No man is an island…we are connected through the atmosphere

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Abstract

Besides the obvious (as an atmospheric chemist presenting this inaugural address) – that we are all connected through the atmosphere (i.e. we all breathe the same air) – this presentation will also focus on the other, more general, obvious aspect of this famous phrase/poem – the interconnectedness of people! This address takes a walk through the foundation, the extended family, the friends, the current family, the inspiration, the academic fathers, the colleagues, the students and the collaborators, without whom this journey of becoming a professor would not have been possible. My atmospheric chemistry research activities are explored through the main collaborative national and international programmes/projects through which my research is conducted, i.e. i) DEBITS (Deposition of Biogeochemical Important Trace Species) programme / INDAAF (International Network to study Deposition and Atmospheric Composition in Africa); ii) Welgegund supersite; and iii) other smaller projects conducted in collaboration with industry and government. The presentation shows how a study of the chemical composition of rain and wet deposition of atmospheric pollutants in the South African interior reflects the changes in composition of the atmosphere due to changes in anthropogenic (human) activities, while the long-term trends of inorganic gaseous species in this region also revealed the impacts of increased anthropogenic activities and population growth with an associated increase in energy demand on concentrations of atmospheric pollutants. Finally, it is illustrated how extensive collaborative research led to a comprehensive assessment of surface ozone in South Africa, which highlighted the regional problem associated with surface ozone levels in southern Africa due the impacts of anthropogenic activities (e.g. household combustion) and regional wild fires. The latter study also showed that the complex chemistry associated with atmospheric ozone must be considered when

developing an effective management plan to reduce surface ozone concentrations in South Africa.

1. Introduction

Besides the obvious (as an atmospheric chemist/scientist presenting this inaugural address) – that we are all connected through the atmosphere (i.e. we all breathe the same air) – this inaugural address will also focus on the other, more general, obvious aspect of this famous phrase – the interconnectedness of people! The inspiration for the title of this presentation comes from a cartoon of one of my favourite cartoonists (also an environmentalist), Gary Larson, which are presented in **Figure 1**. In this cartoon the absurdity/unlikeliness of a man being an island is illustrated trough a man being literally portrayed as an island that is inhabited by a tribe. However, this famous phrase comes from a poem written by John Donne, who is considered one of the most preeminent metaphysical poets of the 17th century, which he presented during a sermon in 1642 as the Dean of St Paul's Cathedral. This saying is generally defined as meaning that "no one is self-sufficient; everyone relies on others" (dictionary.com). According to audience comments on this phrase on google.com, it deals with the concept that humans are social beings that needs contact and interaction with other people, and that we do badly when in an isolated stated. It explores the idea of the interconnectedness of people, as well as the interconnectedness of people with God.

In view of the above, this inaugural address will explore my journey of becoming a professor by considering the influences of and interactions with people in my life. This address takes a walk through the foundation, the new foundation, the extended family, the friends, the inspiration, the academic fathers, the colleagues, the students and the collaborators, without whom my professorship would not have been possible. My atmospheric chemistry research activities are explored through the main collaborative national and international programmes/projects through which my research is conducted, while highlights from my research will illustrate how we are connected through the atmosphere and in what manner humans are changing the chemical composition of the atmosphere. Finally, it is shown how extensive collaborative research led to a comprehensive assessment of surface ozone in South Africa, which

highlighted the regional problem associated with surface ozone levels in southern Africa due the impacts of anthropogenic (human) activities.

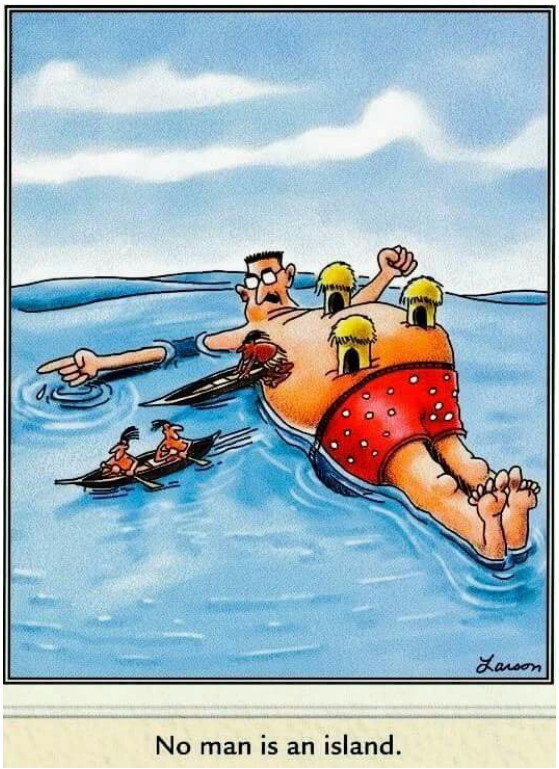


Figure 1: No man is an island cartoon by Gary Larson from the single-panel cartoon series The Far Side gallery

2. The influence of people

2.1 The Foundation (Mother, Father and three sisters)

Of course, the journey starts with the solid foundation that was laid in the household in which I grew up, which moulded me into the person that I am today. My mother, Lettie, and father, Buks, always inspired, encouraged and supported me and my sisters, Amanda, Lindy and Annelize, in our endeavours, while they created opportunities for us to grow and achieve our dreams. We were taught good work ethics and to always keep our feet firmly on the ground no matter our achievements.

2.2. The New Foundation (the life source)

My new foundation is my current close family, i.e. my wife Cecile and our two boys Pieter-Jacob and Emile. They are my life source, my rock and the reason to get up in the morning. Everything I do, I do for them. They are the people that are keeping me firmly grounded and “cutting me down to size”. I also want to educate my children through my example and lay the same foundation for them as was laid for me in the household in which I grew up.

2.3 The Extended Family (in-laws)

Once one gets married, your family is expanded through the new family that is brought into your life from your spouse. I am very fortunate to have the most wonderful extended family, i.e. my mother-in-law, Prof Annette, sister-in-law, Louisemarie and brother-in-law, Jaco, who always supported me ever since they have entered into my life.

2.4 The Friends

The saying “no man is an island” is probably the easiest understood if one considers your friends. My three closest friends are Lourens, Mynhard and Colin with whom I have been friends for >25 years and consider to be my brothers. They provided the distractions from day-to-day business and recharged my batteries through having a braai, drinking a beer in Broken Pot and spending numerous hours on PlayStation (FIFA must be especially mentioned).

2.5 The Inspiration (Mr Bovey)

The role of a good, passionate and inspirational teacher in your life cannot be underestimated. Mr Bovey was the best teacher that I have encountered during my years in school. He taught physical science and he is the person who inspired me to

become a chemist. I would not have pursued my academic career in Chemistry without the influence of Mr Bovey (and his life lessons and quirky humour!).

2.6 The Academic Fathers (Profs Breet and Pienaar)

I am fortunate to have two passionate and inspirational academic fathers, i.e. Prof Ernst Breet and Prof Kobus Pienaar who supervised my postgraduate studies. Although their roles and influence in becoming a professor are obvious, they were more than just supervisors – they became my best friends and confidants! Profs Breet and Pienaar taught me to be meticulous when it comes to attention to detail, while Prof Pienaar also trusted me and gave me the opportunity to become co-group leader of the research group that he started, i.e. the Atmospheric Chemistry Research Group (ACRG).

2.7 The Colleagues (partners)

I had the privilege of having the best close colleagues (partners) from the beginning of my academic career. Paul Beukes and I were co-group leaders of the ACRG and we shared the same vision for our research. We had a wonderful relationship, which was closer to a brotherhood, and we collaborated seamlessly together. This baton was passed on to one of our old PhD students, Kerneels Jaars, with whom I am very excited to continue my journey in the research field of atmospheric chemistry. Another close colleague that needs special mentioning is Colin Read, who I considered a great mentor with regard to my teaching and learning endeavours. Colin is a passionate and inspirational teacher (and friend)!

2.8 The Students

People sometimes jokingly remarks that a university would be a better place without the students. This a view that I can confidently not agree with from my experience during my career at the North-West University. There would be no academic career

without all the students whose postgraduate studies I supervised/co-supervised, which include 17 PhD students, 25 MSc students and four post-doctoral students. They were/are the heartbeat of the ACRG. Their enthusiasm, inquisitiveness and good work ethic inspire!

2.9 The Collaborators

Scientific research cannot be conducted in isolation (no man is an island!). The ACRG has several national and international collaborators at academic/research institutions, as well as in industry and government. I consider all my collaborators as close partners who are part of my research team, while we have mutually beneficial relationships. Together we identify the most relevant questions in our research field, which we aim to answer through inclusive collaboration.

3. The main collaborative projects

My atmospheric chemistry research activities are explored through the main collaborative national and international programmes/projects through which my research is conducted, i.e. i) DEBITS (Deposition of Biogeochemical Important Trace Species) programme / INDAAF (International Network to study Deposition and Atmospheric Composition in Africa); ii) Welgegund supersite; and iii) other smaller projects conducted in collaboration with industry and government.

3.1 DEBITS/INDAAF

DEBITS began in 1990 and it is a programme that is endorsed by the International Global Atmospheric Chemistry (IGAC) project of the World Meteorological Organisation (WMO). The international DEBITS network comprises 25 monitoring stations all around the tropical belt of the earth. The African component of DEBITS is called INDAAF. This programme has also been linked to the International Nitrogen Initiative (INI), while it is also included in the Integrated Nitrogen Studies in Africa

(INSA) project that facilitates researcher mobilisation between European and African researchers. Research in this project is conducted in collaboration with Laboratoire d' Aerologie group at the Paul Sabatier University in Toulouse, France, while DEBITS SA was financially supported by Eskom and Sasol up until the end of 2017.

DEBITS in South Africa (DEBITS SA) was developed to monitor deposition and potential long-term impacts of important trace species emitted in southern Africa. The main aims of DEBITS SA are i) to determine the regional scale atmospheric budgets of key pollutant species – assessment of atmospheric C, S and N cycles; ii) to measure the long-term atmospheric removal rates through dry and wet deposition of biogeochemical important trace species; and (iii) to provide data on deposition that can be related to impact studies of key pollutants on ecosystems (e.g. crops and natural vegetation) and hydrology (e.g. ground- and surface water). In **Figure 2** the DEBITS SA sites are presented, which are considered to be regional background sites, with the exception of the Vaal Triangle (VT) site. Amersfoort (AF) is in proximity of the largest point sources in the industrialised Highveld, while Skukuza (SK) and Louis Trichardt (LT) are rural background sites on the main anticyclonic recirculation path of air masses passing over this region. Measurements at these sites were discontinued at the end of 2017 due financial constraints. DEBITS SA will, however, continue within the Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) research infrastructure of the Department of Science and Innovation.

Measurements conducted at DEBITS SA sites include:

1) Concentrations of atmospheric inorganic gaseous species, i.e. sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), ammonia (NH_3) and nitric acid (HNO_3) with passive samplers. SO_2, NO_2 and O_3 are criteria atmospheric pollutants in South Africa and are mainly associated with industrial and other anthropogenic (human) activities.

2) Chemical composition of precipitation (rain) through collection of rain events with wet-only samplers. Chemical species determined include sulphate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+), chloride (Cl^-), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and water-soluble organic acids. pH and conductivity of rain samples are also determined.

3) Chemical composition of atmospheric aerosols through collection of particulate matter (PM) with Mini-Vol^{TM} samplers. The same chemical species determined in rain samples are determined, while particulate organic- and elemental carbon (OC and EC) are also measured.

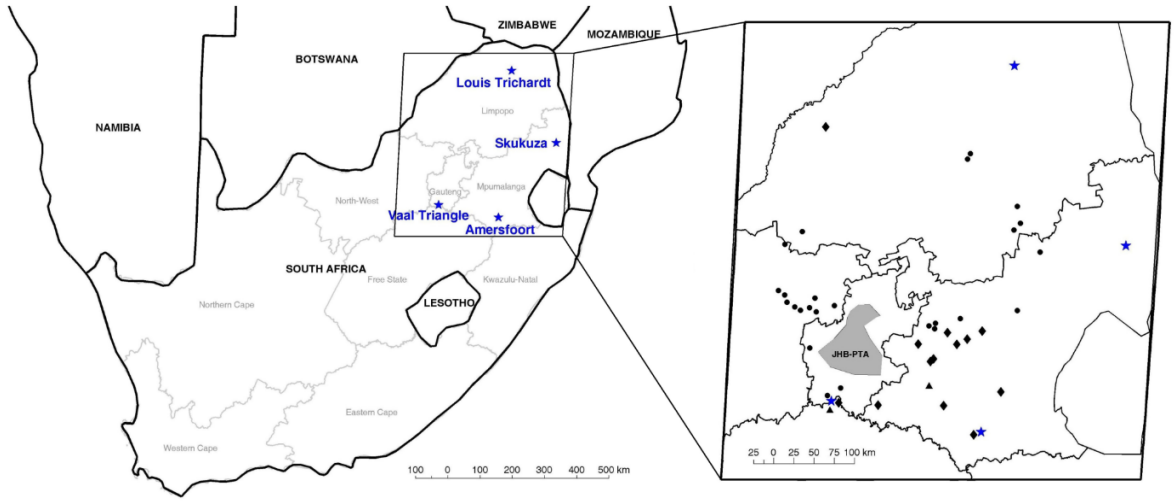


Figure 2: Locations of the South African IDAF sites. The enlarged section indicates the Johannesburg-Pretoria metropolitan area with a grey shade, DEBITS sites are indicated with a star, petrochemical industries with a triangle, coal-fired power stations with a diamond and pyrometallurgical industries with a circle

In the subsequent section I would like to show how long-term measurements of rain chemistry and inorganic gaseous species reflects changes in composition of the atmosphere due to changes in anthropogenic (human) activities.

Rain chemistry and wet deposition

A study of rain chemistry and wet deposition answers the questions i) how are we changing the atmosphere? and (ii) what is the impact thereof? Chemical composition of rain reflects the interacting physical and chemical mechanisms in the atmosphere, i.e. emissions, transport, chemical reactions and removal, as well as changes in composition of the atmosphere due to changes in anthropogenic activities, meteorology and climate. In addition, wet deposition (rain) also delivers acid and acidifying compounds to the earth's surface, e.g. S and N associated with human-induced acidity. In **Table 1** the ionic concentrations and fluxes of wet deposition, as well as the averaged pH values determined at the South African INDAAF sites in the

interior of South Africa from 2009 to 2014 are presented. SO_4^{2-} was the most abundant ionic species measured at the four sites. Since S emissions in southern Africa are mostly attributed to anthropogenic activities, it is evident that these activities have a major influence on the atmospheric chemical processes in the region. The sites closer to industrial sources had significantly larger concentrations of SO_4^{2-}. The second and third most abundant species were NO_3^- and NH_4^+, respectively. Similar to SO_4^{2-}, NO_3^- and NH_4^+ concentrations were also higher at AF and VT than at LT and SK, which also reflect that AF and VT were more affected by anthropogenic emissions.

Table 1. The pH, as well as ionic concentrations (μEq L^{-1}) and fluxes (kg ha^{-1} yr^{-1}) of wet deposition at the four South African INDAAF sites from 2009 to 2014

	Amersfoort 2009-2014		Vaal Triangle 2009-2014		Louis Trichardt 2009-2014		Skukuza 2009 - 2014	
	VWM values	Fluxes	VWM values	Fluxes	VWM values		VWM values	Fluxes
pH	4.32		4.51		4.89		4.66	
H^+	61.18	0.45	44.64	0.43	15.24	0.11	22.24	0.13
Na^+	17.79	2.98	3.50	0.77	7.75	1.30	13.17	1.77
NH_4^+	28.50	3.75	29.06	5.01	10.85	1.42	12.80	1.35
K^+	7.35	2.10	1.41	0.53	5.12	1.46	2.08	0.48
Mg_2^+	5.54	0.49	4.55	0.53	1.93	0.17	3.27	0.23
Ca_2^+	16.39	2.40	16.18	3.10	6.25	0.91	4.69	0.55
NO_3^-	33.40	15.11	22.97	13.62	7.49	3.38	13.20	4.77
Cl^-	17.96	4.65	4.52	1.53	10.83	2.80	15.73	3.25
SO_4^{2-}	67.21	23.56	55.00	25.27	12.37	4.33	18.66	5.23
OA	14.64 (13.24*)	5.57	12.51 (11.49*)	6.10	12.14 (11.10*)	4.54	9.69 (8.69*)	2.93

*Dissociated fractions of the organic acids are indicated in brackets

In **Figure 3** the average annual ionic concentration determined at AF, LT and SK from 2009 to 2014 are compared to previous sampling periods at these sites. It is evident that the total ionic concentration at AF were much higher during 2009-2014 than during 1985-1999, while the total ionic concentration of the measured ions at SK also increased from 1999 to 2002 to 2009 to 2014 . This increase in the concentrations of SO_4^{2-}, NO_3^- and NH_4^+ observed at AF and SK can be attributed to increased anthropogenic activities and population growth. Electricity consumption is a good indicator of the afore-mentioned increase in anthropogenic activities. This region holds nine coal-fired power stations, which generate approximately 90% of the electricity in South Africa (**Figure 2**). A recent study revealed that electricity consumption in South Africa increased with 131 024 GWh from 1993 to 2006, while South Africa also experienced a period of economic growth from 2000 that coincided with increases in

industrial production. The observation that SO_4^{2-} was the species with the highest concentration for both periods at SK indicates that although this site is considered to be a regional rural background site, it is affected by anthropogenic pollution from the industrialised Highveld (no man is an island).

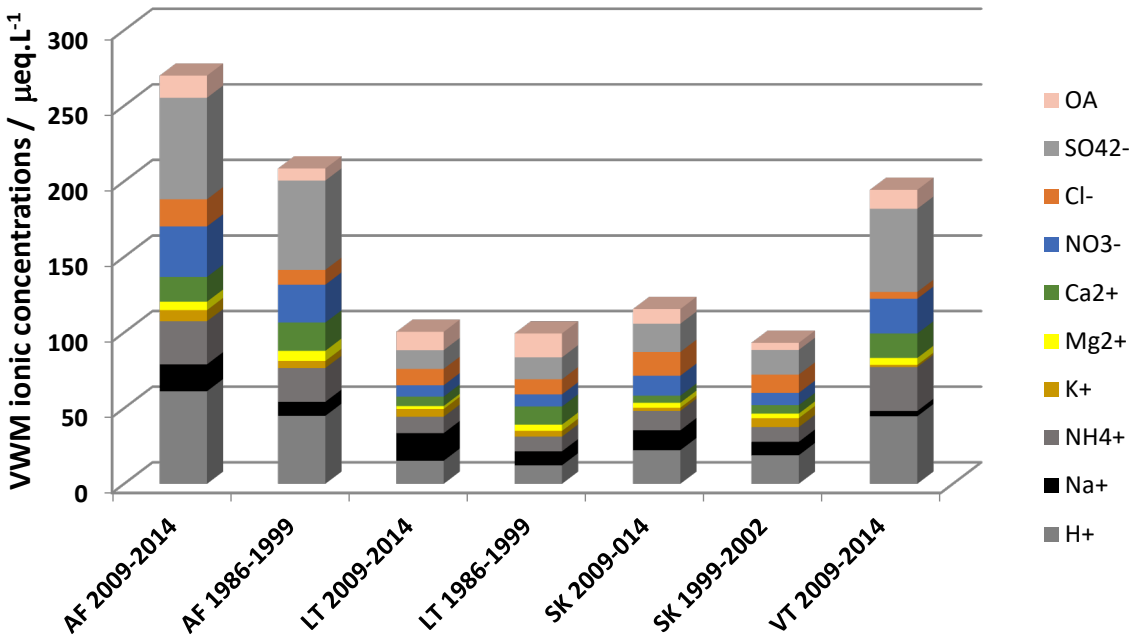


Figure 3: Ionic concentrations of rain determined between 2009 and 2014 at AF, VT, LT and SK, between 1986 and 1999 at AF and LT (Mphepya et al. 2004), and between 1999 and 2002 at SK (Mphepya *et al*,. 2006)

In **Figure 4**, the pH frequency distributions of rain samples collected at AF, SK and LT from 2009 to 2014 are compared to the pH distribution of wet deposition samples collected in previous sampling campaigns at these sites. Although the pH distribution of individual wet deposition rain events was quite different among the sites, over 94% of rain events observed at each site had pH lower than 5.60, i.e. the natural pH of rain water. The pH distribution of wet deposition samples indicates a large shift in the frequency distributions with higher percentage of the rain with lower pH during 2009-2014 compared to measurement conducted during previous sampling campaigns at these sites. The chemical composition of rain and wet deposition of atmospheric pollutants in the South African interior reflects the changes in composition of the atmosphere due to changes in anthropogenic (human) activities.

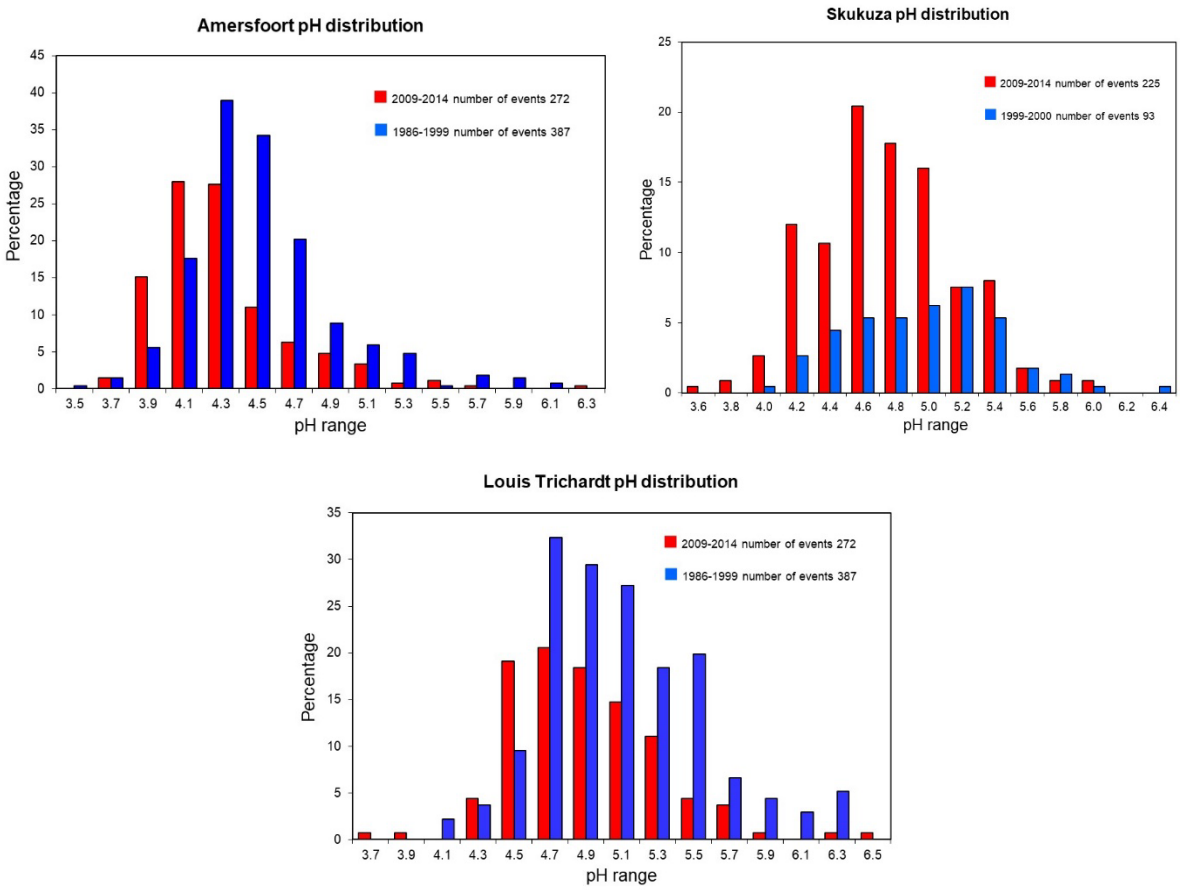
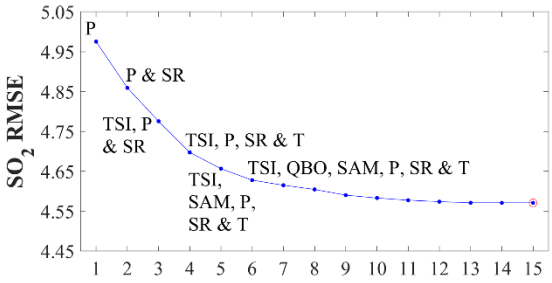


Figure 4: The pH distribution of rain samples collected during individual rain events between 2009 and 2014 at AF, SK and LT compared to pH frequency distributions determined during previous sampling campaigns at these sites

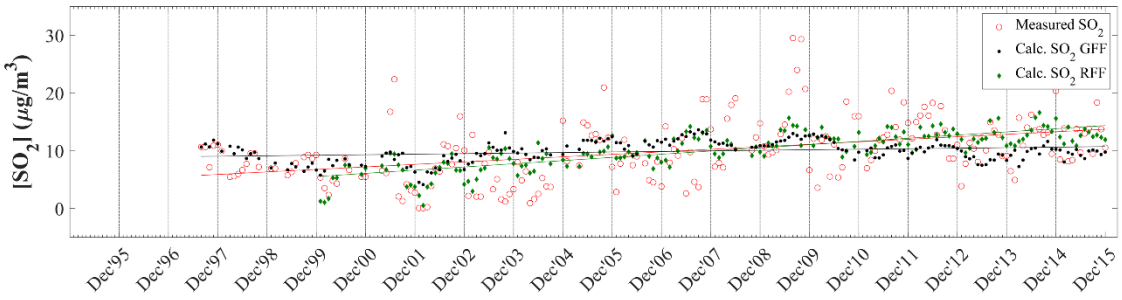
Long-term trends of gaseous species

Long term trends in atmospheric concentrations of SO_2, NO_2 and O_3 based on 21-, 19- and 16-year passive sampling datasets for AF, LT and SK, respectively could be determined due to long-term measurements of these species conducted at the South African INDAAF sites. The interdependencies between local, regional and global parameters, i.e. variances in meteorological conditions and/or source contribution, on variances in SO_2, NO_2 and O_3 levels were investigated in a statistical model (multiple linear regression). In **Figure 5(a)** the root mean square error (RMSE) differences between modelled and measured SO_2 concentrations as a function of the number of independent variables included in the model; the relative important weight percentage

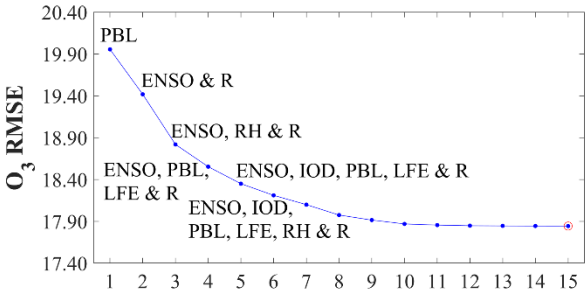
(RIW%) of each independent variable included in the model to calculate SO_2 concentrations; and comparison between modelled and measured SO_2 levels determined for AF is presented. Population growth had the most substantial contribution to the modelled SO_2- (at AF) and NO_2 (at all 3 sites) concentrations (i.e. the dependent variable), which is also indicative of the impacts of increased anthropogenic activities. In addition, it was also indicated that regional circulation of air masses passing over major sources also influences background sites not within proximity of large point sources (no man is an island). A positive slope for SO_2 and NO_2 trend lines indicates an increase in concentrations of these species over the 21-, 19- and 16-year sampling period. The long-term trends of inorganic gaseous species in this region also revealed the impacts of increased anthropogenic activities and population growth with an associated increase in energy demand on concentrations of atmospheric pollutants. In **Figure 5(b)** the RMSE differences between modelled and measured O_3 concentrations and RIW% of each independent variable included in the model at AF are presented, while modelled and measured O_3 levels are also indicated. O_3 concentrations remained relatively constant at all three sites for the entire 19-, 21- and 16-year sampling periods. Interannual variability was mainly attributed to the El Niño-Southern Oscillation (ENSO) cycle, while anthropogenic activities together with local and regional meteorology were important for seasonal variability. The regional O_3 problem in this highly industrialised and densely populated region is also reflected!



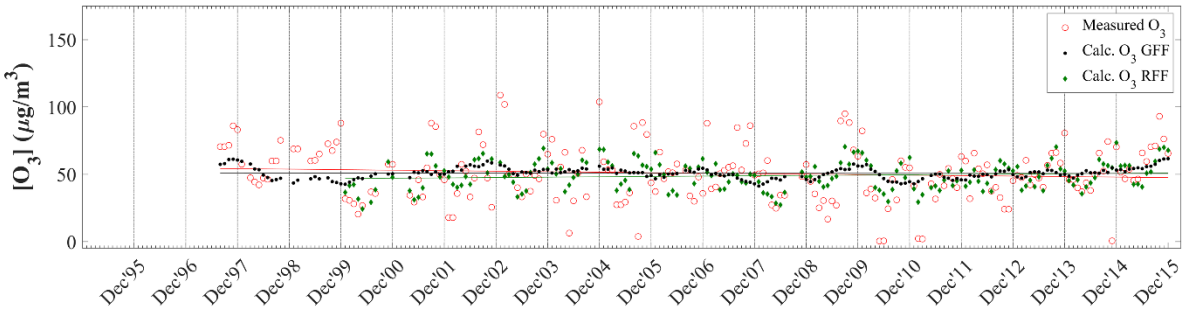
	b	RIW%
P	1.927×10^{-3}	54.5
TSI	-2.373	14.6
SR	0.189	6.2
T	-0.588	4.5



(a)



	b	RIW%
ENSO	7.478	22.6
R	0.122	14.6
Ws	5.988	10.1
SR	0.474	9.4



(b)

Figure 5: RMSE differences between modelled and measured concentrations as a function of the number of independent variables included in the model; RIW% of each independent variable included in the model; and comparison between modelled and measured levels at AF for (a) SO_2 and (b) O_3

3.2 Welgegund supersite

The Welgegund atmospheric monitoring station was established through cooperation between researchers at the North-West University, the University of Helsinki and the Finnish Meteorological Institute since 2006. Initially the station was a mobile unit that conducted air quality and climate change related measurements at a rural background site, i.e. Botsalano, after which the station was moved to an industrial region in the Waterberg Bojanala Air Quality Priority Area near Rustenburg, i.e. Marikana. During this period the ACRG also participated in a large FP6 project of the European Union, i.e. the European integrated project on Aerosol Cloud Climate and Air Quality interactions (EUCAARI) project at Elandsfontein from 2007 to 2010. At the end of the EUCAARI project and after two years of sampling at Marikana with the mobile unit, it was decided to consolidate all instruments into a single supersite at Welgegund. In **Figure 6** the locations of these four measurement sites are presented. Welgegund is a regional site, which is impacted by air masses passing over the major anthropogenic source regions in South African interior, as well as a relatively clean background region to the west (**Figure 7**). The aim is to conduct comprehensive long-term regional measurements in order to address some of past short comings for atmospheric measurements in South Africa. In **Table 1** a comprehensive list of atmospheric measurements conducted at Welgegund is presented. A milestone was reached when Welgegund was included as the atmospheric node of the Biogeochemistry Research Infrastructure Project (BIOGRIP) of the Department of Science and Innovation.

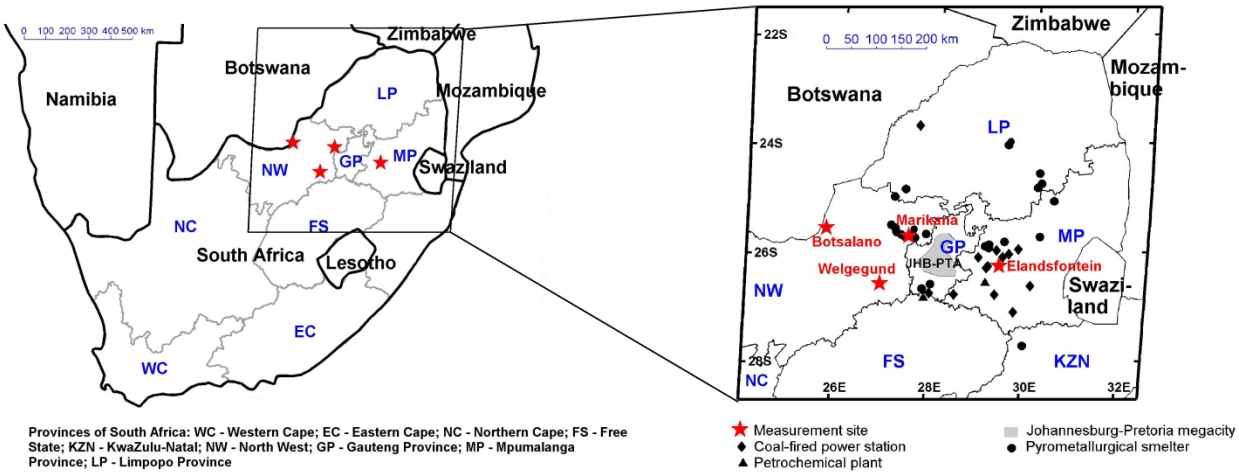


Figure 6: Location of the four measurement sites in South Africa

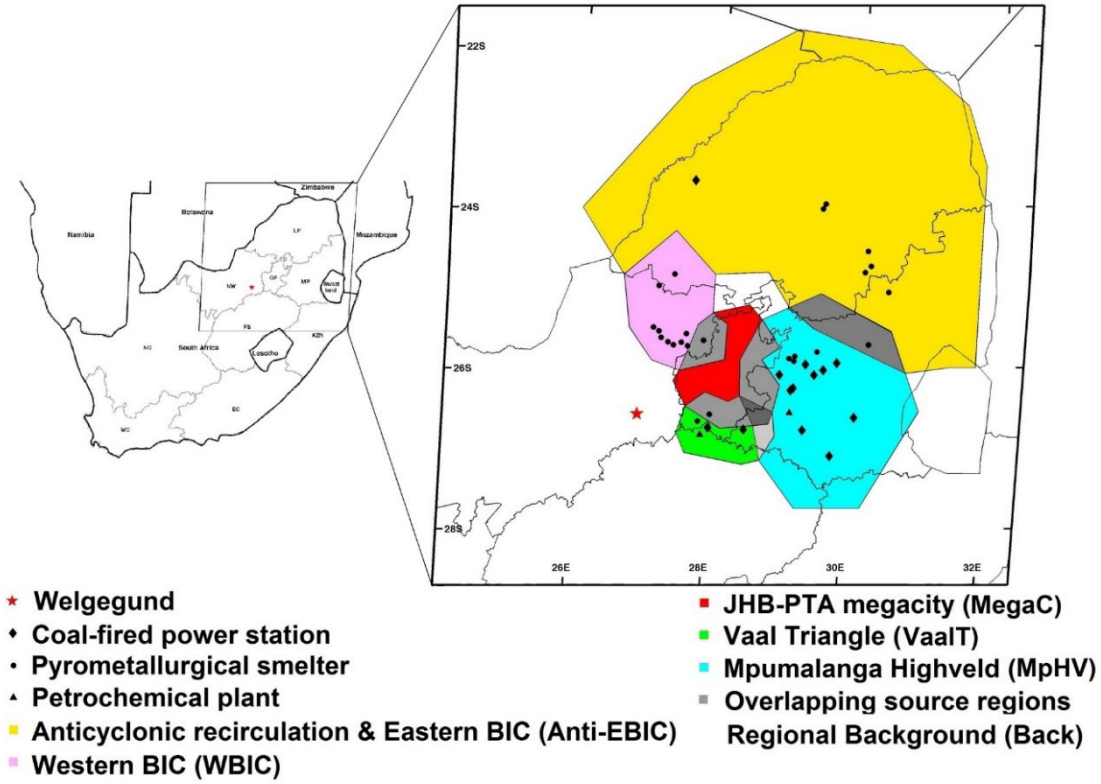


Figure 7: Major anthropogenic source regions and regional background impacting Welgegund

Table 2: Atmospheric measurements conducted at Welgegund

Meteorology	T, RH, WD, WS, Precipitation, Vertical T gradient
Trace gasses:	SO_2, NO_x/NO, O_3, CO
Ion number size distribution (0.4-40nm), Aerosol number size distribution (12-840nm), PM_{10} aerosol mass	
BC, Aerosol light absorption, Aerosol light scattering	
Solar radiation	Direct and reflected photosynthetic photon flux density (PPFD), direct and reflected global & net radiation
Flux measurements	H_2O, CO_2, NO_2, SO_2 and sensible heat fluxes
Soil measurements	Soil T & moisture at different depths, soil heat flux
Ceilometer	vertical column measurements – boundary layer and clouds
Wet deposition	Rain collected with wet-only rain sampler (DEBITS)
Partisol $PM_{2.5}$&PM_{10}, impactors ($PM_{10-0.1}$)	1 y GCXGC-TOFMS analysis of organic components, 1 yr trace metals and Cr(VI), inorganic anions and cations
2 yr VOC measurement campaign – anthropogenic and biogenic sources	
0.5 yr vertical column measurement campaign - Pandora (Penn State University, USA)	
1 yr PM_1 Aerosol Chemical Speciation Monitor (ACSM) campaign (Aerodyne, USA)	
Interdisciplinary botany and entomology studies with surveys conducted 4/yr, on several transects in the proximity of the measurement site	

Surface O_3 variability in continental South Africa

Extensive collaborative research at the Welgegund supersite and though the EUCAARI project, as well as the period during which the mobile atmospheric monitoring unit was deployed at Botsalano and Marikana, led to a comprehensive assessment of surface ozone in South Africa (**Figure 6**). High O_3 concentrations are observed in many areas within the interior of South Africa exceeding the South African air quality standard regularly. Since O_3 is a secondary pollutant, high levels of O_3 can also be found in rural areas downwind of city centres and industrial areas (no man is an island!). Photolysis of NO_2 in the presence of sunlight is the only known way of producing surface O_3, while NOx (nitrogen oxide and -dioxide) and volatile organic compounds (VOCs) (and CO) are the main precursor species. Secondary O_3 production in the atmosphere has a complex and non-linear dependence on precursor emissions, which makes it difficult to control – complex chemical interaction must be understood. In order to develop an effective management plan to reduce surface O_3 it is important to determine whether a region is NO_x- or VOC(CO)-limited. In order to develop an effective management plan to reduce O_3 it is important to determine whether region is NO_x- or VOC(CO)-limited. O_3 concentrations increase with increasing VOCs under VOC-limited conditions, while O_3 production increases with increasing NO_x concentrations under NO_x-limited conditions. It is generally considered that O_3 production in regions close to anthropogenic sources are VOC-limited, while rural areas distant from source regions are NO_x-limited.

In **Figure 8** the seasonal and diurnal variation of O_3 concentrations at Welgegund, Botsalano, Marikana and Elandsfontein are presented. A typical seasonal pattern is observed with O_3 concentrations peaking during late winter and early spring, while the diurnal pattern coincides with peak daytime photochemical O_3 production. The seasonal pattern is indicative of the main source of O_3 precursor species in this region, i.e. increased household combustion for space heating during winter and seasonal wild fires during late winter/early spring.

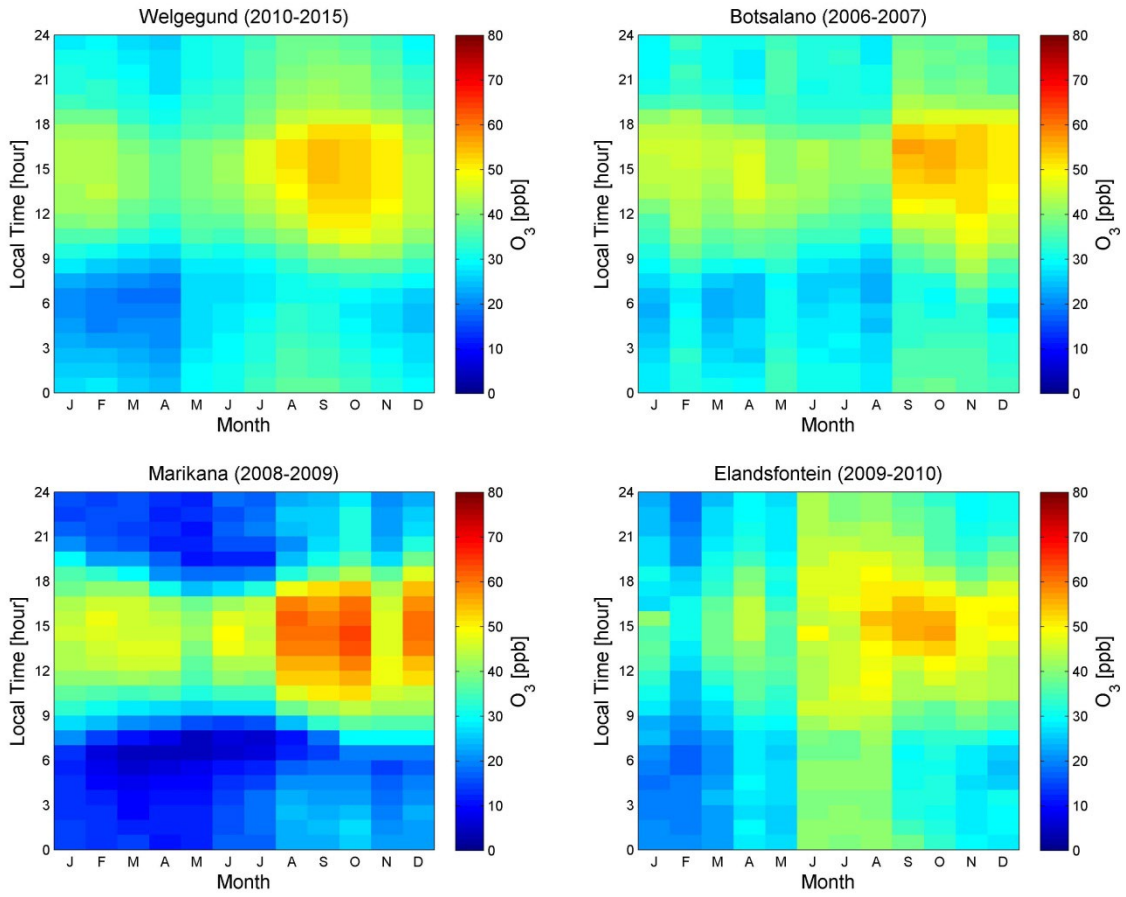


Figure 8: Seasonal and diurnal variation of median O_3 concentrations at Welgegund, Botsalano, Marikana and Elandsfontein.

In **Figure 9** O_3 concentrations determine at these sites were combined with 18 routine monitoring station measurements and 36 passive sampling sites to spatially contextualised surface O_3 levels in the north-eastern interior of South Africa. The regional O_3 problem in continental southern Africa is evident – no man is an island!

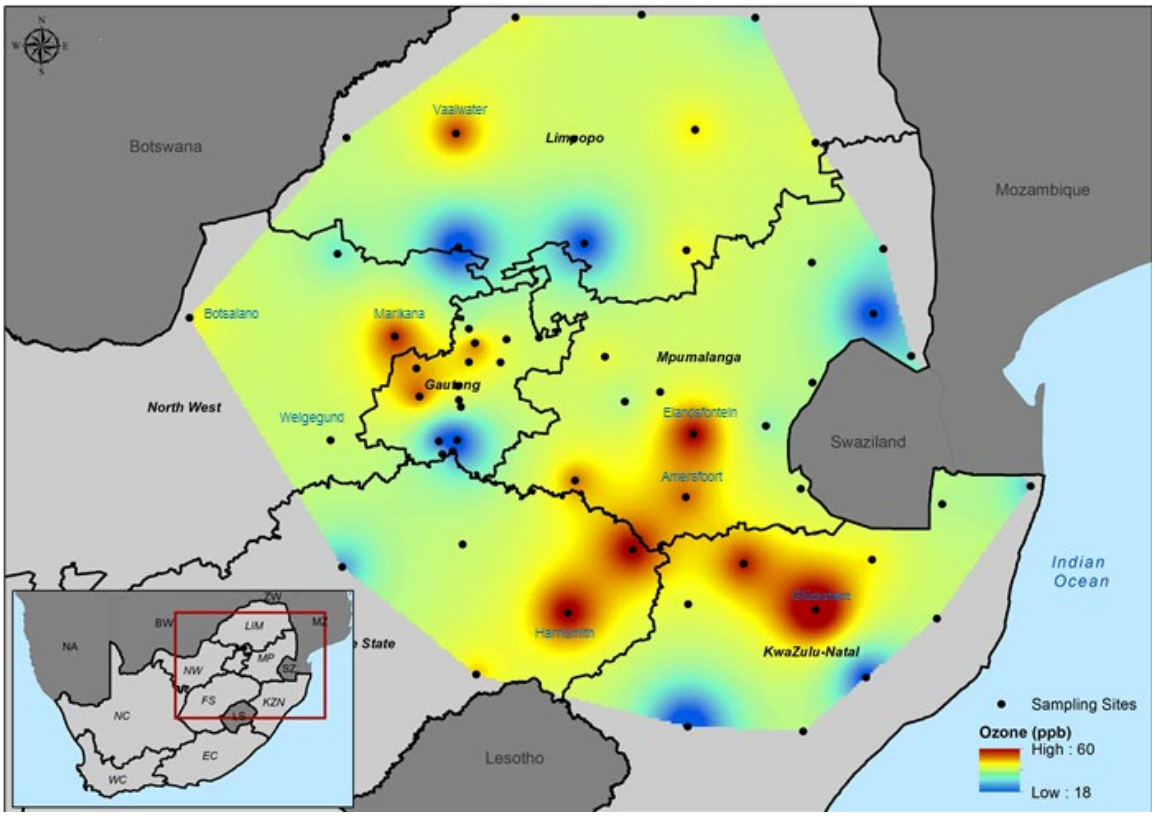
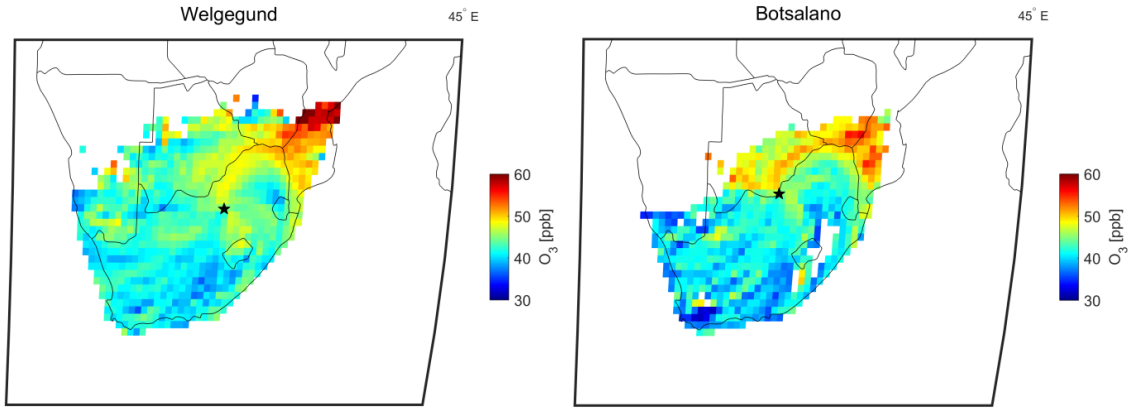
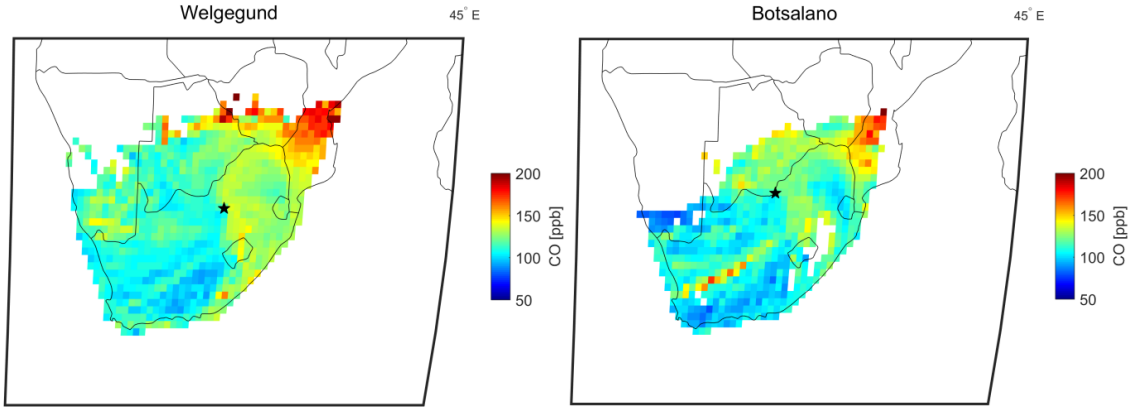


Figure 9: Map indicating spatial distribution of mean surface O_3 levels during springtime over the north-eastern interior of southern Africa ranging between Black dots indicate the sampling sites.

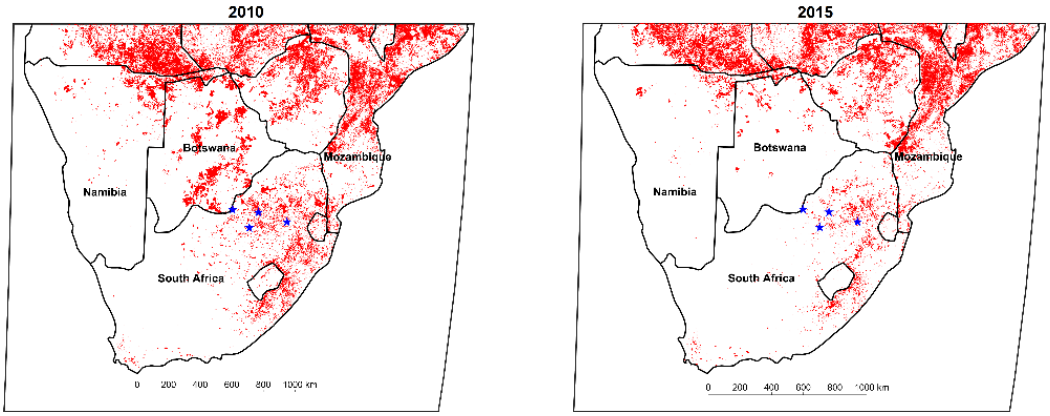
The spring maximum O_3 concentrations can be attributed to increases in widespread regional (open biomass burning) wildfires in this region during this period. Source area maps of O_3 and CO were compiled by relating measured O_3 and CO concentrations with air mass history, which are presented in **Figure 10 (a) and (b)**. Source area maps were only generated for the background sites Welgegund and Botsalano, since local sources at the industrial sites would obscure the influence of regional biomass burning. In addition, maps of spatial distribution of fires during 2010 and 2015 compiled with the MODIS collection 5 burnt area product are presented in **Figure 10 (c)**. It is evident from **Figure 10** that the highest O_3 and CO concentrations were observed for air masses passing over a sector north to north-east of these sites, i.e. southern and central Mozambique, southern Zimbabwe and south-eastern Botswana where a large number of wildfires occurs. Therefore the regional transport of CO (and VOCS) associated with biomass burning is an important source of surface O_3 in the north-eastern interior of South Africa (no man is an island).



(a)



(b)



(c)

Figure 10: Source area maps of (a) O_3 concentrations and (b) CO concentrations for the background sites Welgegund and Botsalano. The black star represents the measurement site and the colour of each pixel represents the mean concentration of the respective gas species. (c) Spatial distribution of fires in 2010 and 2015 from

MODIS burnt area product. Blue stars indicate (from left to right) Botsalano, Welgegund, Marikana and Elandsfontein

In the absence of continuous VOC measurements at these sites, the relationship between O_3, NO_x and CO was investigated to gain insights into the O_3 production regime, which are presented in **Figure 11**. Higher O_3 concentrations associated with increased CO levels are clearly indicated, while O_3 levels remain relatively constant (or decrease) with increasing NO_x. These correlations between NO_x, CO and O_3 indicate that O_3 production in continental South Africa, even at rural backgrounds sites, is limited by CO (and VOCs) concentrations, i.e. VOC-limited. This finding shows a strong correlation between O_3 on CO and suggests that high O_3 can be attributed to the oxidation of CO in the air masses, i.e. as long as there is a sufficient amount of NO_x present in a region, CO serves to produce O_3.

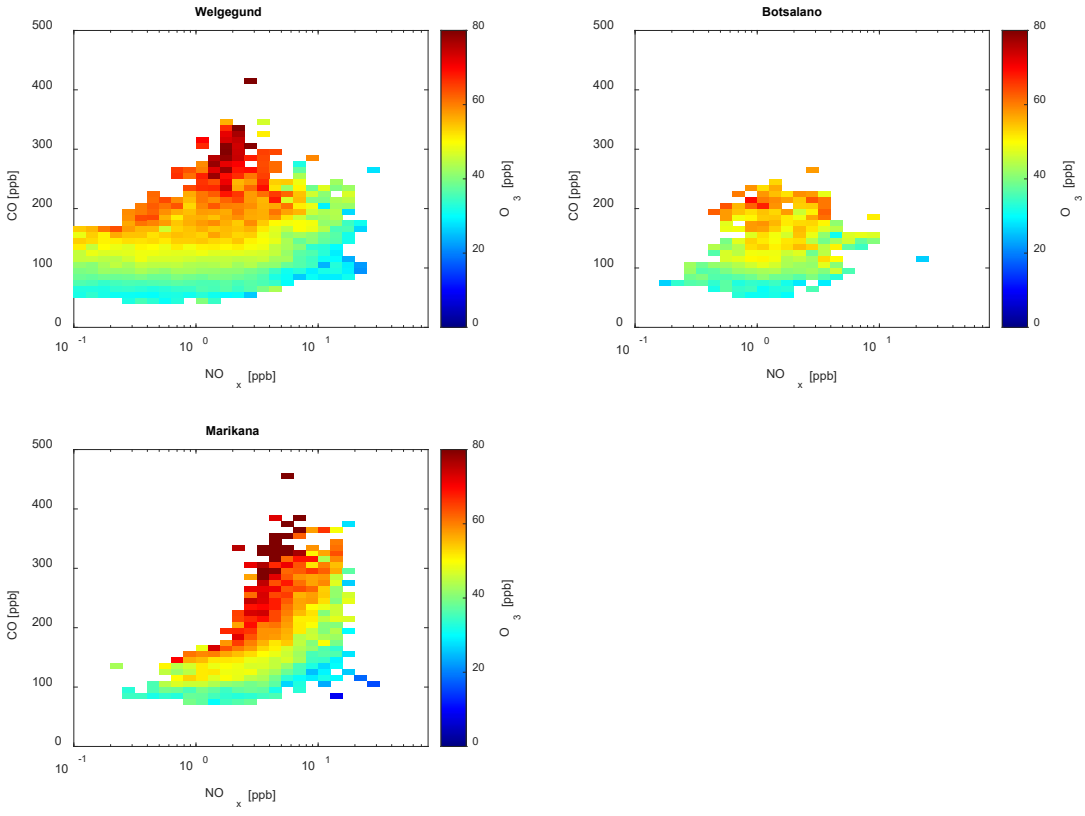


Figure 11: Correlations between O_3, NO_x and CO concentrations

A two-year grab sample VOC dataset was available for Welgegund, which was used to model the instantaneous production rate of O_3 ($P(O_3)$) as a function of NO_2 levels and VOC reactivity. The $P(O_3)$ as a function of VOC reactivity and NO_2 concentrations

is presented in **Figure 12**. The dashed black line in **Figure 12**, called the ridge line, separates the NO_x- and VOC-limited regimes. To the left of the ridge line is the NO_x-limited regime, when O_3 production increases with increasing NO_x concentrations. The VOC-limited regime is to the right of the ridge line, when O_3 production decreases with increasing NO_x. It is evident that modelled O_3 production transitions between NO_x- and VOC-limited regimes at Welgegund. According to the O_3 production plot presented, approximately 40% of the data is found in the VOC-limited regime area, which would support the regional O_3 analysis conducted for continental South Africa. O_3 production in the NO_x-limited regime is most-likely associated with clean background air impacting Welgegund. Correlations between O_3, NO_x and CO, as well as the modelled O_3 production rate indicate that continental southern Africa can generally be considered VOC(CO)-limited due to high anthropogenic emissions of NO_x in this region, which is very important for policy makers. No man is an island.

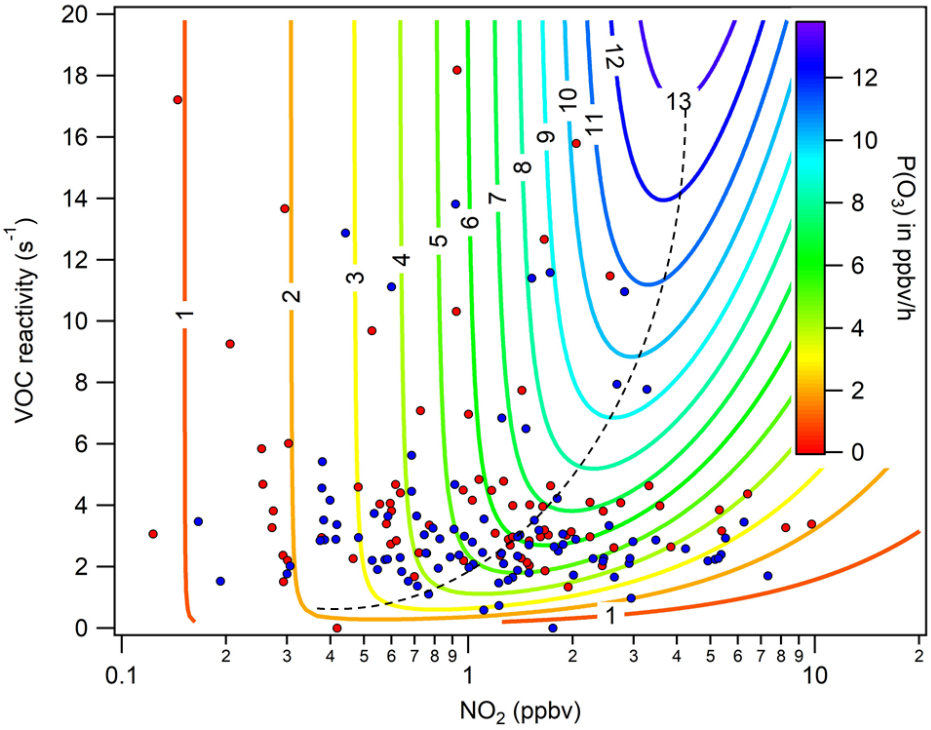


Figure 12: Contour plot of modelled instantaneous O_3 production ($P(O_3)$) at Welgegund using daytime grab sample measurements of VOCs and NO_2. The blue and red dots represent the two different grab sampling campaigns

3.3 Other projects

SO_2, NO_2 and O_3 in rural areas of the North West Province

Special mention must be made to one other project that was not conducted through the two main collaborative projects, which illustrates our commitment to engagement with the community. An air quality assessment in rural areas of the North West Province was performed in collaboration with the North West Provincial government in which SO_2, NO_2 and O_3 were monitored with passive samplers at 10 sites in the western rural parts of the North West Province presented in **Figure 13**. SO_2 and NO_2 did not exceed air quality standards. Spatial patterns indicated higher SO_2 concentrations in the west mainly due to industrial emissions, while the NO_2 spatial map indicated two areas of higher concentration, i.e. Bapong in the east due mainly to industrial emissions, and Taung with its higher population density (**Figure 14**). Spatial maps also revealed the regional O_3 problem in this area (**Figure 14**).

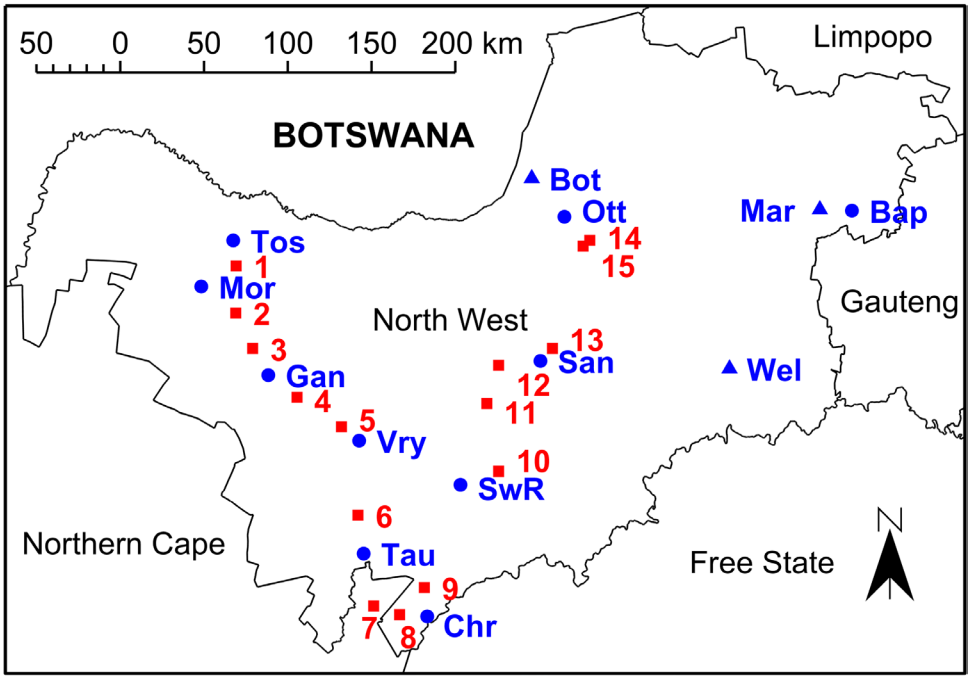


Figure 13: The locations of the 10 sites where measurements were conducted over the entire measurement period are indicated with blue dots and the reference sites are indicated with the blue triangles. Red squares indicate 15 additional sites monitored during the intensive campaign.

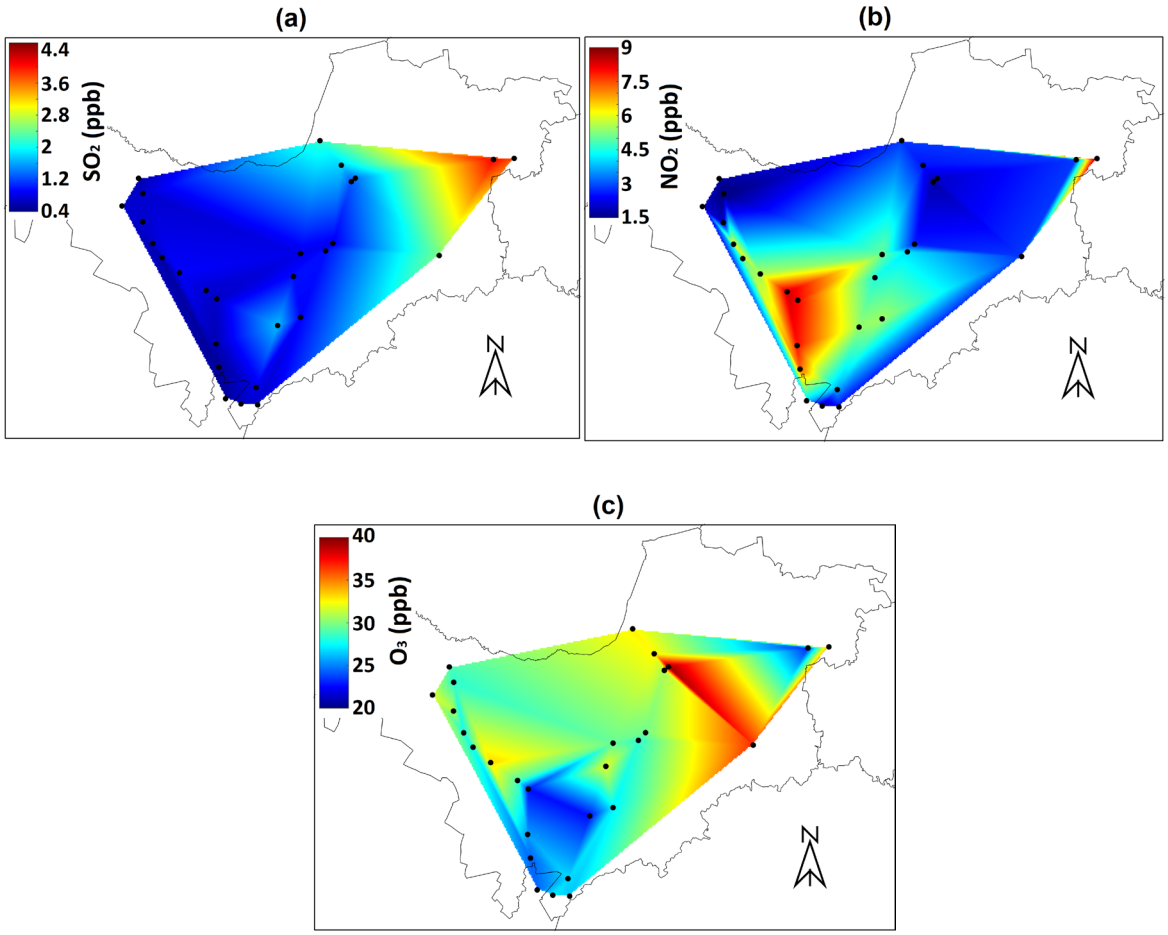


Figure 14: . Spatially interpolated average SO_2 (a), NO_2 (b) and O_3 (c) concentration maps across the area of interest

4. Concluding remarks

We worked hard together, we worked and played hard together, we worked as a team – this journey of becoming a professor would not have been possible without the interconnectedness of people and extensive collaborative research projects. My research in atmospheric chemistry has revealed how we are connected through the atmosphere and how we are interdependently changing the chemical composition of the atmosphere.

I stand here alone – no man is an island!