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Xolile G. Ncipha[1,2], Venkataraman Sivakumar[2], Rakotondraompiana Solofo[3], Hassan Bencherif[4]

[1]442 Rigel Avenue South, Erasmusrand, Pretoria, Gauteng, 0001, South Africa

South African Weather Service, Private Bag X097, Pretoria, South Africa, 0001, xolile.ncipha@weathersa.co.za

[2]School of Chemistry and Physics, University of KwaZulu-Natal, Durban 4000, South Africa

[3]Remote Sensing and Environmental Geophysics Laboratory, Institute & Observatory of Geophysics, Antananarivo (IOGA), University of Antananarivo, P.O. Box 3843, 101, Antananarivo, Madagascar

[4]Laboratoire de l'Atmosphère et des Cyclones UMR, 8105, 15 Avenue René Cassin, Université de la Réunion, CS 92003, 97744 Saint—Denis, Cedex, Réunion, France

ABSTRACT

Southwest Indian Ocean (SWIO) Islands States are vulnerable to environmental hazards, caused by pressure on the environment to satisfy the socio-economic needs of growing human population. The forests of these tropical islands are rich in biodiversity and they are large carbon sinks. Rapid population growth in these islands is identified as one of the main factors responsible for deforestation, which in turn is the main source of carbon dioxide (CO_2) emissions. This study is born from the Agence Universitaire de la Francophonie (AUF) programme called *observation des Risques naturels en Milieux Insulaires (RAMI)*. In this study we contrast the CO_2 3-dimensional atmospheric loading between the wet austral summer and dry spring seasons, and compare the relative CO_2 loading over the Comoros, Madagascar, Reunion and Mauritius islands. We found there is a general shift to higher concentrations from summer to spring season and the CO_2 concentration is highest at the southern part of Madagascar in both seasons. This study also illustrates the influence of source strength and meteorology.

Keywords: Tropical forest deforestation, carbon dioxide

Introduction

The Southwest Indian Ocean (SWIO) islands states are vulnerable to natural hazards, these environmental threats are intensified by the changing climate caused by pressure on the environment to satisfy the socio-economic needs of growing human population (AUF, 2015). One of the important natural terrestrial ecosystems that are affected by this anthropogenic pressure in this region is its tropical forests. The human pressure on the tropical forests leads to their removal and degradation. Tropical forests provide various ecosystem services and social benefits (Vieilledent *et al*., 2013). Tropical forests of SWIO islands states provide natural habitat to diverse fauna and flora and they are regarded as a global biodiversity hotspots (Hansen *et al*., 2013; Vieilledent *et al*., 2013).

Forests cover approximately 28% of global land surface and contain 77% of all terrestrial above ground carbon (Goodman and Herold, 2014; Baccini *et al*., 2012). They play a crucial role in the global carbon cycle by exchanging trace gases between the atmosphere and biosphere and they are large carbon sinks. They sequester about a third of the total anthropogenic emissions (Rodda *et al*., 2016; Vieilledent *et al*., 2013; Pan *et al*., 2011). Tropical forests are the biggest with the largest carbon density and they are most diverse forests on Earth. Intact tropical forests store more carbon per unit area than forests in temperate or boreal zones (Goodman and Herold, 2014). Forest clearing particularly in the tropics is a key source of carbon dioxide (CO_2) to the atmosphere (Baccini *et al*., 2012).

As tropical forest deforestation and degradation is an important source of atmospheric CO_2 over the SWIO islands, however there are other contributing emitters of this greenhouse gas with varied relative strength in each island. Reunion and Mauritius islands are net sources of CO_2, whose emission is dominated by the energy sector. While Madagascar and Comoros islands are net sinks of CO_2, in these islands CO_2 emissions are dominated by land use and land change sector (Praene *et al*., 2016; Praene *et al*., 2011; Ministry of Environments and Forests (MEF), 2010; Ministry of Environment and Sustainable Development (MESD), 2010). In this study we are comparing the CO_2 3-dimensional atmospheric loading between the wet austral summer and dry spring seasons, and compare the relative CO_2 loading over the Comoros, Madagascar, Reunion and Mauritius islands. This study is part of the Agence Universitaire de la Francophonie (AUF) programme called *observation des Risques naturels en Milieux Insulaires (RAMI).*

Instrumentation and Method

The data used in this study were collected from the Tropospheric Emission Spectrometer (TES) instrument on-board the Aura satellite. TES is an infrared, high resolution Fourier transform spectrometer (FTS) and it operates in both nadir (downward view) and limb (side view) modes to measure atmospheric profiles. It covers the spectral range 650–3050 cm (3.3–15.4 μm) at a spectral resolution of 0.1 cm (nadir viewing) or 0.025 cm (limb viewing) (Beer, 2006).

We analysed TES nadir view data over the SWIO region bounded by (42.04°- 60.13°) E longitude and (9.04°-26.93°) S latitude. Five areas of interest over the SWIO region were chosen to characterize the austral summer and spring season vertical distribution of CO_2. Table 1 shows these areas and their demarcations. Averaged CO_2 vertical profiles over the areas of interest (Table 1) were constructed by averaging atmospheric CO_2 horizontally at different altitudes up to 18 km altitude during the summer (DJF) 2004-2009 and spring (SON) 2005-2009 seasons. Geographic Information System (GIS) was used to plot all five year surface seasonal spatial distribution maps. The CO_2 data was collected from a column representing the boundary layer with the top at 700 hpa (approximately 3400 m) the level of the first semi-permanent stable layer (Garstang *et al*., 1996). The CO_2 column data was averaged vertically from the surface to 700 hpa first and the averaged data at different locations was mapped and the spatial data gaps were filled by interpolation.

Table 1: SWIO study areas spatial demarcations

Area	Latitude (°S)	Longitude (°E)
Comoros (C)	12.21	44.48
North Madagascar (NM)	15.07	48.62
Central Madagascar (CM)	18.31	46.76
South Madagascar (SM)	21.94	45.77
Reunion-Mauritius (RM)	20.70	56.58

Results and Discussion

Figures 1(a) and 1(b) show the vertical distribution of CO_2 in austral summer, and spring seasons, over selected study areas over SWIO islands. Between the two seasons there is a clear shift to higher surface concentrations from summer to spring. This is due to that the peak fire occurrence season in SWIO islands is in spring (van der Werf *et al*., 2003). There is no particular order in the relative CO_2 surface loading among the study areas in the two seasons, except for SM which has the highest concentrations in both seasons (Figure 1). In both seasons there is a clear influence of the semi-permanent stable layers at about 3400m (700 hpa) and 5500 m (550 hpa) on the vertical tropospheric loading of CO_2 over the SWIO islands (Figure 1). These stable layers separate the tropospheric CO_2 into three bands of layers of different loading, the one between the surface and 700 hpa stable layer, the one between the 700 hpa and 500 hpa stable layers and the layer above 500 hpa.

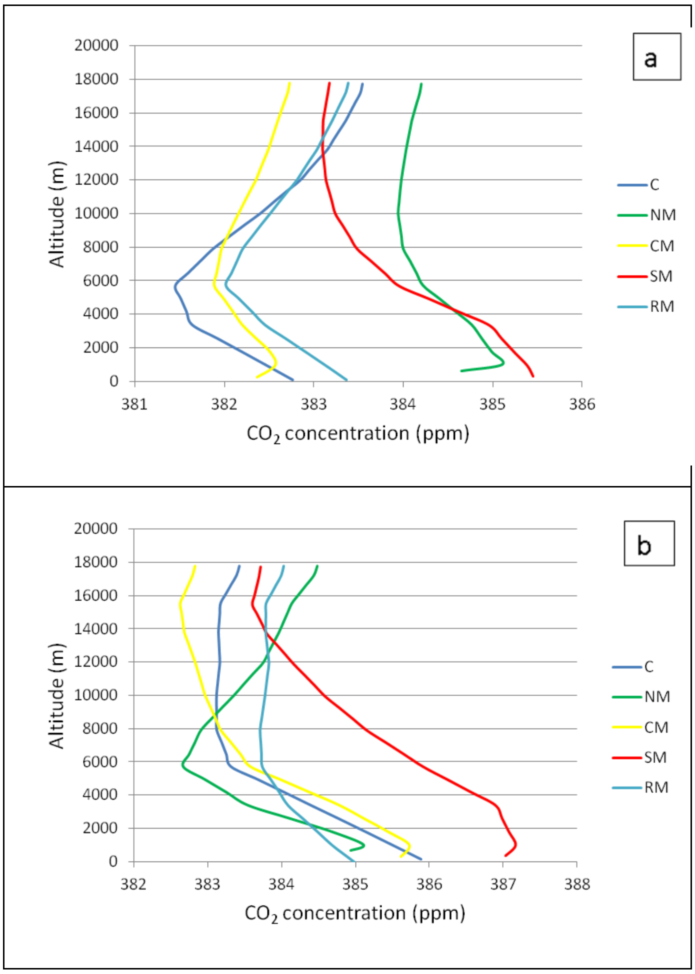

Figure1. Seasonal CO_2 vertical profiles over selected areas over SWIO islands: Figures 1(a) to (b) are profiles during the summer and spring seasons respectively.

Figures 2(a) and 2(b) show the surface spatial distribution of CO_2 over the SWIO islands in austral summer and spring respectively. Mauritius and Reunion islands show a weak gradient of the spatial concentration distribution, with the concentrations decreasing from the northwest to southwest parts of the islands. There is no clear difference in the spatial distribution of CO_2 concentration in Comoros islands. In Madagascar there is a clear spatial concentration variation over the island. There are several CO_2 hotspots over the island, with the southern part (SM) having the most and then followed by the central part (CM). These hotspots coincide with the locations of gemstones and gold mines reported by Cook and Healy, (2012). The spatial extent of high CO_2 levels in spring is wider than in summer, this should be due to the contribution of biomass burning which is at its peak in this season (van der Werf *et al*., 2003).

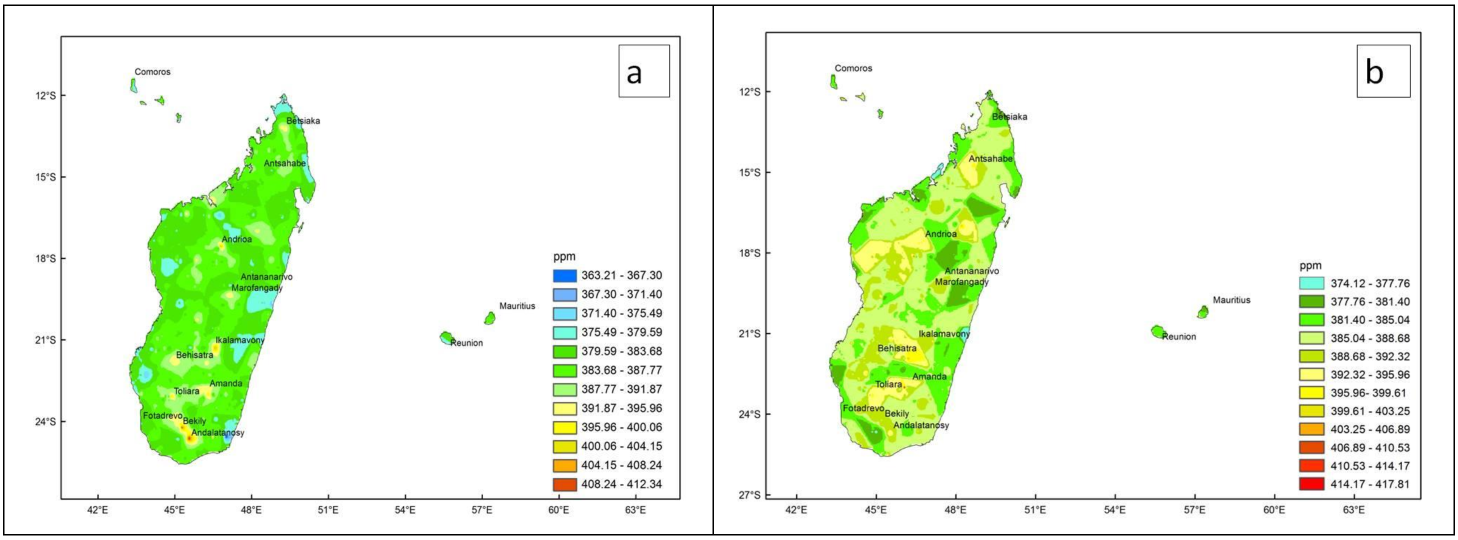

Figure 1. Seasonal CO_2 surface spatial distribution over the SWIO islands: Figures 2(a) and 2(b) are spatial distributions during the austral summer and spring seasons respectively.

Conclusions

The results show that the semi-permanent stable layers at about 3400 m (700 hpa) and 5500 m (500 hpa) play important roles in the vertical tropospheric loading of CO_2 over the SWIO region. The stable layers separate the troposphere into three bands of CO_2 layers of different loading, the one between the surface and 700 hpa stable layer, the one between the 700 hpa and 500 hpa stable layers, and the layer above 500 hpa. These stable layers exert control on the vertical motion of air by inhibiting mixing of air parcels between them. Resulting tropospheric CO_2 layers of different loading.

There is a clear shift to higher surface concentrations from summer to spring. This is due to the peak fire occurrence season in the SWIO islands in spring. There is no particular order in the relative CO_2 surface loading among the study areas in the two seasons, except for SM which has the highest concentrations in both seasons.

The surface CO_2 foot print in Madagascar resembles the spatial distribution of reported mining activities, especially during the summer season when the background CO_2 surface loading is relatively low. During the summer season the impact of industrial CO_2 emissions stands out, as there are several occurrences of localised high surface CO_2 concentration places surrounded by large areas of low background concentrations. In the spring season the surface CO_2 foot prints are spatially expanded as a result of contributions of emissions from biomass and domestic fuel-wood combustion. The wide CO_2 signatures are prevalent in the south and the west part of Madagascar particularly in the spring season, as a result of the burning of dry forests that are growing in limestone grounds.

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References

Agence Universitaire de la Francophonie, (2015). Observation des Risques Naturels en Milieux Insulaires (RAMI). https://translate.google.com/translate?hl=en&sl=fr&u=https://www.auf.org/bureau/bureau-ocean-indien/actions-regionales/formation/college-doctoral-rami-observation-des-risques-naturels-en-milieu/&prev=search

Baccini, A., Goetz, S.J., Walker, W.S., Laporte, N.T., Sun, M., Sulla-Menashe, D., Hackler, J., Beck, P.S.A., Dubayah, R., Friedl, M.A., Samanta, S. and Houghton, R.A. (2012). Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change*. DOI:10.1038/NCLIMATE1354

Beer, R., 2006. TES on the Aura Mission: Scientific Objectives, Measurements, and Analysis Overview. *IEEE Transactions on Geoscience and Remote Sensing*, 44, 5, 1102-1105.

Cook, R., and Healy, T. (2012). Madagascar Case Study: Artisanal Mining Rushes in Protected Areas and Response Toolkit. *World WildLife Fund. Estelle Levin Ltd*. https://portals.iucn.org/library/sites/library/files/documents/Bios-Cons-Nat-Pro-691-008.pdf

Garstang M., Tyson, P.D., Swap, R., Edwards, M., Kållberg, P. and Lindesay, J.A., (1996). Horizontal and vertical transport of air over southern Africa. *Journal of Geophysical Research*, 101, D19, 23,721-23,736.

Goodman, R.C., and Herold, M. (2014). Why Maintaining Tropical Forests is Essential and Urgent for a Stable Climate. *Centre for Global Development*. http://www.cgdev.org/publication/why-maintaining-tropical-forests-essential-and-urgent-stable-climate-working-paper-385

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O. and Townshend, J.R.G. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science*. *342,850-853, DOI:10.1126/science.1244693*.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvindeko, A., Lewis, S.L., Canadell, J.G., Cias, P., Jackson, R.B., Pacala, S.W., McGuire, A.D., Piao, S., Rautiainen, A., Stich, S. and Hayes, D. (2011). A Large and Persistent Carbon Sink in the World's Forests. *Science. 333, 988-993, DOI:10.1126/science.1201609*.

Praene, J-P., Radanielina, H. and Rakotondramiarana, H.T. (2016). Dish Stirling System Potential Assesment for Eight Main Sites in Madagascar. Journal of Heat and Mass Transfer, 13(1), 119-141. <10.17654/HM013010119>. <hal-0117730>

Praene, J-P., David, M., Sinama, F., Morau, D. and Marc, O. (2011). Renewable energy: Progressing towards a net zero energy island, the case of Reunion island. Renewable and Sustainable Energy Reviews, doi:10.1016/j.rser.2011.08.007

Rodda, S.R., Thumaty, K.C., Jha, C.S. and Dadhwal, V.K. (2016). Seasonal Variations of Carbon Dioxide, Water Vapor and Energy Fluxes in Tropical Indian Mangroves. *Forests, 7, 35;doi:10.3390/f7020035*.

van der Werf, G.R., Randerson, J.T., Collatz, G.J. and Giglios, L. (2003). Carbon emissions from fires in tropical and subtropical ecosystems. *Global Change Biology, 9, 547-562*.

Vieilledent, G., Grinand, C. and Vaudry, R. (2013). Forecasting deforestation and carbon emissions in tropical developing countries facing demographic expansion: a case study in Madagascar. *Ecology and Evolution, 3(6):1702-1716*.

Ministry of Environments and Forests, (2010). Madagascar. Second national communication on climate change submitted under the United Nations Framework Convention on Climate Change. Executive summary. http://unfccc.int/resource/docs/natc/mdgnc2exsume.pdf

Ministry of Environment and Sustainable Development, (2010). Second National Communication of the Republic of Mauritius under the United Nations Framework Convention on Climate Change (UNFCCC). http://unfccc.int/resource/docs/natc/musnc2.pdf