TROPOSPHERIC OZONE CLIMATOLOGY OVER SOUTHERN AND EQUATORIAL AFRICA USING CLIMATE CHANGE PARAMETERS

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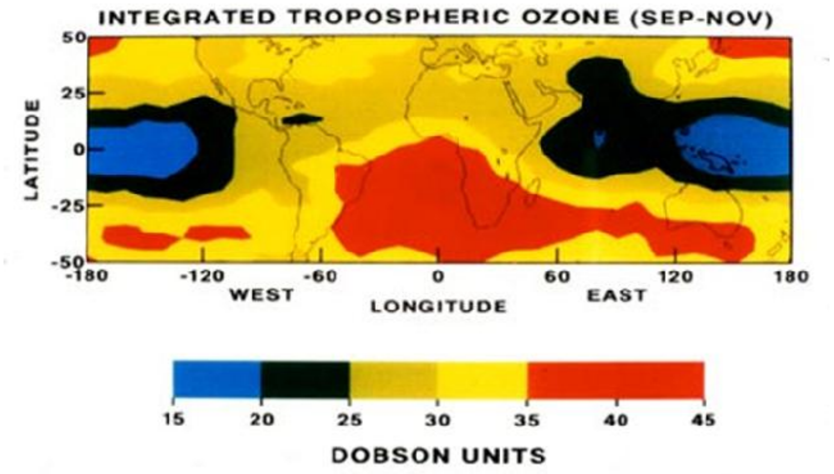
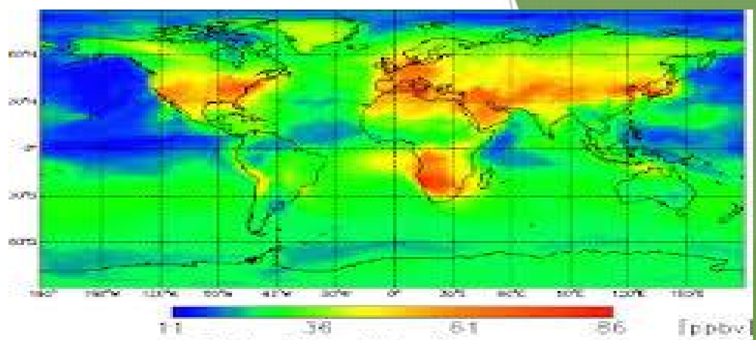
CONTENTS

Background

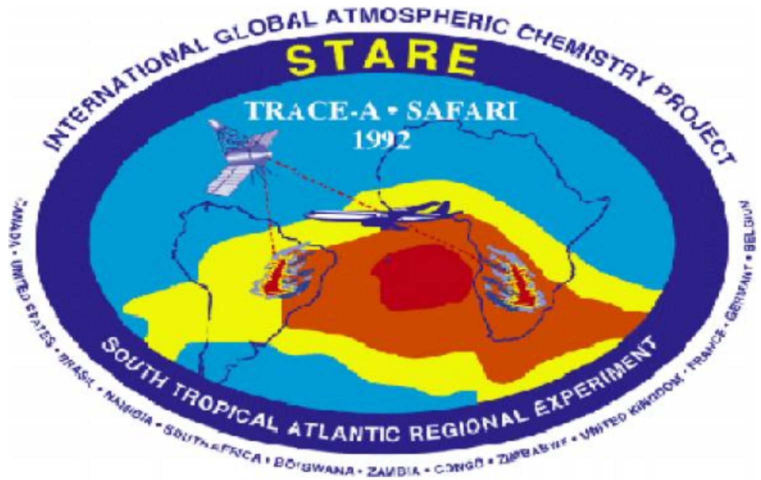
- Over the past 3 decades, tropospheric ozone concentrations have been increasing over the tropics, especially in central and southern Africa;
- Ozone as a greenhouse gas and secondary pollutant has negative effects on climate, on human health and the environment:
  - Global warming, climate radiative forcing;
  - Acute respiratory diseases children and aged people;
  - Damage to agricultural crops.
- Satellite images and ground based data show diverse contributing sources including **natural** (STE, biogenic and lightning emissions), and **man made** activities (biomass burning emissions, industrial and domestic emissions);
- The dynamic and trends of these contributing factors strongly depend on prevailing meteorological parameters;
- Since tropical and subtropical African regions are known as major sources of photochemical ozone precursors in the globe, change on climate parameters are likely to impact on ozone characteristics and trends.

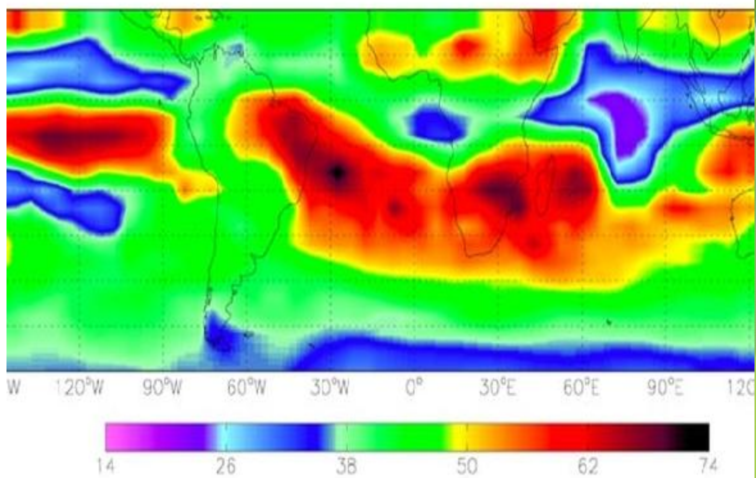




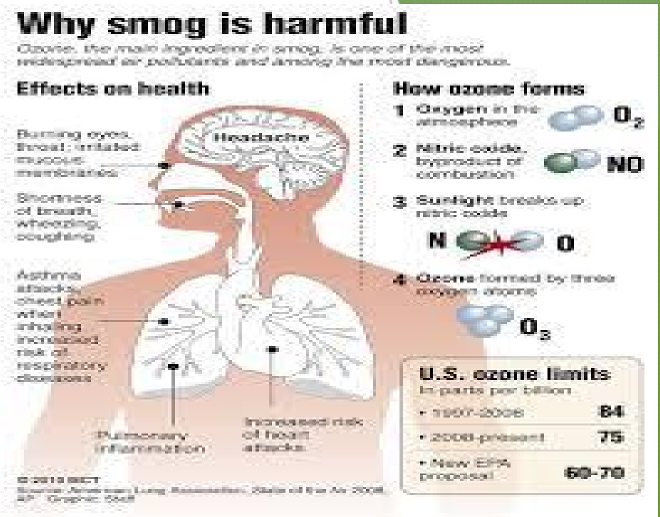
Global ambient ozone concentrations due to air pollution

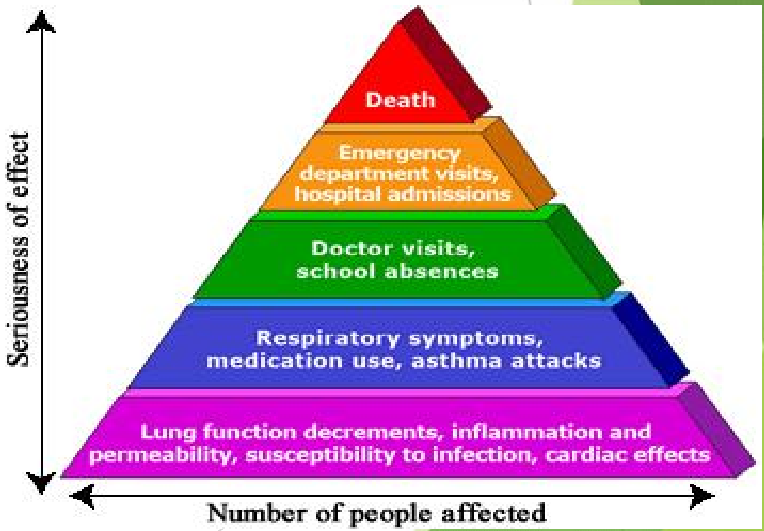
Elevated ozone levels over and downwind of biomass burning regions in the southern tropics, calculated by combining Aura satellite data with the GEOS-Chem atmospheric model. Image credit: NASA





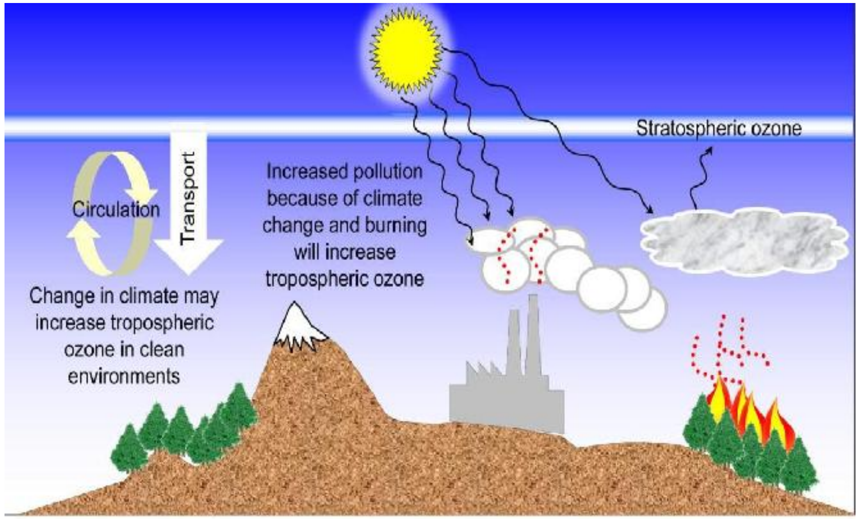
Effect on vegetation and human health

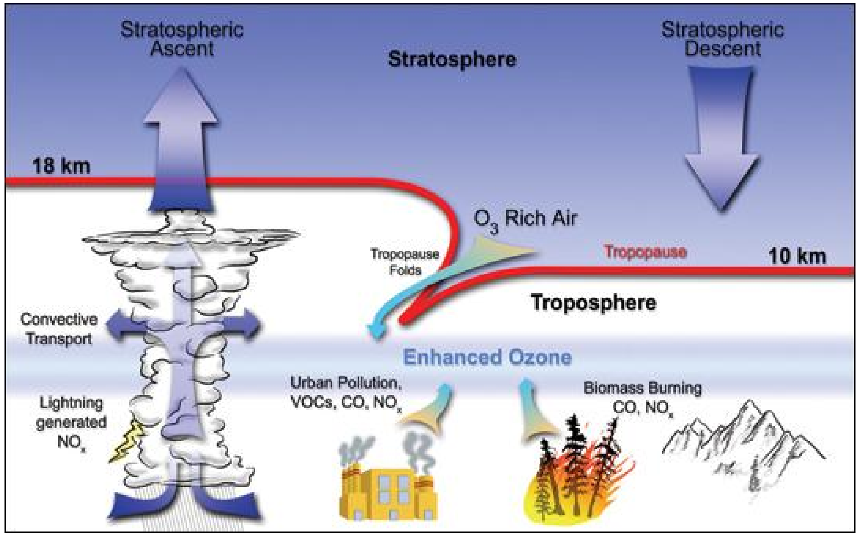


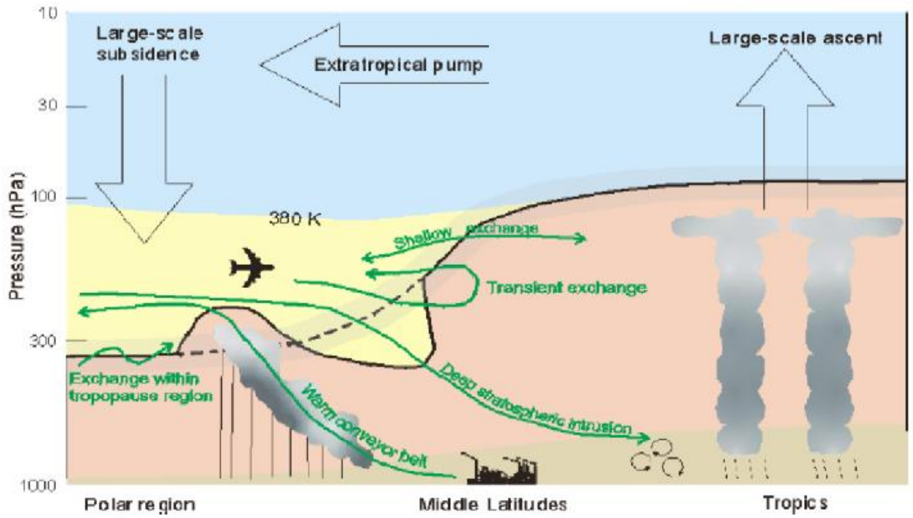


Pyramid of effects caused by ozone

Effect on climate

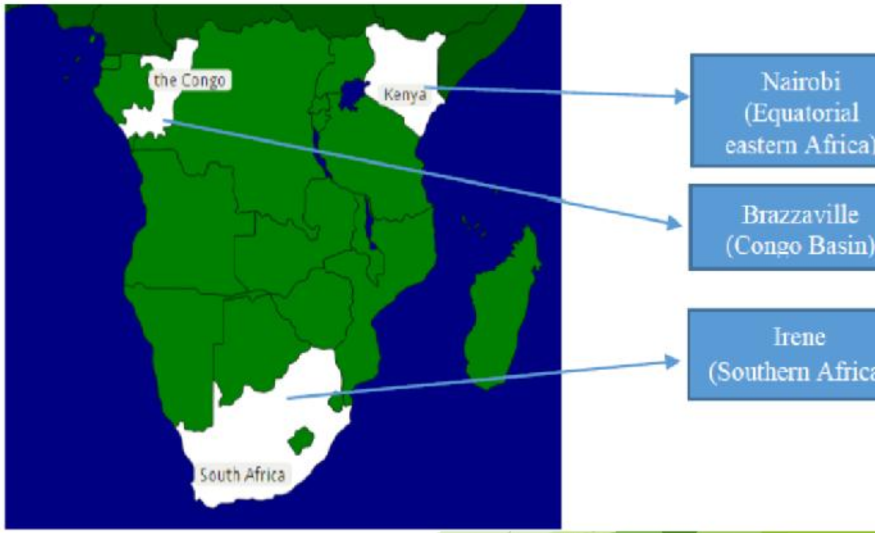






PURPOSE AND OBJECTIVES

- To assess tropospheric ozone characteristics and trends in the three climatic regions including southern Africa, the Congo basin and the eastern equatorial Africa;
- To assess the main contributing sources of tropospheric ozone, their dynamic and occurrence in individual location;
- To investigate the relationship between climatic factors and tropospheric ozone variation and distribution;
- To document and fill the existing gap on tropospheric ozone climatology with regard to their relationship with climate change parameters;
- To assess tropospheric ozone trends with regard to climate change parameters, and suggest suitable solutions for a better management strategy and climate change mitigation programme.



DATA AND METHOD

- Southern Hemisphere ADditional Ozonesondes (SHADOZ) data used from 1998-2013 for Irene (South Africa) and Nairobi (Kenya);
- Measurement of OZone by Airbus In-service airCraft' (MOZAIC) program MOZAIC data from 1998-2001 used for Brazzaville (Rep of Congo);
- Daily tropospheric ozone profiles from ground up to tropopause (~16 Km) for individual month selected and computed to assess horizontal and vertical variation of TTO;
- Monthly climate change parameters (temperature, humidity) computed to assess their horizontal and vertical variation in comparison with TTO variations;
- Ozone partial pressure computed to assess the dynamic factors contributing to ozone enhancement;
- A regression model performed to assess the relationship between TTO and climate change parameters (air temperature and relative humidity) as suggested by Akdemira *et al*. (2013) for Irene.
- Meteorological data from NCEP/NCAR reanalysis used to assess the role played by dynamic factors using for case studies (Brazzaville and Nairobi)
- Partial pressure (the fraction of the atmospheric pressure at a given altitude for which ozone is responsible) computed for individual case studies in winter and summer to assess STE intrusion into the troposphere through divergence and vorticity models (Nairobi);
- HYSPLIT_4 model analysis used to determine the origin of ozone precursors that affect ozone levels in Nairobi and Brazzaville.

RESULTS DISCUSSION

a) Irene (Southern Africa)

Table 3-1: Polynomial coefficient for TTO (DU), Air temperature (C°) and Relative Humidity (%) per layer

Layer (Km)	TTO (DU)	Air Temperature (°C)	Relative Humidity (%)
Surface -2	0.8979	0.9502	0.7074
2-4 km	0.9790	0.9179	0.9063
4-6 km	0.9609	0.6614	0.9698
6-8 km	0.9675	0.5657	0.9657
8-10 km	0.9668	0.6155	0.8890
10-12 km	0.9656	0.6670	0.8545
12-14	0.9590	0.7720	0.9026
14-16 km	0.9442	0.8297	0.7747

General regression model

$$Y = a0 + a1x1 + \cdots + amxm + \varepsilon \quad (1)$$

where ***Y*** is an objective variable (ozone concentrations);

m is the number of independent variables (meteorological variables);

xj are independent variables (Temperature, Relative humidity);

aj are regression coefficients (estimated using the least squares procedure);

ε is an error term associated with the regression analysis.

$$y = a0 + a1x1 + \cdots + a2x2 + \varepsilon, \quad (2)$$

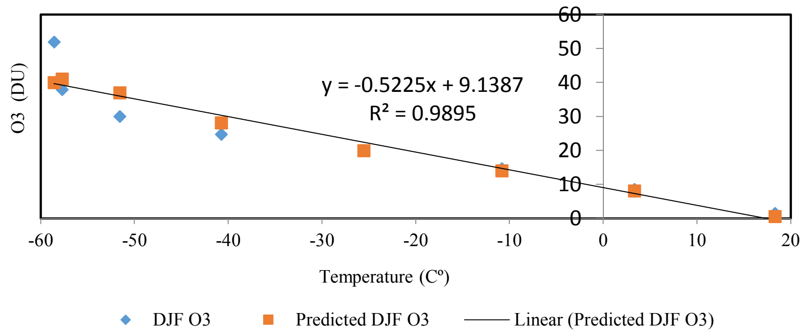
$$Ys = -8.47 - 0.79\, X_1 + 0.41\, X_2 + \varepsilon \quad (3)$$

$$Ya = -16.4 - 0.82\, X_1 + 0.62\, X_2 + \varepsilon \quad (4)$$

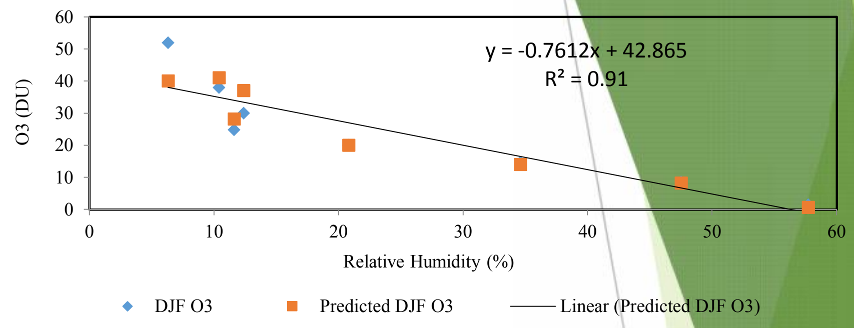
$$Y_w = 4.5 - 0.53X_1 + 0.04\, X_2 + \varepsilon \quad (5)$$

$$Yp = 7.02 - 0.68\, X1 + 0.08\, X_2 + \varepsilon \quad (6)$$

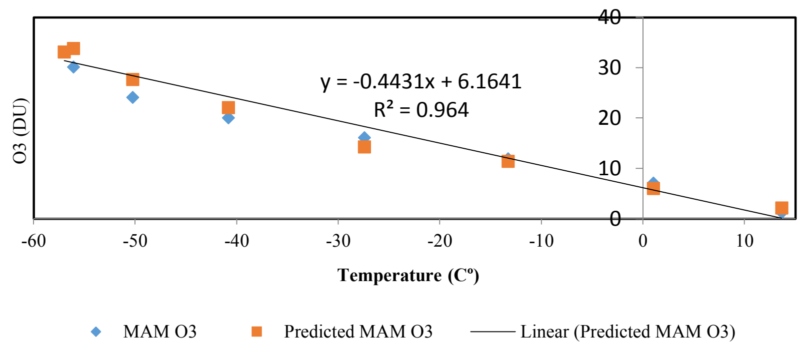
Where *Ys* = summer ozone concentrations
Ya = autumn ozone concentration
Yp =spring ozone concentration
Yw = winter ozone concentration
X_1 =air temperature
X_2 =relative humidity and
ε = an error term which can be associated with the regression analysis or data measurement.



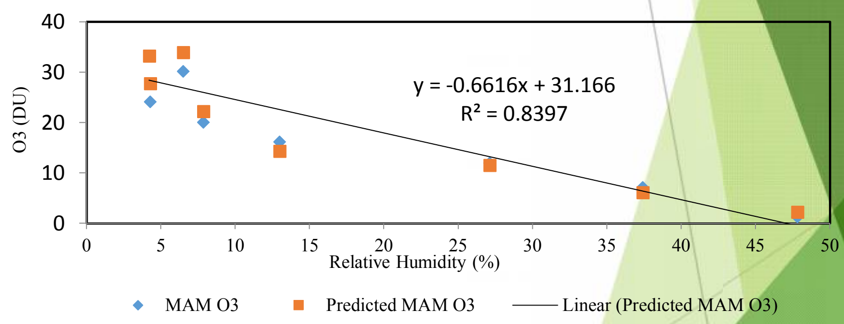
Linear regression model for summer ozone-temperature line fit plot



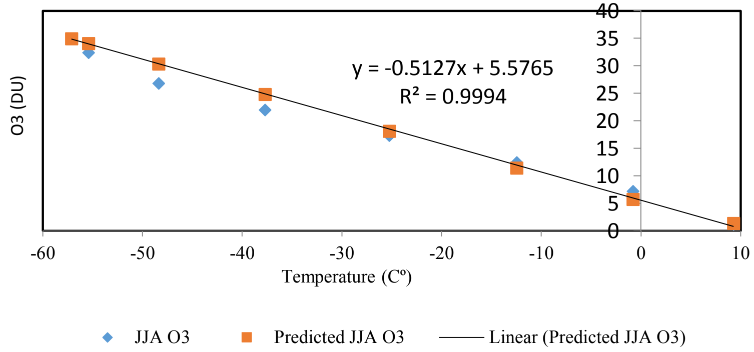
Linear regression model for summer Ozone- Relative humidity line fit plot



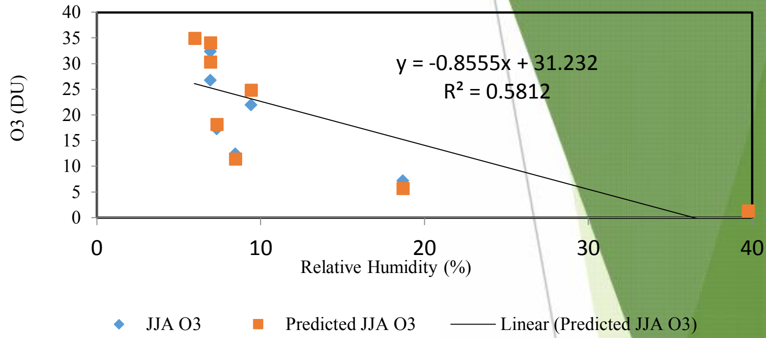
Linear regression model for autumn Ozone-Temperature line fit plot



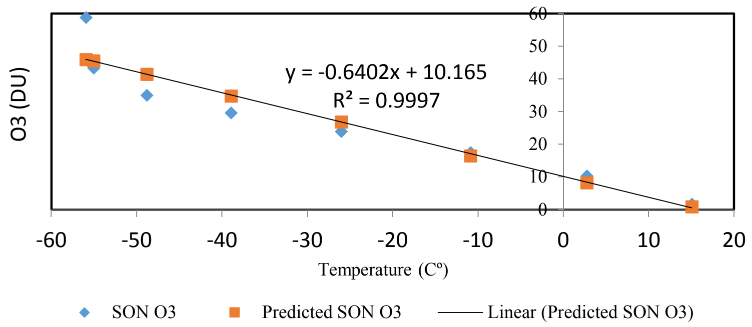
Linear regression model for autumn Ozone- Relative humidity line fit plot



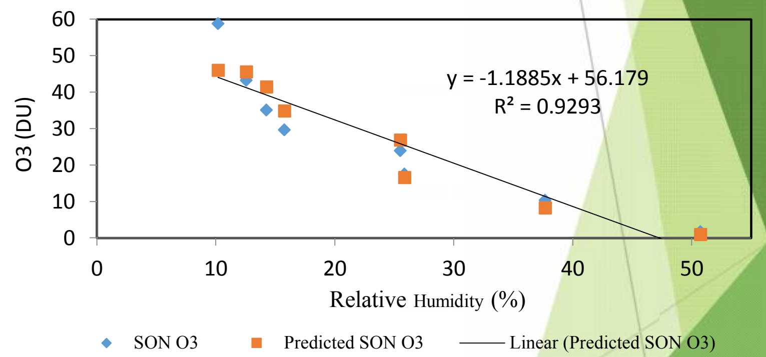
Linear regression model for winter Ozone- Temperature line fit plot



Linear regression model for winter Ozone- Relative humidity line fit plot



Linear regression model for spring Ozone- Temperature line fit plot



Linear regression model for spring Ozone- Relative humidity line fit plot

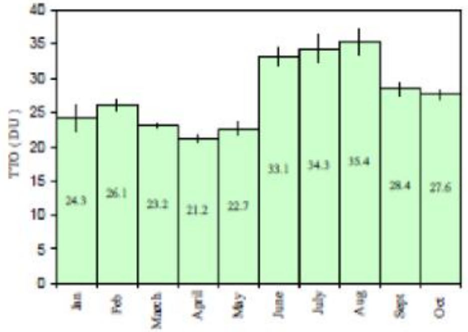
Correlation coefficient for TTO (DU), Air temperature (Cº) and Relative Humidity **(%)** per layer

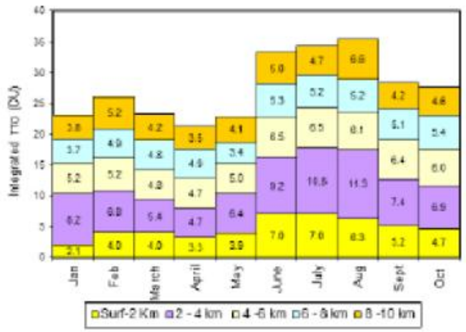
Layer (Km)	TTO (DU)	Air Temperature (˚C)	Relative Humidity (%)
Surface -2	0.8979	0.9502	0.7074
2-4 km	0.9790	0.9179	0.9063
4-6 km	0.9609	0.6614	0.9698
6-8 km	0.9675	0.5657	0.9657
8-10 km	0.9668	0.6155	0.8890
10-12 km	0.9656	0.6670	0.8545
12-14	0.9590	0.7720	0.9026
14-16 km	0.9442	0.8297	0.7747

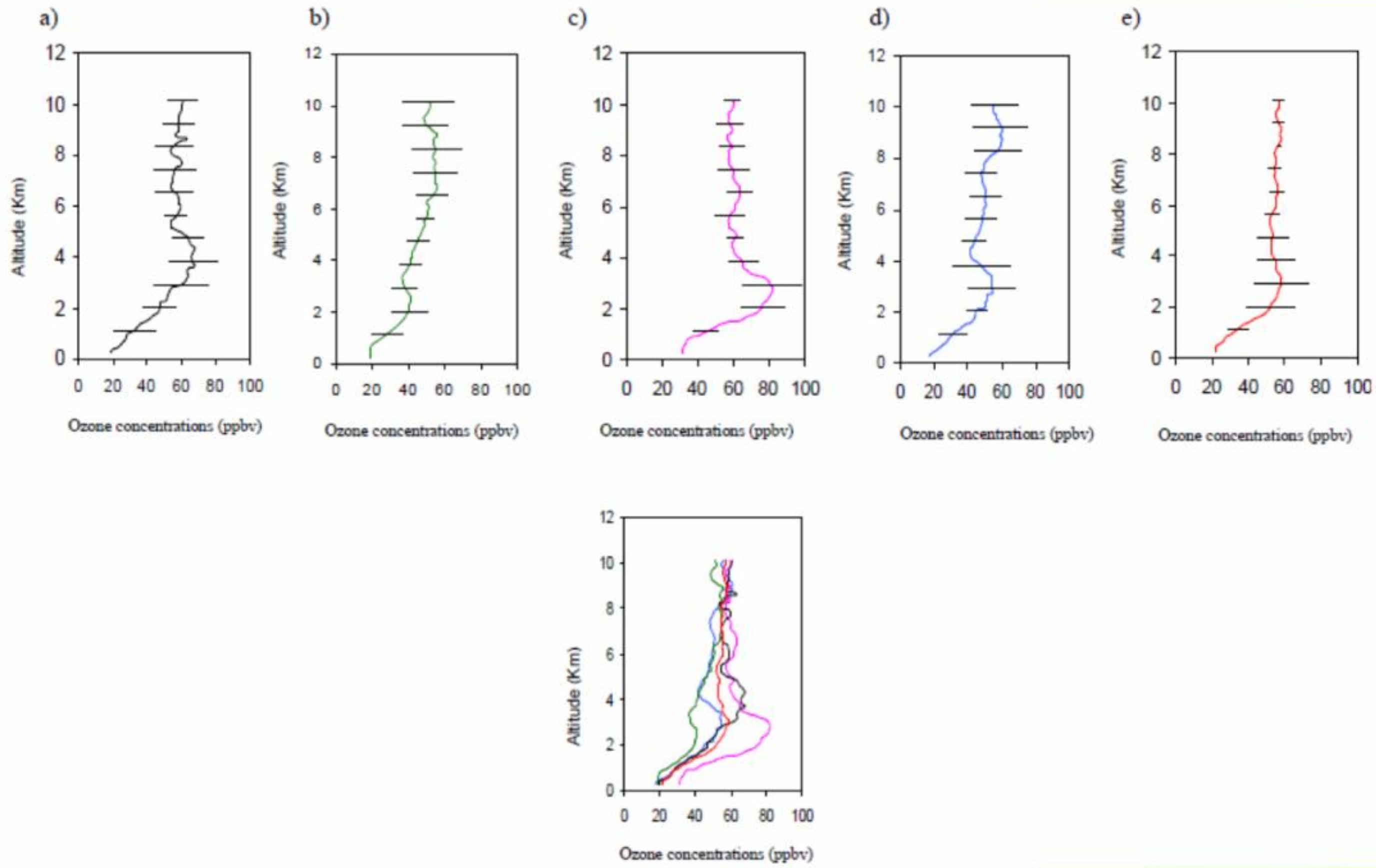
Seasonal regression coefficient for TTO and meteorological factors

Seasons	Regression coefficient (R^2)	
	Ozone /Temperature	Ozone /Relative humidity
Winter	0.99	0.91
Autumn	0.96	0.94
Spring	0.99	0.58
Summer	0.99	0.92

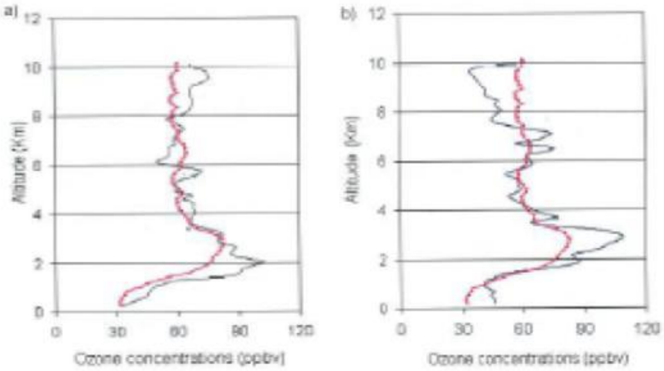
b) Brazzaville (Congo Basin)







Mean seasonal vertical of ozone (ppbv) for: a) summer, b) autumn c) winter, d) spring and e) mean annual vertical of ozone (ppbv) over the period 1998-2001, f) Mean seasonal vertical of ozone profiles (ppbv) compared to annual profile for the same period, standard deviation bars plotted at interval of 500 m show ozone variation at different layers.



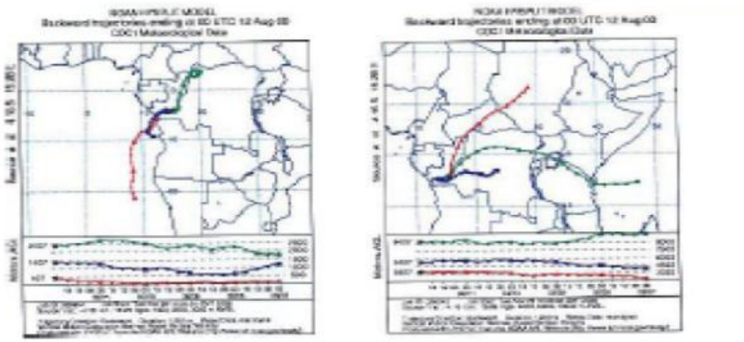
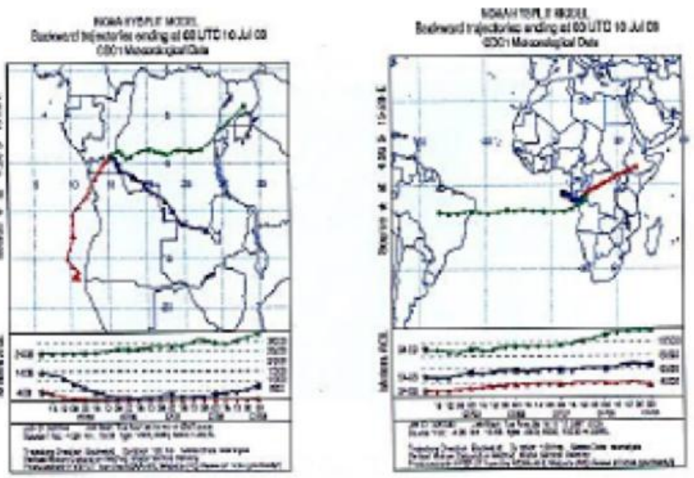


Fig. 4-9. Composite plot of five-day back trajectory HYSPLIT model results for 12 August showing lower trajectory at 1 km (red) 2 km (blue) and 3 km (green) and mid troposphere trajectories right at 4 km red 5 km blue and 6 km (green)



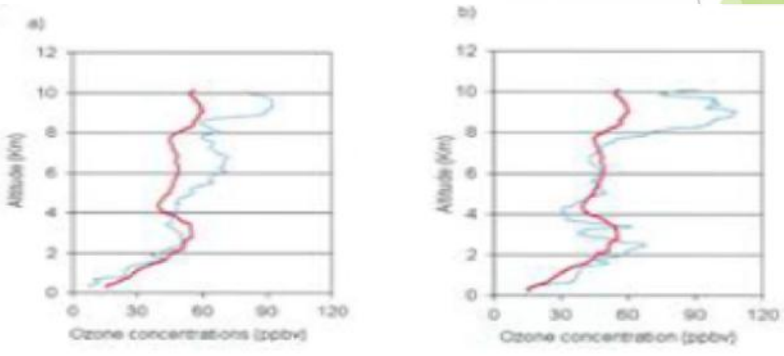
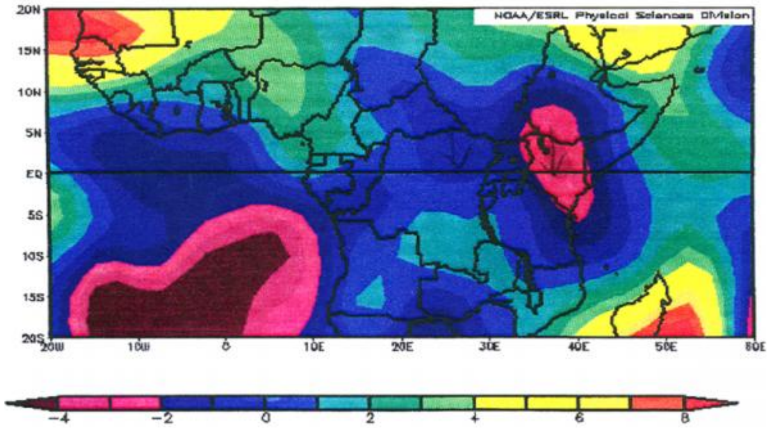
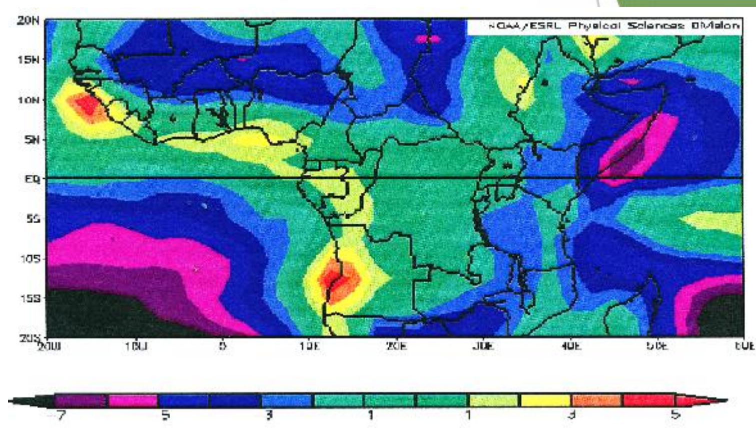


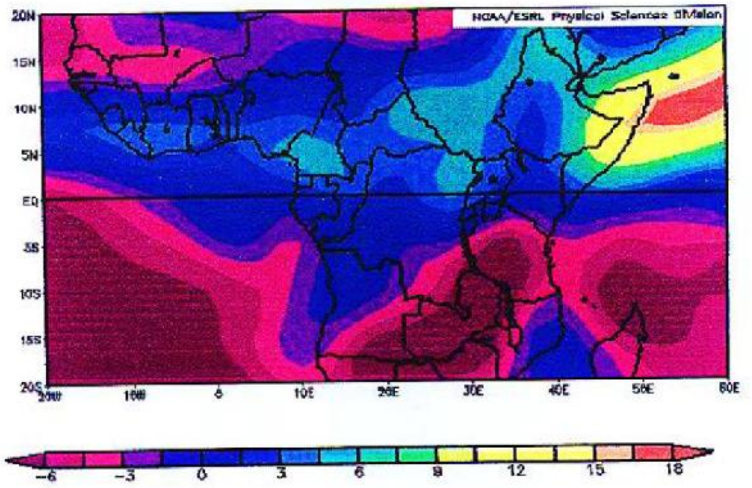
Fig. 4-12. Comparison of mean summer profile (red) with individual ozone profiles (blue) on 8 February 1999 (a) and 26 February 2001 (b).



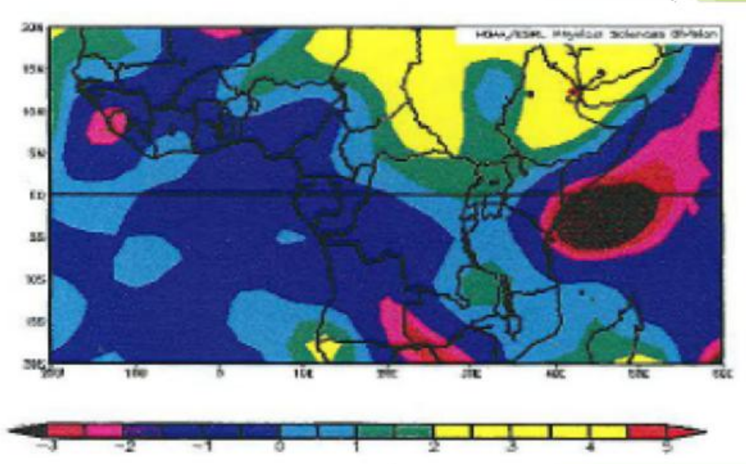
Meridional winds (ms-1) plotted at 300 hPa for the period 21-26 February 2001.
Sources: http:\www.cdc.noaa.gov/cdc/reanalysis.shtml



Zonal winds (ms-1) plotted at 500 hPa for the period 21-26 February 200.
Sources: http:\www.cdc.noaa.gov/cdc/reanalysis.shtml

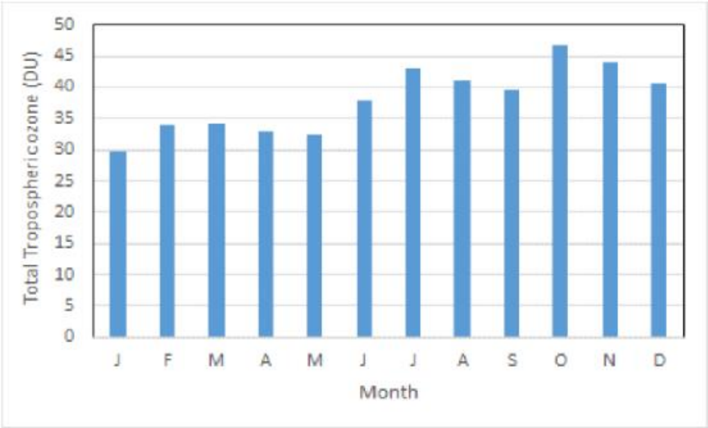


Zonal winds (ms-1) plotted at 850 hPa for the period 7-12 August 2000.
Sources: http:\

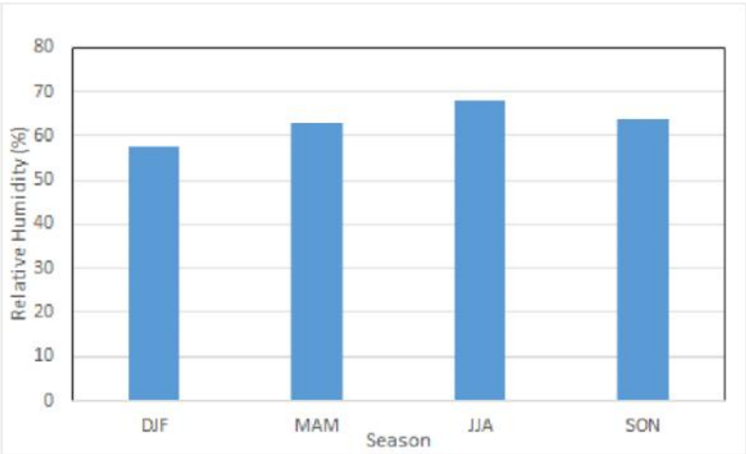


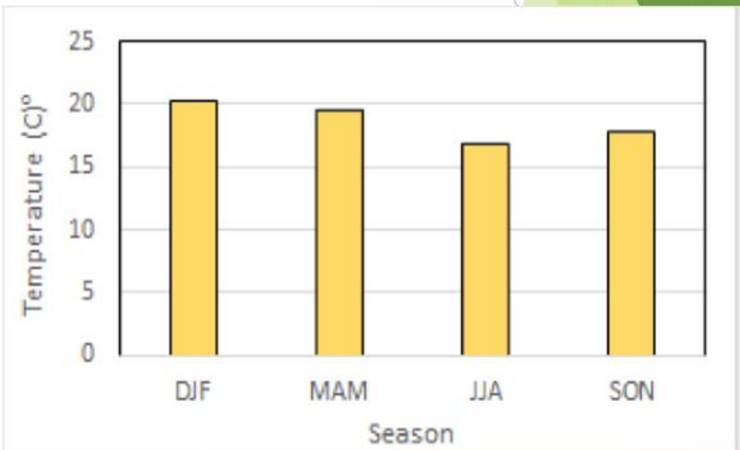
. Zonal wind winds (ms-1) plotted at 850 hPa for the period 21-26 February 2001.

c)Nairobi (Eastern Equatorial Africa)



Mean Monthly Total Tropospheric Ozone column variation for the period 1998-2013.





Tropospheric ozone concentration varies according to the logarithmic equation as follows:

$$Y = t \ln(x) + c$$

and relative humidity varies in linear equation

$$Y' = ax' + b$$

with Y and Y' representing the barometric pressure at which ozone concentration and relative humidity have the same mixing ration (m).

t = ozone concentration lapse rate as function of barometric pressure,

a = relative humidity lapse rate as function of barometric pressure

x = ozone concentration (ppbv)

x' = relative humidity in percent

b = relative humidity coefficient

c = ozone coefficient

The intersection point of these parameters is found through the equation (3) where we suppose

$$Y=Y' \quad (3)$$

and we obtain the equality

$$t \ln(x) + c = ax' + b \quad (4)$$

with (x, y) and (x', y') represent the mixing ratio point (M) coordinates.

Because Y = Y' M = (x,y; x'y') then

$$M = (x, y; x', y) \quad (5)$$

Seasonal models for the determination of common mixing ratio as function of barometric pressure.

Seasons	Y	Y'	R^2	R'^2
DJF	-302 ln(x) +1653	10.969 x' + 149	0.66	0.92
MAM	-278.1 ln(x) + 1576	9.6254 x' + 162	0.66	0.90
JJA	-229.4 ln(x) +1397	8.1344 x' + 193	0.57	0.81
SON	-268.3 ln(x) + 1559	8.6185 x' + 179	0.74	0.85

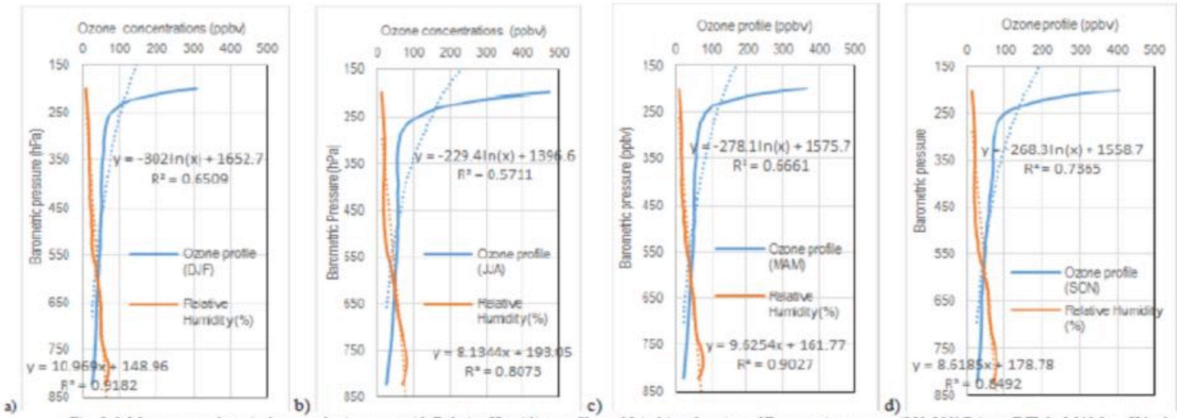


Fig. 5-6. Mean seasonal vertical tropospheric ozone with Relative Humidity profiles at Nairobi as function of Barometric pressure (850-200hPa): a= DJF; b=MAM; c=JJA; d=SON

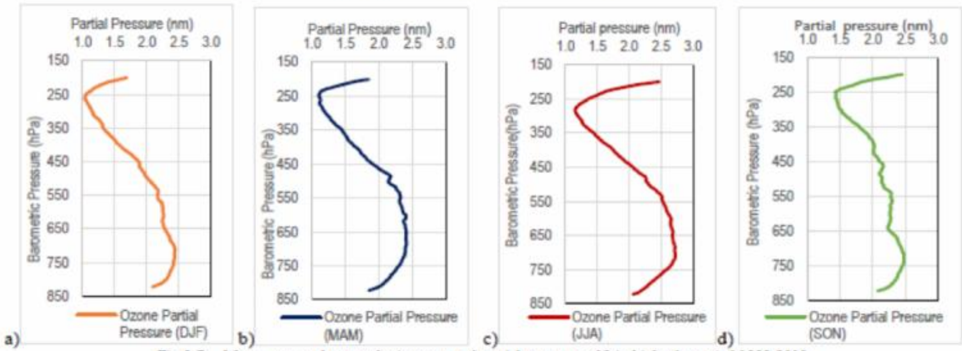


Fig.5-7. Mean seasonal tropospheric ozone and partial pressure at Nairobi for the period 1998-2013

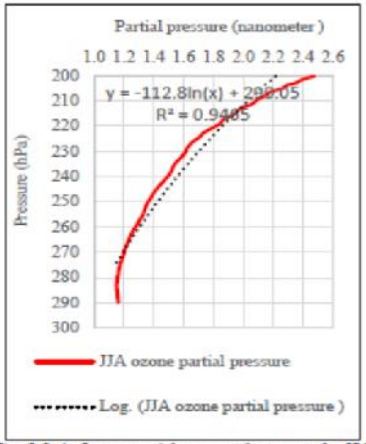


Fig. 5-8 c). Ozone partial pressure lapse rate for JJA

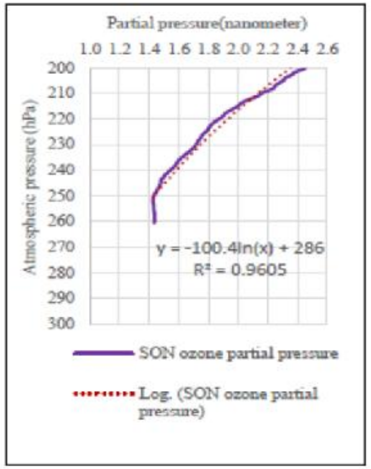


Fig. 5-8 d). Ozone partial pressure lapse rate for SON

Table 5-4. presents seasonal ozone partial pre
inversion variation at 200 hPa.

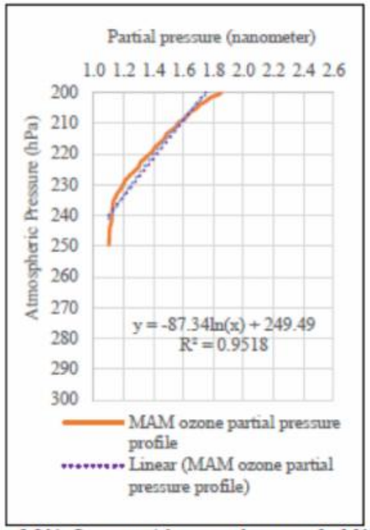


Fig. 5-8 b). Ozone partial pressure lapse rate for MAM

$$\frac{dT}{dZ} = \frac{1}{Cp\,\rho}\left(\frac{dp}{dz}\right)$$

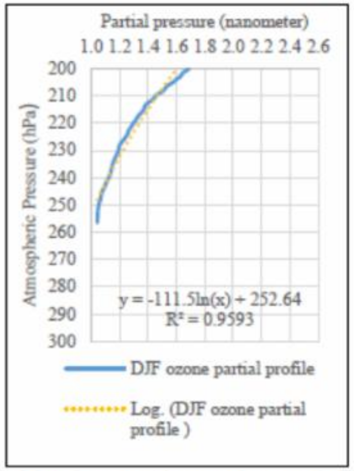


Fig. 5-8 a). Ozone partial pressure lapse rate for DJF

Table 5-2. Seasonal ozone partial pressure inversion point variation as function of barometric pressure

Season	Ozone Partial pressure	Barometric Pressure inversion point (hPa)
DJF	1.0	256
MAM	1.1	250
JJA	1.2	290
SON	1.0	261

Table 5-3: Seasonal ozone partial pressure inversion variation at 200 hPa

Season	Barometric Pressure with high value (hPa)	Ozone Partial pressure
DJF	200	1.0
MAM	200	1.8
JJA	200	2.5
SON	200	2.5

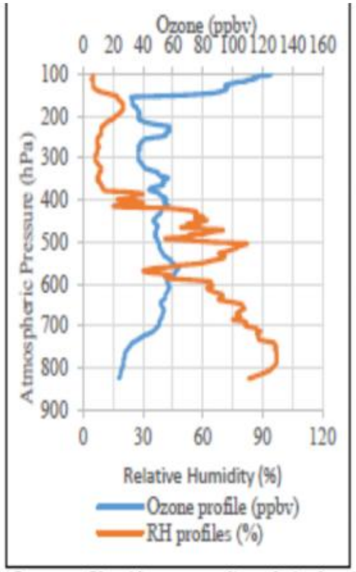


Fig.5-9. Ozone profile with corresponding relative humidity on 25 July 2001 at Nairobi.

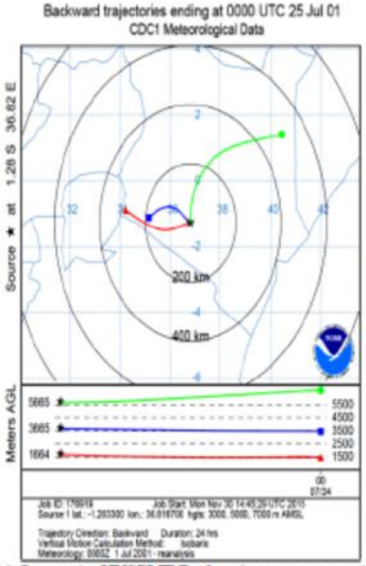


Fig. 5-10 a) Composite HYSPLIT Back trajectory representing the air mass pathway at three different altitude 3000 m, 5000 m and 7000 m over Nairobi on 25/07/2001.

Sources: http://ready.arl.noaa.gov

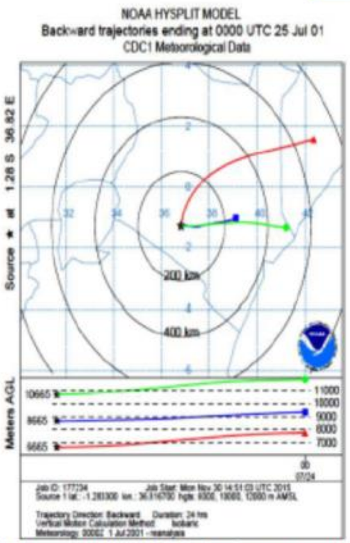


Fig. 5-10 b) Composite HYSPLIT Back trajectory representing the air mass pathway at three different altitude 10000 m, 8000 m and 6000 m over Nairobi on 25/07/2001.

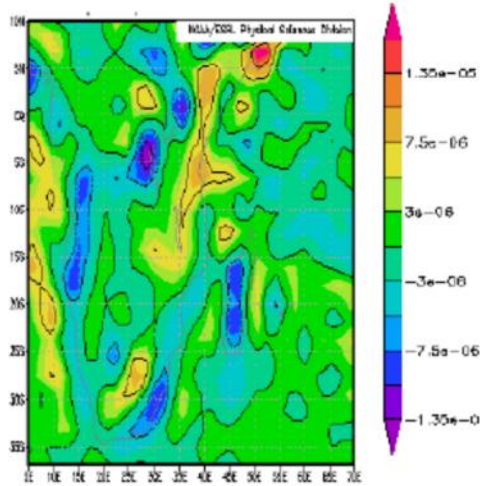


Fig. 5-11. Mean Eddy divergence average over June and July 2001

Sources:

http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html

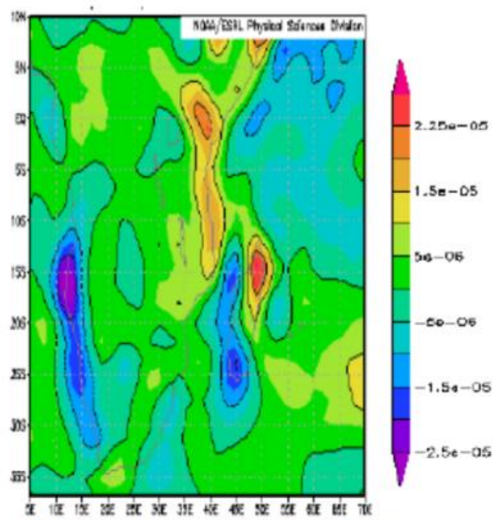


Fig. 5-12 Vorticity Mean eddy vorticity June-July 2001

Sources

http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html

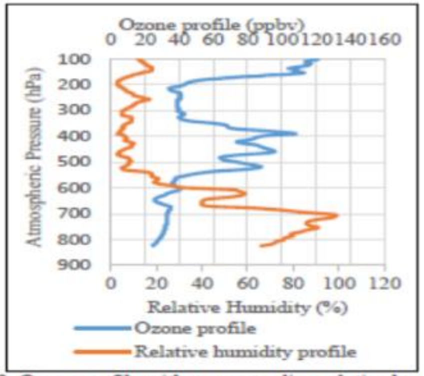


Fig. 5-13. Ozone profile with corresponding relative humidity on 09/October 2002 at Nairobi.

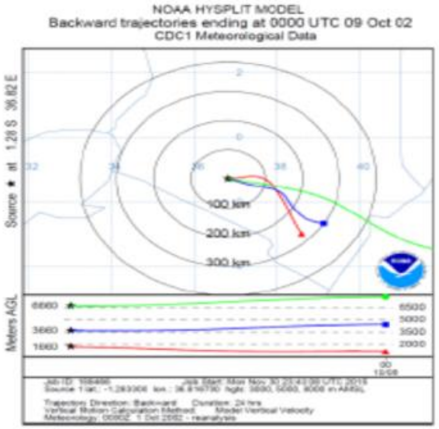


Fig. 5-14 a) Composite HYSPLIT Back trajectory representing the air mass pathway at three different altitude 3000 m, 5000 m and 7000 m over Nairobi on 25/07/2001.

Sources: http://ready.arl.noaa.gov

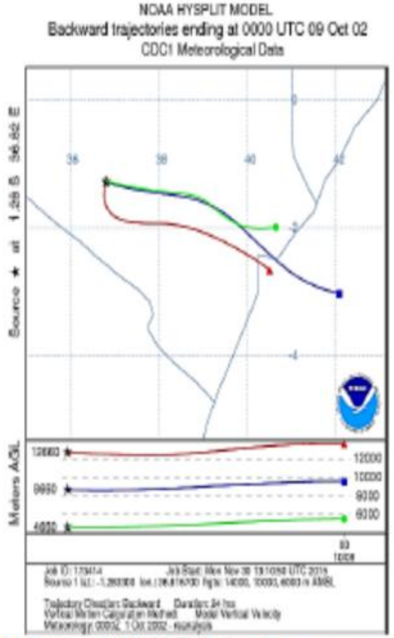


Fig. 5-14 b) Composite HYSPLIT Back trajectory representing the air mass pathway at three different altitude 6000 m, 10000 m and 14000m m over Nairobi on 9/10/2002.

Sources: http://ready.arl.noaa.gov

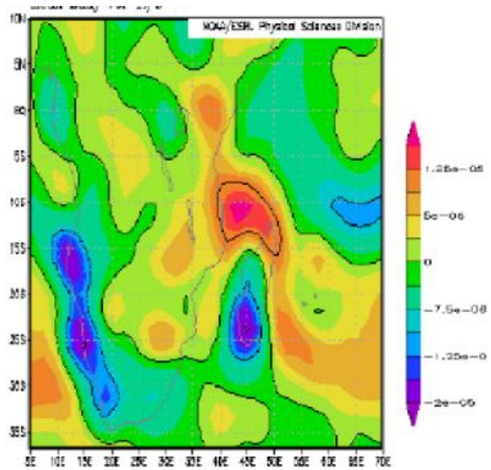


Fig. 5-16 Vorticity Mean eddy vorticity June-July 2001
Sources
http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html

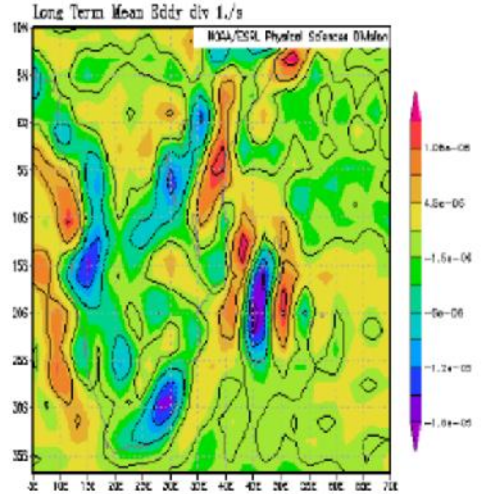


Fig.5-15. Mean Eddy divergence average over June and July 2001
Sources:
http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html
DC Derived NCEP Reanalysis Products Sigma Level Data GrADS image

Conclusion and recommendations

- Stratospheric tropospheric exchange (STE), Biomass burning (BB), anthropogenic emissions (AE), biogenic emissions (BE) and lightning emissions (LE), contribute to ozone enhancement over equatorial and subtropical region;
- Their dynamic as well as the occurrence strongly depend on prevailing meteorological factors which are exacerbate by climate change.
- Horizontal and vertical TTO concentrations are due to increase by ~10 to 15% by decades and will impact on regional and global climate.
- In Eastern Africa STE occurrence in all seasons may contribute to strong radiative heating due to latent heat release at low latitude and extend rainfall period (floods), increase lightning emissions on ozone precursors, increase biogenic emissions, sea surface temperature increase, etc.
- Change in global circulation due to STE occurrence will cause drought in southern Africa due to increase in temperatures and and decrease in relative humidity (less cloud formation due to increase in wind intensity and frequency).
- Eastern Equatorial African region is more vulnerable to ozone increase and climate change consequences as it is influenced by different climate future (El nino, movement of the ITCZ, monsoonal streams from Indian Ocean,etc.)

Conclusion and recommendations (continued)

- Ozone results and studies in Africa still relying more on satellite data. The accuracy of the findings could be well understood if compared with ground based data.
- Hence, implementation of ambient air quality monitoring stations for the measurement of greenhouse gases including carbon dioxide, methane, and nitrous oxide and ozone in mega cities over the continent may be a milestone toward the identification and control of local sources and their mitigation.

FUTURE WORK

- Inventory of biomass burning and biogenic emissions Congo basin and east Africa may also contribute to fill the gap on the existing data and consequently ensure future scenarios on tropospheric ozone concentrations trends.

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Thanks you
for your
attention