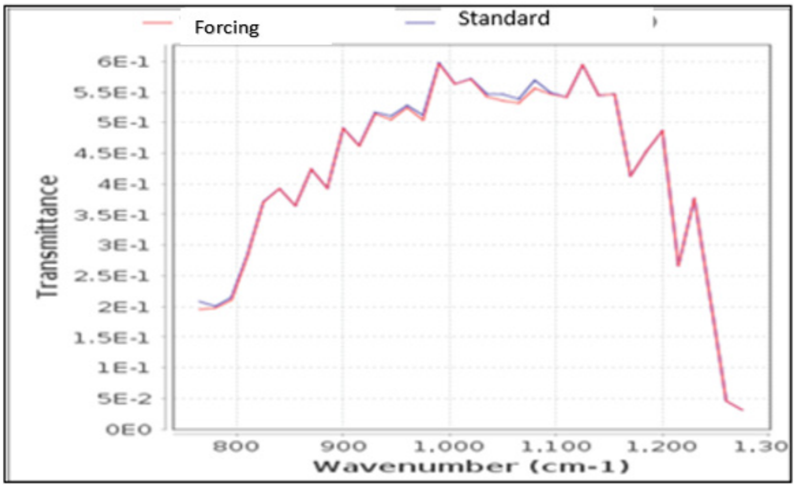
Concerning radiance, the standard and real curves have the same paces (curve f); however, there is an almost constant decrease of the order of 0.12×10^{-5} W.cm^{-2}.sr^{-1} for wave numbers between 800



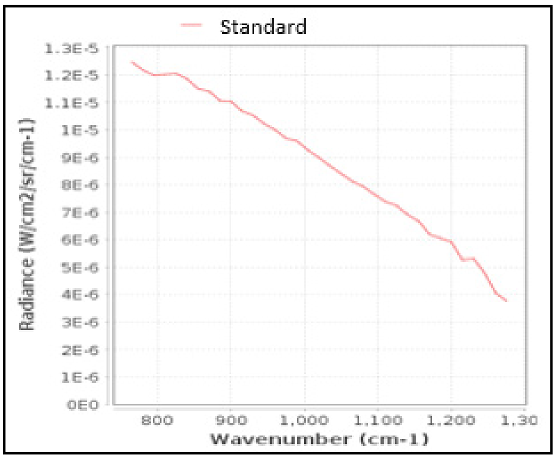
a) Standard Transmittance



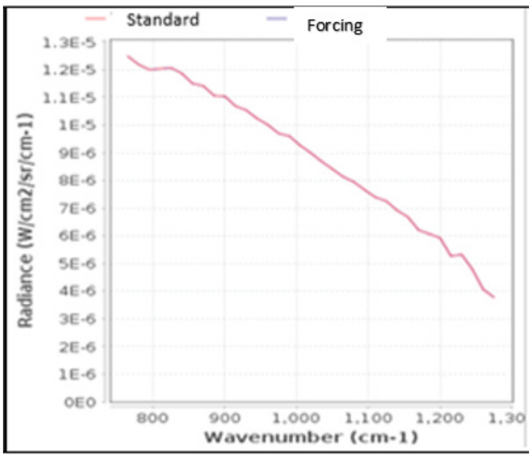
b) Real Transmittance



c) Standard and Real Transmittances

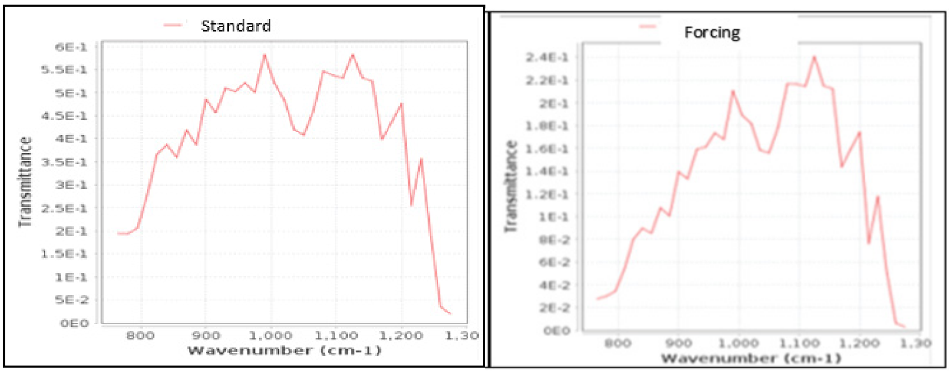


d) Standard Radiance

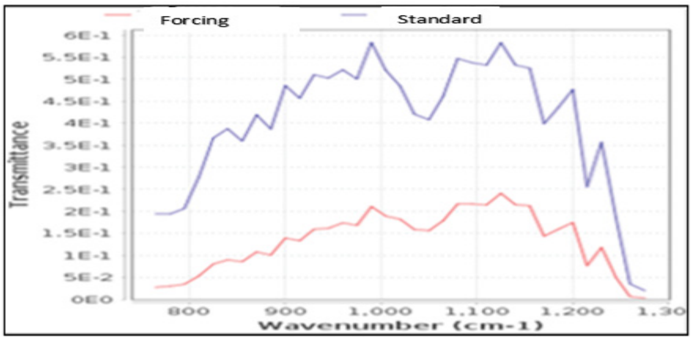


e) Standard and Real Radiances

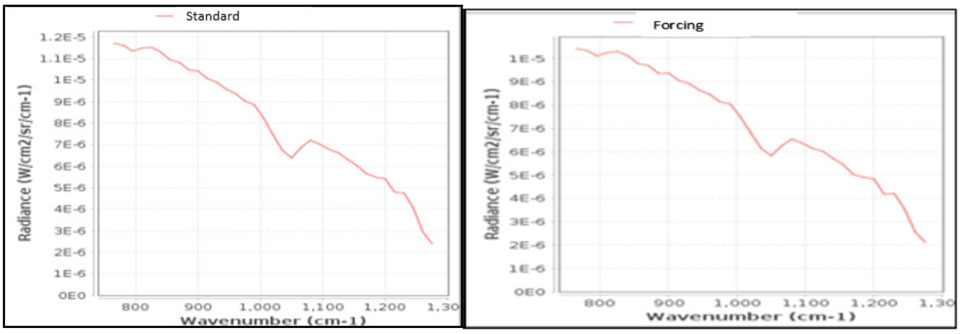
Figure 1: Radiative forcing of the month of February 2013 estimating the modifications of the atmospheric transmittance and the total radiance in the spectral band. Figure 1 obtained from the following parameters:- Standard model: 800-1300 cm^{-1} -Tropical ATM h=5 km: T=300 K at 12h. Forcing: CO_2: 538 ppm/CO: 0.96 ppm/NO_2: 0.018 ppm; Relative Humidity 70%. Wind: 4 $m.s^{-1}$.



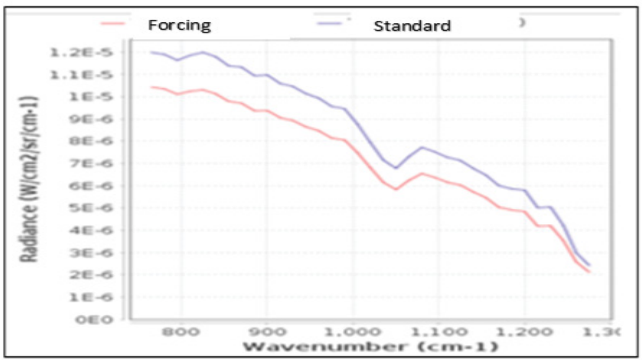
a) Standard Transmittance **b) Real Transmittance**



a) Standard and Real Transmittances



d) Standard Radiance **e) Real Radiance**



f) Standard and Real Radiances

Figure 2: Radiative forcing of August 10, 2013 estimating changes in atmospheric transmittance and total radiance in the spectral band. - Standard model: 800 - 1300 cm^{-1} Tropical ATM h=5 km: T=300 K at 12h. Forcing: CO_2: 538 ppm/CO: 1.57 ppm/NO_2: 0.038 ppm; Relative humidity 79%. Wind: 4 $m.s^{-1}$; Precipitation: 0,10 $mm.hr^{-1}$.

cm^{-1} and 995 cm^{-1}. From about 1000 cm^{-1}, the difference in radiance evaluated following the radiative forcing compared to the standard curve becomes smaller and smaller. The August rains associated with the high relative humidity seem to be the basis of this decrease in radiance, unlike the dry season. From 1200 cm^{-1}, the effect of pollutant concentrations on the total radiance decreases very strongly. This decrease in total radiance is certainly more related to cloud cover than to increasing pollutants in the lower troposphere of Dakar.

Conclusion

The concentration of industries and a large old car fleet in the city of Dakar is the main source of pollutants production in the lower atmosphere. The concentrations of carbon oxide (CO_2 and CO) and nitrogen oxide (NO_2 and NO) in the Dakar lower atmosphere subjected to the atmospheric radiative model Modtran6 have shown their impact in radiative transfer.

The transmittance and radiance of August 10 show the important role of water vapor in radiative forcing; indeed, the high relative humidity and the characteristic rainfall of this month sufficiently justify the large decreases in transmittance observed compared to the dry season represented by the month of February. This study also shows slight changes in the total radiance and a no less negligible place of ozone (especially in the dry season) whose peak absorption is of the order of 1040 cm^{-1} in infrared; this ozone, which is not emitted directly, produces the processes of atmospheric transformations of primary pollutants emitted from the ground.

This study showed the radiative forcing in the lower troposphere of Dakar due to anthropogenic emissions of CO_x and No_x. The radiative imbalance resulting from the increase in atmospheric pollutant concentrations may be manifested by a change in radiative temperatures at a local or regional scale.

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