Internship report

Contribution of water vapor to the greenhouse effect from measurements during the SHADOW campaign

Athanasios Ntoumos

Master 2 Atmospheric Environment

Université de Lille

June 2018

Supervisors: Yevgeny Derimian and Olivier Pujol

Abstract

The purpose of this research internship is to study the contribution of water vapor to the greenhouse effect and compare it with the contribution of mineral dust. More precisely, the radiative impacts in thermal infrared due to water vapor and dust aerosol particles are scrutinized. To achieve this objective, a dataset of real observations conducted during the SHADOW (Study of SaHAran Dust Over West Africa) campaign was used. The data, which concern March and April 2015, consist of realistic observations of water vapor, aerosol optical thickness and downwelling thermal infrared (TIR) broadband flux at the surface conducted during two dust episodes. The two dust episodes are, however, associated with different general meteorological conditions – very dry and relatively wet. All these measurements came from an observation site located at IRD (Institute for Research and Development) Center, Mbour, Senegal (14°N, 17°W). The site is known to be influenced by Saharan dust, sea salt and biomass burning during part of the dry season.

The work presents the evaluation of water vapor effect on the values of downward TIR flux. In addition, the water vapor effect on TIR flux is compared to that of the desert –dust aerosol particles. The sensitivities to different aerosol characteristics and influence of varying profile of air temperature are also considered.

Key words: Water vapor, desert dust aerosol, thermal infrared, SHADOW campaign

Table of contents

1. Introduction

In the context of the current climate change, it is fundamental to monitor and quantify the contribution of different factors to Earth's warming and cooling mechanisms. In addition, water vapor versus aerosol contributions to TIR radiation is important for a proper interpretation of remote sensing observations. The work of this internship, therefore, is focused on the impacts of water vapor and aerosols (coarse dust particles essentially).

Water vapor is a very important trace gas in the atmosphere since it controls cloud formation and it has the most important greenhouse effect: its contribution represents around 60 % in clear air conditions. Furthermore, the total mass of the atmosphere, a fundamental quantity for all atmospheric sciences, varies mainly from changes in water vapor loading (Trenberth et al. 2005).

At this point, some information will be provided regarding the scientific context and research background of the present research topic, as well as the main objectives of the study.

1.1 Scientific context and research background

Water vapor is defined as the gaseous phase of water. It is one state of water within the hydrosphere. Under typical atmospheric conditions, water vapor is continuously generated by evaporation and removed by condensation. It is less dense than air and triggers convection currents that can lead to clouds.

Water vapor is widely recognized to be a key climate variable, and has an important influence on global climate change which makes it necessary to know the distribution, transport and radiative impacts of water vapor (Zhang et al. 2012). However, the extent of its contribution to global warming has been debated. Climate models have estimated the strength of water vapor feedback, but until now the record of water vapor data was not sophisticated enough to provide a comprehensive view of at how water vapor responds to changes in Earth's surface temperature.

Apart from the uncertainties concerning water vapor, aerosol radiative forcing is also a critical, though variable and uncertain, component of the global climate. Lack of detailed knowledge of the optical properties of aerosols results in aerosol being one of the largest uncertainties in climate forcing assessments. Aerosols are highly inhomogeneous and variable, and the available accuracy of aerosol characterization is often not sufficient. Consequently, monitoring of atmospheric aerosols is a fundamentally difficult problem. (Dubovik et al. 2002)). At this point, it is also worth mentioning that most remote sensing studies focus on the solar spectrum, whereas the closure of the terrestrial radiative balance also needs knowledge of the dust effect on terrestrial and atmospheric infrared radiation, e.g., (Volgelmann et al., 2003).

Regarding aerosols, in the present study we are mainly interested in dust which is a major component of the climate over large regions of the planet, e.g., (Legrand et al., 2001), Central and Northern Africa probably being the most dramatic example. Mineral dust is a major contributor to total aerosol loading and has been the subject of an increasing number of studies (Pierangelo et al., 2004). According to remote sensing analyses in the Sahara region, dust presence is associated with a decrease of downward SW radiance and an increase of downward LW radiance (and the associated brightness temperature).

1.2 Internship main objectives

The main objectives of this internship are to evaluate and inter-compare the radiative impacts of water vapor(WV) and desert dust, in thermal infrared (TIR) based on observations in a desert environment . For this purpose, were analyzed WV vertical profiles derived from LILAS lidar system (Bovchaliuk et al., 2016; Veselovskii et al., 2016), broadband TIR radiative flux measurements station operated by LOA and AOT and column integrated WV data from AERONET platform. All these measurements came from an observation site located at IRD (Institute for Research and Development) Center, Mbour, Senegal (14°N, 17°W).

More specifically, in the first part of the present study, a measurements based analysis was performed by analyzing the data from the instruments. I investigated the effect of water vapor nighttime content on the downward TIR flux. I analyzed water vapor vertical profiles from the lidar instrument, and observed their effect on the corresponding downward TIR flux. The night time data was selected first because of the low noise in lidar WV retrievals.

Then, I took into account daytime water vapor and AOT data from the AERONET platform in order to observe and analyze their contribution on downward TIR flux. Moreover, Angstrom exponent dependency was also added to this study. Angstrom exponent is inversely related to the aerosol average particle size and hence it will be interesting to investigate and confirm that higher downward TIR flux is associated with larger dust particles.

In the second part of the internship, additional factors were introduced to the analysis through the usage of a radiative transfer model. The calculations should investigate AOT as the most intriguing factor. Knowing that water vapor concentrations affect the Earth's climate, it would be quite interesting to assess the aerosol contribution to this effect and conclude on their relative importance. Furthermore, I estimated the direct radiative impact due to varying aerosol concentrations and types, as well as performing tests for varying air temperature profiles.

2. Methodology

2.1 SHADOW campaign

West Africa and the adjacent oceanic regions are the crossroads of several types of particles such as desert dust (Sahara), sea spray (Atlantic ocean) and biomass burning aerosols. Consequently, it is a very important location for studying dust properties and their influence on weather and climate. The SHADOW (Study of SaHAran Dust Over West Africa) campaign is performing a multi-scale and multi-laboratory study of aerosol properties and dynamics using a set of in situ and remote sensing instruments at an observation site located at IRD (Institute for Research and Development) Center, Mbour, Senegal (14°N, 17°W).

The main objectives of SHADOW campaign are to better determine the physical and chemical properties of particles in this region, largely influenced by high concentrations, and to establish a link between them, the atmospheric dynamics, aerosol load and optical properties, e.g., (Rivellini et al., 2017).

During this campaign conducted in March – April 2015 and December 2015 – January 2016, a comprehensive dataset about aerosols and gases like water vapor has been collected.

2.2 Data analysis and numerical tools

The measurements data that was used in the present study includes water vapor data obtained from multi-wavelength Raman lidar (LILAS), AOT values measured by AERONET sun/sky photometer and broadband TIR radiative flux measure by the pyrgeometer instrument of Kipp & Zonen fluxmeter station. The instruments were installed in M'Bour (Senegal) performing measurements routinely

Python programming language was used for the data treatment and analysis. Mastering the observation with a programming language was necessary because of large amount of data and operations on the matching of the data from different measurement instruments.

Firstly, in order to derive an initial assessment of the radiative impact of water vapor on the downward TIR flux, we compared the water vapor measurements from the Raman lidar with the corresponding TIR flux from the fluxmeter station. The lidar instrument provides the nighttime data of water vapor mixing ratio (WVMR) vertical profiles ranging from the surface till the altitude of roughly 17 km. However, above the height of 5 km the profiles become quite noisy and had to be excluded from the data analysis. Then, we integrated these vertical profiles and matched them with the derived values of the corresponding TIR flux.

In the next section, we expanded our measurement based data analysis by introducing daytime water vapor and AOT data. This was done through measurements from AERONET sun/sky photometer. Consequently, we were able to further investigate the radiative impacts of water vapor by completing daytime values and compare them to the nighttime ones obtained with the lidar. In addition, with the AOT dataset we studied the impact of desert dust on downward TIR flux.

In the following part of the present study, we performed calculations through the usage of a radiative transfer model. The radiative transfer model GAME (Global Atmospheric ModEl) (Dubuisson et al., 2006) was employed in order to better understand and confirm the observed in the field tendencies in water vapor and aerosols (coarse dust) influences on TIR flux and performed radiative sensitivity studies to other variables. Using the radiative transfer code we were able to compute the vertical profiles of downward TIR flux as a function of the varying input parameters. In particular, the values of different water vapor vertical profiles were introduced to the model and through the computation of the TIR radiation profiles we were able to observe and quantify the radiative impact of water vapor in several altitudes. Furthermore, the variation of the AOT input values allowed us to compute its radiative impact and to inter-compare the influence of both aerosols and water vapor. Finally, we observed the TIR flux sensitivity to other input parameters such as Aerosol Single Scattering Albedo (ASSA) and air temperature.

3. Results

3.1 Measurements based analysis

In the first step of the measurement based analysis we investigate the radiative impact of the water vapor nighttime content and derive the first conclusions.

In the next part of the present chapter we expand the analysis to daytime and introduce dependence on AOT solar spectrum, which also includes indications of the involved aerosol size Angstrom Exponent calculated between 440 and 870nm.

3.1.1 Impact of water vapor on the downward TIR flux

The relationship between the measured downward TIR flux and the lidar water vapor observation during nighttime is outlined in Figure 1. The hourly averaged nighttime values of water vapor mixing ratio (g/kg) are used to improve the signal to noise ratio of Raman signal. Moreover, due to the noise at high altitudes, the used vertical profiles of water vapor are limited to the height of 5 km. In addition, it should be mentioned that the flux station provides measurements of the downward thermal radiation, in W/m^2, every minute. Thus, the flux data was hourly averaged in order to match with the water vapor dataset.

Observations show that the values of downward thermal flux increase and range between about 360 W/m^2 to 390 W/m^2 for the given variability of the atmospheric water vapor (abscissa in Fig. 1 shows column integrated water vapor).). Despite the scatter plot is relatively noisy, the upward tendency in TIR flux values is quite pronounced. The presented dispersion of the points could be expected given the limit of usage of hourly integrated water vapor (IWV) values and corresponding hourly mean TIR flux. Nevertheless, it can be concluded that the observed in a desert environment water vapor variability (of about five times) cause the corresponding downward TIR flux variability of about 20%.

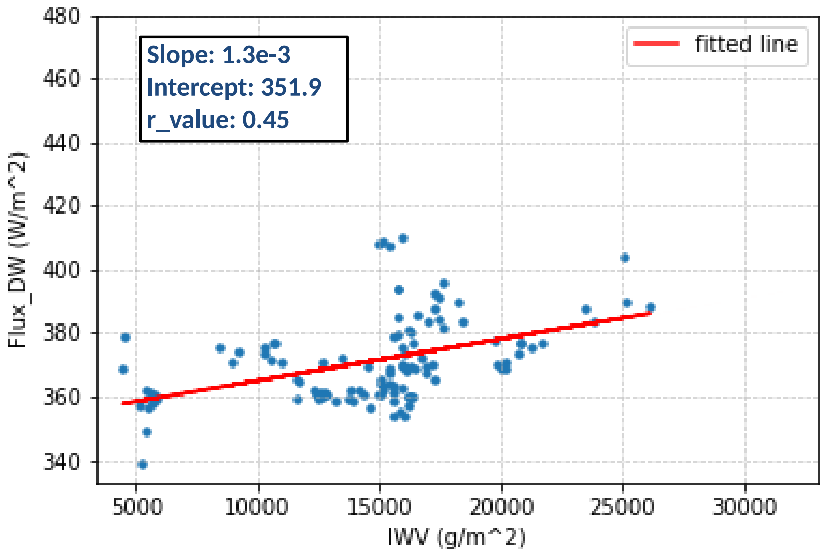


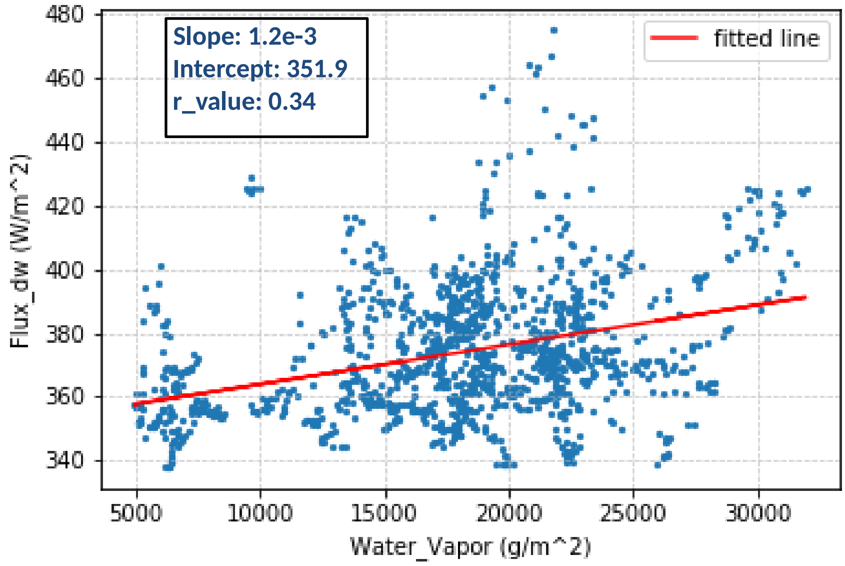
Figure 1. Measured downward thermal infrared flux versus measured atmospheric column water vapor mixing ratio integrated over first five 5 kilometers. Both values of these variables are hourly averaged.

3.1.2 Relative importance of water vapor vs. desert dust aerosol impact on TIR flux

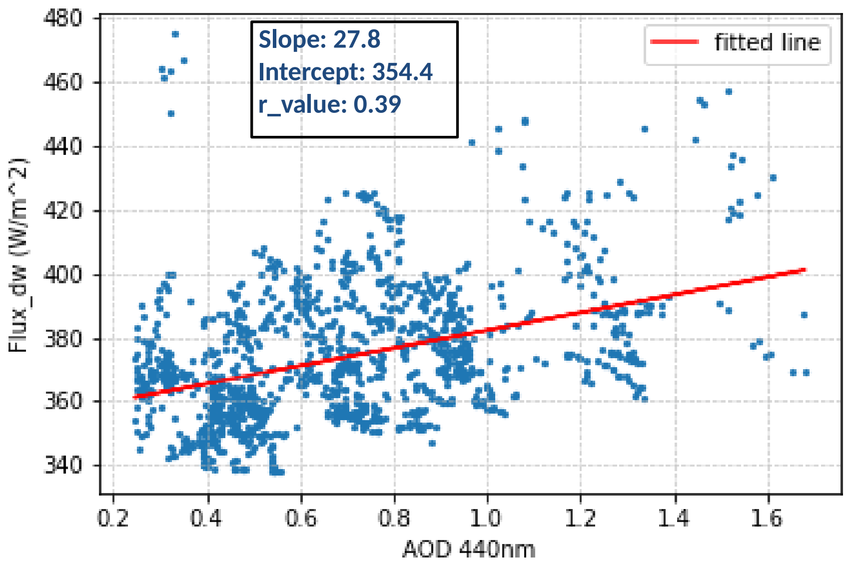
Figure 2a shows the daytime downward TIR flux values, as measured by the flux station, versus the AERONET retrieved total column water vapor values (in g/m^2). According to the derived plot, TIR flux values tend to increase as the atmosphere becomes more humid, which is in line with the former analyses. Moreover, the downward TIR flux values increase and range between about 360 W/m^2 to 395 W/m^2 for the given variability of the atmospheric water vapor. It is remarkable that a closer inspection of Figure 2a and its comparison with Figure 1 (nighttime lidar data), reveals a resemblance between these two plots. This similarity regarding the radiative impact could further validate the derived results. We should also note that, in this case, the daytime water vapor values used present variability of about six times and that corresponds to roughly 38% variability in the downward TIR flux.

In Figure 2b are plotted downward TIR values versus visible AOT at 440nm. It seems quite evident that higher AOT values, or in other words higher aerosol loading, are associated with an increase to downward TIR flux. Noteworthy, however, that the downward TIR flux dependence on aerosol concentration is somewhat comparable with the effect of water vapor (depicted in Fig. 2a). We can observe that dependence on aerosol concentration is slightly stronger. Note also that the data represent a real and quite wide range WV and AOT variability in a desert environment. On average, the downward TIR flux increase from 360 to 400 W/m^2 for low and high AOT values respectively, even though presenting a remarkable dispersion caused by other elements influencing the TIR radiation.

(a)



(b)



(c)

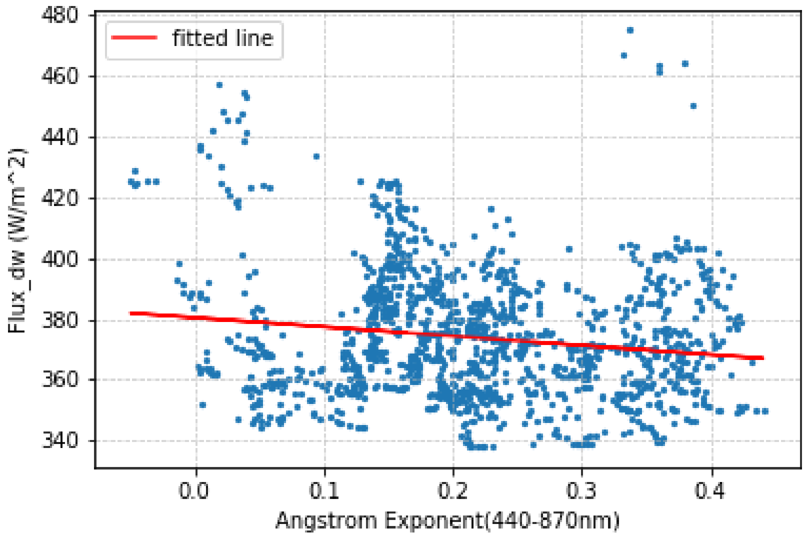


Figure 2. Influence of **(a)** water vapor daytime values **(b)** visible aerosol optical depth (AOD) and **(c)** Angstrom exponent (440-870nm) to the downward (dw) TIR flux.

Figure 2c depicts the variations of downward TIR flux to the values of Angstrom exponent at 440-870 nm. In general, as we already mentioned the Angstrom Exponent is inversely related to the particle size. For our spectral interval, two measurements of AOT, $\tau_{\lambda o}$ and τ_{λ} has to be taken at the two corresponding wavelengths λ_{440nm} and λ_{870nm}. Thus, the Angstrom exponent α can be obtained through the following equation:

$$\tau_{\lambda} = \tau_{\lambda_0} \left(\frac{\lambda}{\lambda_0} \right)^{-\alpha}$$

To be more precise, a value below 1.0 is usually linked to coarse mode dominating aerosols such as dust. In our case the Angstrom exponent was retrieved through the AERONET platform and presents quite low values below 0.5, which is logical given the site location and the analyzed season that is primary exposed to the Sahara dust. Moreover, as could be expected, the plot shows an increase of the downward thermal radiation for larger size particles, i.e. lower value of Angstrom exponent.

3.2 Analysis of numerical simulations

With the goal to confirm the observed range of the downward TIR flux possible variability due to an observed range of the WV concentration variability, we now conduct some radiative transfer calculation. In addition, sensitivities to aerosol loading and ambient temperature are studied. New variables are also introduced in order to expand our downward thermal flux assessments in several atmospheric layers and not only the surface. Thus, in this section, we will analyze the impact of water vapor and AOT on the downward TIR flux in various levels through radiative transfer model calculations.

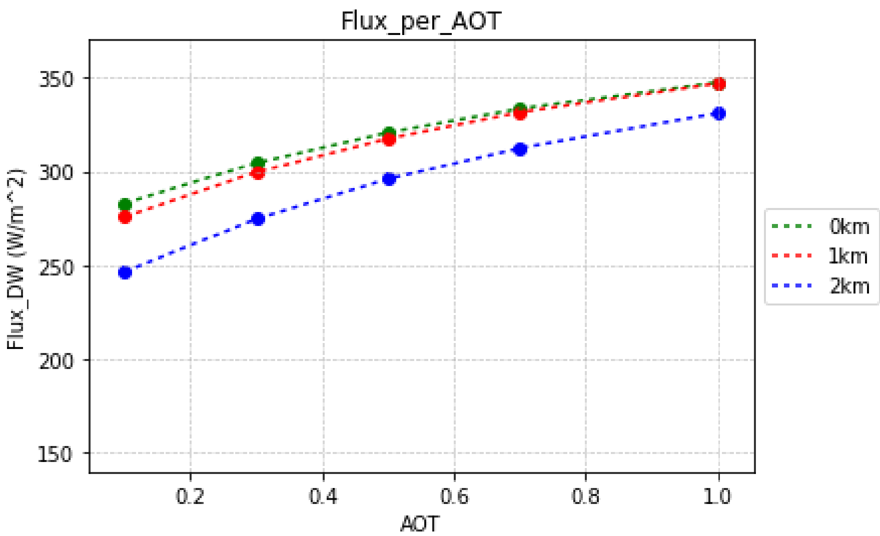
It should be mentioned that the TIR AOT can have a strong spectral variability. For example, AOT strongly depends on atmospheric dust mineralogical composition, size distribution and even non-sphericity (Legrand et al., 2014). Lack of knowledge on aerosol complex refractive index in TIR makes the accurate calculations of AOT as a challenging task and can be subject of a separate study. Therefore, for the sake of simplicity and aiming estimation of a range of variability only, the AOT values in the current study are assumed to be the same at all wavelengths. The TIR AOT values are assumed to varying from 0.1 to 1.0, reflecting low and very high aerosol loading respectively. In general, there is a nearly linear relationship between infrared and visible AOT. According to remote sensing studies for the Sahara region (Pierangelo et al., 2004) the average ratio between the visible and TIR AOTs is in the order of 0.35. To be more precise, in our case a value around 0.35 for the employed TIR AOT corresponds to roughly 1.0 for visible AOT, which is typical for an atmosphere with high aerosol loading. Therefore, regarding the values employed in this chapter, AOT = 0.1 corresponds to a relatively clear atmosphere and, one the other hand, AOT = 1.0 corresponds to an extreme-high value for desert-dust saturated atmosphere.

3.2.1 Sensitivity of downward thermal flux to variability in aerosol optical thickness and water vapor concentration

The influence of the infrared AOT on downward thermal flux at different altitudes in the atmosphere is depicted in Fig. 2 (a). As could be expected the calculations illustrated that higher values of downward flux are linked to higher aerosol content in the atmosphere. This upward trend between the two extreme values of AOT results in about 70 to 80 W/m^2 increment or, in other words about 23% variability. Note that because the aerosol layer is assumed to be located under 3 km the illustrated downward TIR flux values correspond only to the aerosol layer up to 2 km.

Figure 2 (b) shows the range of downward TIR flux variability due to the observed variability in water vapor. Note that the whole WV profiles are used in the code, but the abscissa in Fig. 2(b) represents only the integrated values seeking convenience of the presentation. It can be observed that the downward flux increases as the atmosphere becomes more humid, as could be expected. However, in contrast with the effect of aerosol optical thickness, in the case of WV there is a less increase of the downward flux, which is consistent with the trends obtained from the field observation data. Between the two extreme water vapor integrated values the variation of the downward TIR flux is in the range of 50 W/ m^2 and 25 W/m^2 for the altitudes of 0km and 5 km respectively. In particular, the downward TIR flux exhibits 13.1% variability at the surface and it is reduced to 10.7% at the height of 5km.

(a)



(b)

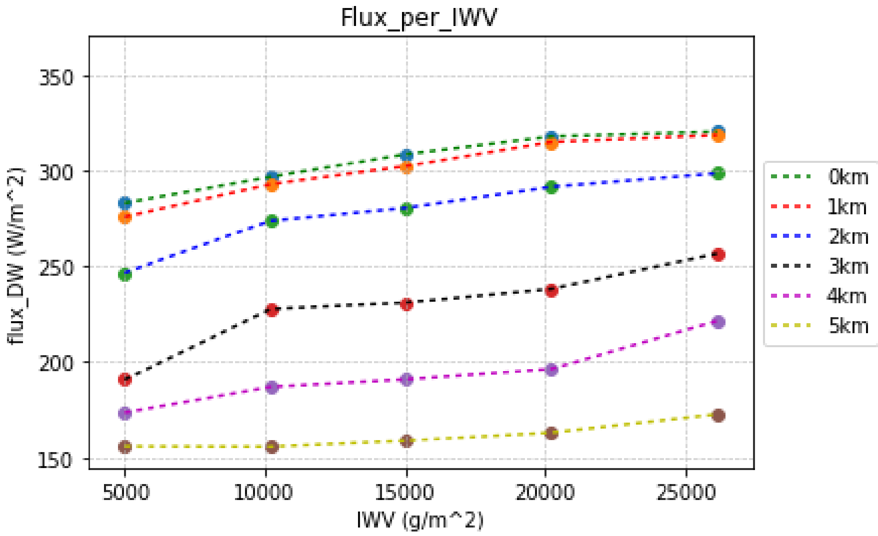


Figure 3. (a) Downward TIR flux values for three reference altitudes as a function of AOT in TIR **(b)** Downward thermal flux values for six reference altitudes as a function of various integrated water vapor profiles.

A closer analysis of the Figure 3(a) reveals that a radiative saturation effect occurs for higher aerosol loading which could slow down the tendency in the TIR flux increase. In other words, the downward flux increase is somewhat greater for aerosol addition to an initially clear atmosphere.

The former conclusions can be better clarified and quantified through Table 1, which refers to surface level values (0 km). It is shown that the TIR flux value from AOT =0.1 to AOT =0.3 presents a 7.6 % increase. On the contrary, the increase is attenuated to 3% for AOT = 0.7 to AOT = 0.9 transition.

Downward Flux (W/m^2)	AOT TIR	Percent change (%)
283.0	0.1	-
304.5	0.3	7.6
320.7	0.5	5.3
333.3	0.7	3.9
343.3	0.9	3.0

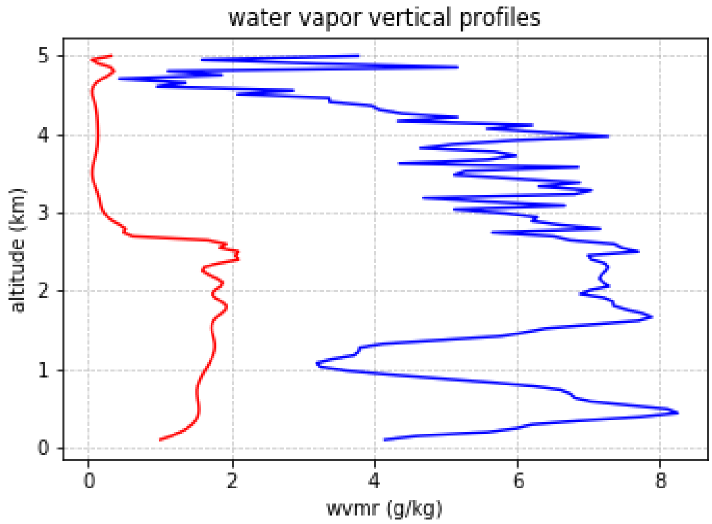
Table 1 Downward TIR flux as a function of several AOT values, accompanied with the corresponding percent change, for ground level (0 km). The radiative transfer model was used for the calculations.

On the other hand, when it comes to the range of the observed water vapor concentrations as illustrated in Figure 3 (b), the downward thermal flux is not subjected to any radiative saturation in the range of the used here WV concentrations.

3.2.2 Presenting reference water vapor and air temperature vertical profiles

Aiming to estimate the impact of the water vapor and air temperature profiles on the profiles of the downward thermal flux, we present here the specific water vapor and temperature vertical profiles that were used in the calculations as a reference. From the available data I chose two extreme - a dry and a wet WVMR (water vapor mixing ratio) profile, always with respect to the period of measurements. The same procedure was followed in the case of temperature. These vertical profiles are represented in Fig.4 (a), (b).

(a)



(b)

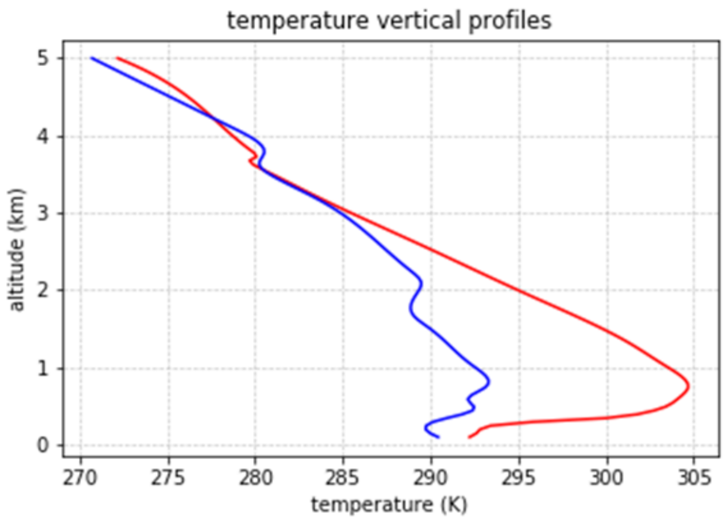


Figure 4. (a) Illustration of a dry and a wet water vapor vertical profile, and **(b)** of air temperatures vertical profiles up to 5 km altitude in the both cases.

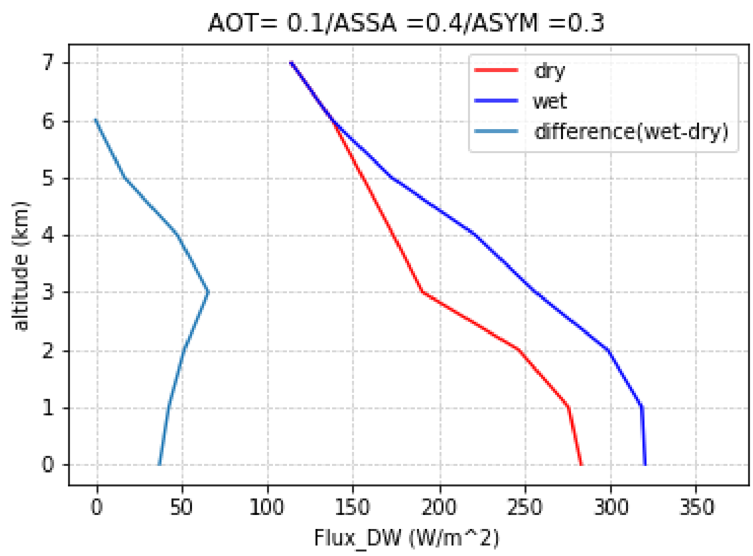
3.2.3 Sensitivity of TIR flux to varying aerosol concentration

At the following graphs the effect of water vapor on the downward thermal flux vertical profiles, under different atmospheric conditions, is scrutinized. In particular, a comparison can be made between an atmospheric profile with low aerosol loading (Fig. 5a) and high aerosol loading (Fig. 5b).

First and foremost, we observe that the above - mentioned figures differentiate under the height of 3 km, because we assume that the aerosol layer is located under the altitude of 3 km. Furthermore, a very distinct relationship can be noted between the low aerosol loading and the high aerosol loading profile. To be more precise, in the case of low aerosol loading (AOT =0.1), the radiative influence of water vapor is more intense than in the case of an atmosphere with higher aerosol loading (AOT =1.0).

This reduction of water vapor impact on downward thermal flux due to the presence of aerosols can be interpreted as a masking effect. In other words, the contribution of water vapor to the greenhouse effect can be overcome by aerosols as the aerosol concentration increases. For instance, for a low aerosol concentration (AOT =0.1) the value of the downward TIR flux has a 13.2% increase due to the impact of water vapor, concerning the flux value at the surface (0km). On the contrary, high concentration of aerosols (AOT =1.0) partially mask the water vapor contribution and, therefore drop the downward TIR flux increasing tendency, at the surface, to 4%.

(a)



(b)

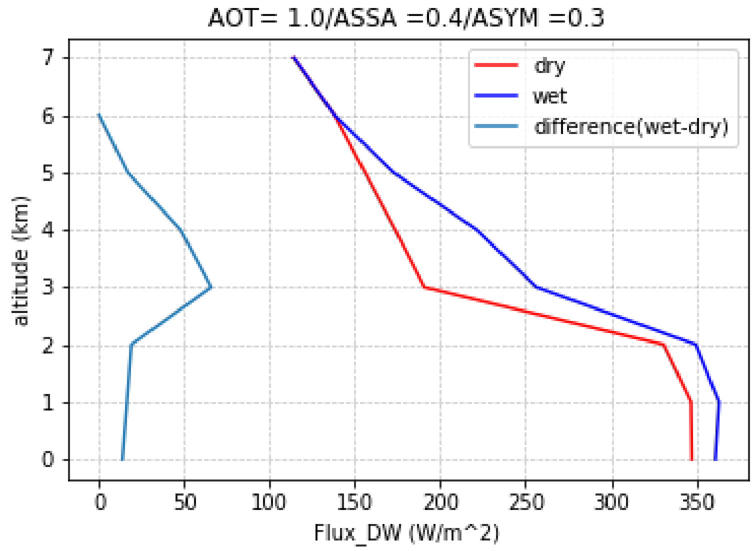


Figure 5. Impact of the water vapor content on the downward thermal radiation for an atmosphere with (a) low aerosol loading (AOT =0.1) and (b) high aerosol loading (AOT =1.0) regarding aerosols of the same type (TIR Single Scattering Albedo (ASSA) of 0.4 and Asymmetry factor ASYM of 0.3 – the values are taken from (Legrand et al., 2014)).

3.2.4 Sensitivity of TIR flux to varying aerosol type

The aerosol type defines such aerosol optical parameters as Aerosol Single Scattering Albedo (ASSA) and Asymmetry factor (ASYM). Using the literature (Legrand et al., 2014) we set these parameters to 0.4 and 0.3 for ASSA and ASYM, respectively, as representative of mineral dust. However, it would be also interesting to investigate the downward TIR flux sensitivity to the aerosol type.

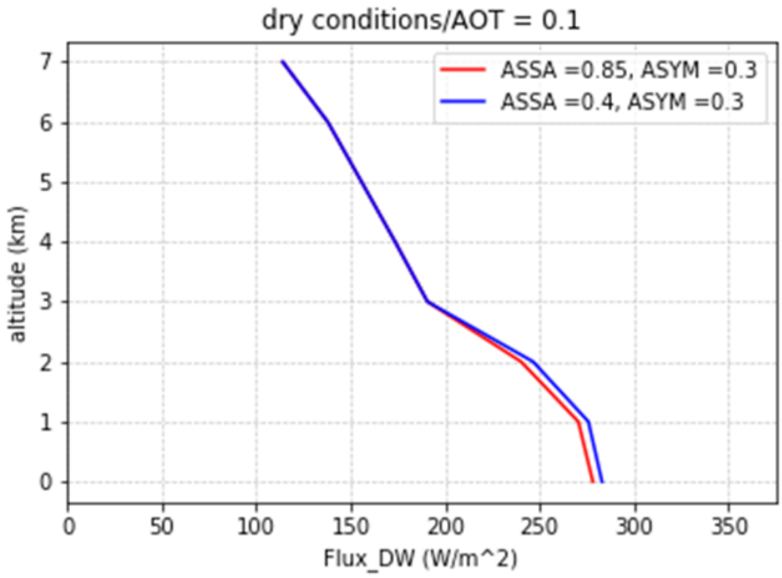
The following figures (Fig. 6(a), (b)) depict the dependence of the downward TIR flux to the aerosol nature through a comparison of different values of ASSA and ASYM.

It becomes clear that ASSA has quite a weak impact on the downward flux (Fig. 7a), while the impact of ASYM is practically negligible (Fig. 6b).

More specifically, in Figure 6 (a) we compare the value of the downward thermal flux between the case of mainly scattering aerosols (ASSA =0.85) to more radiation - absorbing aerosols (ASSA =0.4) under a fixed value of the asymmetry factor

(ASYM =0.3). It is apparent that aerosols with more absorbing than scattering nature are re-emitting the radiation that they absorb, hence causing an increase in downward thermal flux. However, the thermal radiance sensitivity regarding the aerosol type appears to be weak relative to the effect of concentration and presenting roughly 2% variability.

(a)



(b)

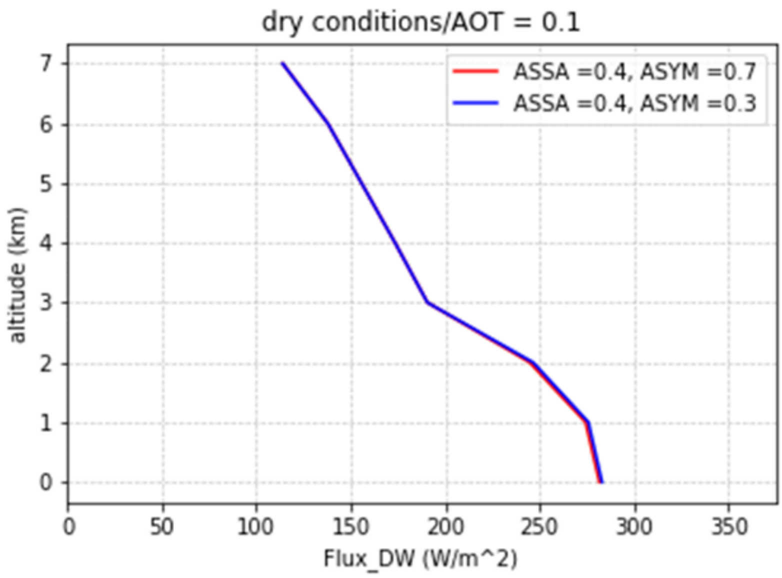


Figure 6. (a) Calculated downward TIR flux sensitivity to varying ASSA, and **(b)** to varying ASYM values

3.2.5 Sensitivity of TIR flux to varying air temperature profiles

Figure 7 compares vertical profiles of the downward TIR flux up to 7 km altitude. Each one corresponds to a different air temperature profile. The variability of the observed during the field campaign average air temperature of these profiles is quite low, around 1,5 % (ΔT_{avg} = 4K), nonetheless a substantial increase of the downward flux for higher temperatures is observed for altitudes lower than 3 km reaching a maximum increase of roughly 12 % at 1 km altitude. The following graph can be linked with the Fig. 4 (b) which shows almost no temperature difference for altitudes above 3 km but an apparent difference for lower altitudes. We can conclude that a realistic variability of air temperature profile can cause up to about 30 W/m^2 variability in TIR flux.

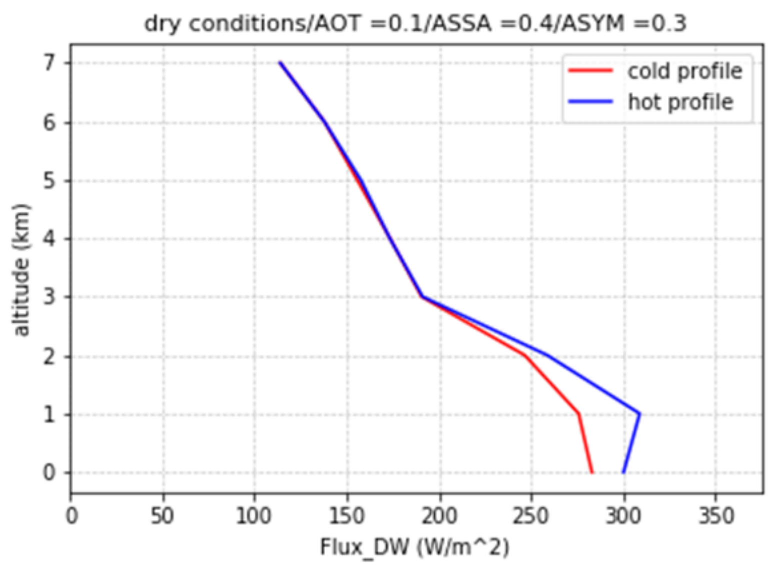


Figure 7. Calculated downward thermal flux sensitivity to varying air temperature profiles.

4. Conclusions

In this internship report, we discussed the relative importance of the water vapor and AOT radiative impacts on TIR radiation. The study employed the SHADOW field campaign observations of lidar and flux station measurements as well as data from the AERONET platform regarding the western African coastal site of Mbour (Senegal). A series of sensitivity tests to variabilities in such parameters as aerosol concentration, aerosol type and air temperature profiles were also performed. The data analysis proves a relation between values of downward TIR flux and water vapor loading and also analyzes its dependence on the dust aerosol loading. The implementation of the radiative transfer model allowed us to expand downward TIR flux assessments to various heights in the atmosphere.

In particular, we compared the impacts of water vapor and dust (AOT) on the downward TIR radiance. The results showed a somewhat higher dependence of the thermal flux to aerosols (coarse dust) comparing to the corresponding water vapor dependence. Regarding Angstrom exponent, the results confirmed that low values, i.e. bigger size particles, are responsible for the increase of the downward thermal radiance. An interesting finding was the observed radiative saturation effect that occurs at high AOT values. In addition, the results indicated that the effect of water vapor on TIR radiation can be masked or overtaken by high dust aerosol loading. Furthermore, we assessed the influence of different aerosol type on the TIR flux via a comparison of ASSA (aerosol single scattering albedo) and ASYM (asymmetry factor). The derived figures showed that aerosols with the lower ASSA (0.4), namely they absorb more radiance than they scatter, increase the downward thermal radiance by a small extent, while the ASYM variability does not exhibit any significant longwave radiative influence. Finally, additional calculations verified the downward thermal flux sensitivity to varying profiles of ambient temperature.

As already stated in this report, the dust and water vapor are considered as critical components of the climate, and uncertainties regarding their impact on current climate change remain. Consequently, further investigations and clarifications are required in order to enhance our understanding of the Earth’s climate shifts. These difficulties can be overcome by extending the data to cover the whole year and therefore obtaining the annual variability of the components. More stations around the world should be also involved to the analysis with a view to obtain geographical characteristics of water vapor radiative impacts. Finally, high accuracy surface observations, improving surface flux retrievals from satellite products and refining modeling approaches are necessary. The combination of all these efforts could ultimately allow narrowing down the uncertainties concerning water vapor and aerosols radiative forcing.

At this point, I would also like to highlight the skills that I learned and acquired during this internship. This internship was a great opportunity to test out the skills I developed in lectures previous studies and see how they are applied in research. Apart from the knowledge that I already had, this internship gave me the chance to develop new skills. In particular, I developed my programming skills. With no initial experience in programming I learned how to use the Python programming language in order to perform the data treatment and analysis required. I also become familiar with UNIX/LINUX environment and did calculations using a radiative transfer model. Last but not least, through my research in scientific literature mainly regarding aerosols and water vapor radiative forcing, I have widen my knowledge about these atmospheric components and their influence to the global climate.

Acknowledgments

I would like to express my sincere gratitude to my internship supervisors Mr. Yevgeny Derimian and Mr. Olivier Pujol for their invaluable guidance, comments, and suggestions throughout the course of this internship.

Also I would like to thank all the staff members of LOA and my colleagues for their support and assistance all these five months.

I am also grateful to all professors and people involved in Master Atmospheric Environment and Labex CaPPA project for providing me such an opportunity to study in one of the highest level universities.

References

V. Bovchaliuk, P .Goloub, T. Podvin, I. Veselovskii, D. Tanre, A. Chaikovsky, O. Dubovik, A. Mortier, A. Lopatin, M. Korenskiy .: Comparison of aerosol properties retrieved using GARRLiC, LIRIC, and Raman algorithms applied to multi-wavelength lidar and sun/sky-photometer data, Atmospheric Measurement Techniques, 2016, 9, 3391

O Dubovic., B. Holben , F. Eck. T., A. Smirnov, J. Kaufman, M. D. King : Variability of Absorption and Optical Properties of Key Aerosol Types Observed in Worldwide Locations, J. Atmospheric Science, 2002, 59, 590

P. Dubuisson, J. C. Roger, M. Marret, O. Dubovik,.: A code to compute the direct solar radiative forcing: application to anthropogenic aerosols during the Escompte experiment, Proceedings of IRS 2004: Current Problems in Atmospheric Radiation, 23–28 August 2006, Busan, Korea, 127–130, 2006.

M. Legrand, O. Dubovik, T. Lapyonok and Y. Derimian: Ac- counting for particle non-sphericity in modeling of mineral dust radiative properties in the thermal infrared, J. Quant. Spectrosc. Ra., 2014 149, 219

M.Legrand, A. Plana-Fattori, C. N'doume: Satellite detection of dust using the IR imagery of Meteosat 1. Infrared difference dust index, J. Geophys. Res., 2001, 106, 18,251

C. Pierangelo, A. Chedin, S. Heilliette, N. Jacquibet-Husson, R. Armante : Dust altitude and infrared optical depth from AIRS, Atmos. Chem. Phys., 2001, 4, 1813

L.-H. Rivellini, I. Chiapello, E. Tison, M. Fourmentin, A. Feron, A. Diallo, T. N'Diaye, P. Goulob, F. Canonaco, A. Prevot, V. Riffault : Chemical characterization and source apportionment of submicron aerosols measured in Senegal during the 2015 SHADOW campaign, Atmos. Chem. Phys., 2017, 17, 10291

K.E. Trenberth, L. Smith: The Mass of the Atmosphere: A Constrain on Global Analyses, J. Climate, 2005, 18, 864

A. Vogelmann, P. Flatau, M. Szczodrak, K. Markowicz, P.Minnett : Observations of large aerosol infrared forcing at the surface, Geophys. Res. Lett., 2003, 30, 1655

I. Veselovski, P. Goloub, T. Podvin, V. Bovchaliuk, D. Tanre, Y. Derimian, M. Korenskiy, O. Dubovik: Study of African dust with multi-wavelength Raman lidar during "SHADOW" campaign in Senegal, Web of Conferences, 2016, 08003, 119

I. Veselovski, P. Goloub, T. Podvin, V. Bovchaliuk , Y. Derimian, P. Augustin, M. Fourmentin, D. Tanre, M. Korenskiy, D. Whiteman .: Retrieval of optical and physical properties of African dust from multiwavelength Raman lidar measurements during the SHADOW campaign in Senegal, Atmos. Chem. Phys, 2016, 16, 7013

S. Zhang, X. Lisheng, J. Ding, H. Liu, X. Deng: Perceptible water vapor retrieval using neural network from infrared hyper-spectral soundings, Key Eng. Materials, 2012, 396, 390