MODELLED LONG TERM TRENDS OF SURFACE OZONE OVER SOUTH AFRICA

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Summary

Currently little is understood about the potential local response of air quality to anthropogenically induced changes in the regional climate of southern Africa. The modelling of surface ozone within a large timescale seeks to provide a spatially comprehensive view of trends while also creating a baseline for comparisons with future projections of air quality through the forcing of air quality models with modelled predicted long term meteorology. Previous research within CSIR has enabled the photochemical air quality model CAMx to be forced with fields from the CCAM atmospheric model, which is also capable of simulating forecasted meteorological conditions at the climate change time scale.

Here, CAMx is nested within a regional climate model, CCAM, and is used to simulate the present-day spatial distribution and trends of near-surface ozone over South Africa. The study gives insight into the skill of the modelling system in providing simulations of near-surface ozone concentrations, and its potential to be used to obtain the sensitivity of future changes in near-surface ozone concentrations over southern Africa. For this baseline trend study, the period 1989-2009 was chosen since necessary ancillary input for CAMx, such as total column ozone and background air quality data, is readily available for this time. Additionally, for CCAM to provide CAMx with realistic meteorological fields, representative real world initial and boundary conditions were required. This came in the form of the NCEP Reanalysis dataset, from which CCAM has been initialized and forced with during its integration.

Results show the simulated trends in surface ozone concentrations over South Africa during 1989-2009. The simulations are compared against point measurements of near-surface ozone concentrations. It is shown that the CCAM-CAMx system performs reasonably well retrospectively over the period, thereby providing a baseline trend for comparison with CAMx simulations forced with CCAM climate change projection data over southern Africa within the context of the IPCC AR4 emission scenarios.

1. Introduction

Currently little is understood about the potential local response of air quality to anthropogenically induced changes in the regional climate of southern Africa. Such changes are likely to influence the future transport and chemistry of air pollutants over the region. Previous monitoring campaigns have described local trends of surface and profile ozone (e.g. Thompson et al 2007); however results are spatially limited and temporally sparse.

The modelling of surface ozone within a large timescale seeks to provide a spatially comprehensive view of trends while also creating a baseline for comparisons with future projections of air quality through the forcing of air quality models with modelled predicted long term meteorology. Previous research within CSIR Climate Studies, Modelling and Environmental Health (CSM&EH) group has enabled the photochemical air quality model CAMx (Comprehensive Air Quality Model with Extensions; http://www.camx.com) to be forced with fields from the CCAM (Conformal Cubic Atmospheric Model; McGregor and Dix 2008) atmospheric model, which is also capable of simulating forecasted meteorological conditions at the climate change time scale. The use of forecasted climate change data to drive CAMx is the final objective in a larger research initiative that aims to understand the influence future projected changes in climate will have on air quality. The research presented in this paper discusses the model simulations used to derive the baseline from which comparisons with future simulations will be made.

The CCAMCAMx system was used to simulate the present-day spatial distribution and trends of near-surface ozone over South Africa. This also gives insight into the skill of the modelling system in providing simulations of near-surface ozone concentrations, and its potential to be used to obtain the sensitivity of future changes in near-surface ozone concentrations over southern Africa. For this baseline trend study, the period 1989-2009 was chosen since necessary ancillary input for CAMx, such as total column ozone and background air quality data, is readily available for this time. Additionally, for CCAM to provide CAMx with realistic meteorological fields, representative real world initial and boundary conditions were required. This came in the form of the NCEP Reanalysis dataset, from which CCAM has been initialized and forced with during its integration. Note that years 1995 and 1996 have not been simulated by the CCAMCAMx system as the TOMS instrument (data from which CAMx bases albedo/haze and then photolysis rates) was not active during this time.

2. Model approach

A description of development and initial results for the CCAMCAMx system are fully presented in Naidoo and Engelbrecht (2010). An important improvement to the previous system is the inclusion of vertically disaggregated rainfall, that is, rainfall at every model level, as opposed to previously only considering surface rainfall. This is achieved by distributing surface rainfall into each model level (per volume) up until cloud base is reached. The CAMx model setup used here is similar to the initial testing; however it may be of use to reiterate by way of summary. The CAMx model domain covers all of South Africa and is nested within the CCAM domain as in Figure 1.

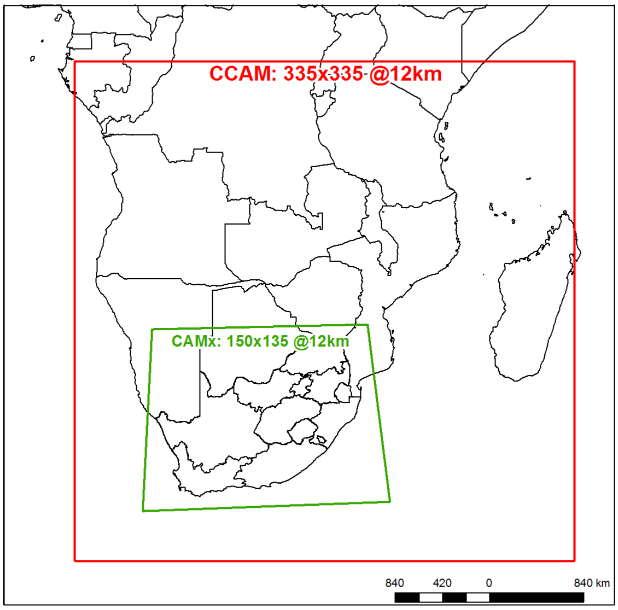

Figure 1: CAMx and CCAM domain

The emissions inventory, developed previously (CSIR 2009), covers the entire CAMx model domain and includes the pollutant species: SO_2, NOx, CO, NMVOC, NH_3 and PM. The original intent for the emissions inventory was to understand the dynamics of ozone formation over the Highveld area, particularly with respect to emissions from power generation and the synthetic petrochemical industry. Therefore, even though the inventory covers a national domain, more emphasis on detail was applied to the NOx and NMVOC species from those sources within the Highveld area. Sources that make up the inventory include:

- Residential – Emissions from domestic fuel burning
- Transportation – Emissions from road vehicles, diesel trains and airport ground vehicles
- Large Industry – Emissions from Sasol, Eskom and refineries
- Small Industry – Emissions from smaller more disperse industry
- Biogenic – Emissions from vegetation and soil

Since the main aim of the larger research initiative is to understand the influence future projected changes in climate will have on air quality, the emissions inventory remains unchanged for all simulation years, thus leaving meteorology as the main variable.

Initial and boundary conditions for CAMx are based on data from the Cape Point GAW station. The model is initialized at the beginning of every simulation month. The column ozone/haze/albedo data, necessary to derive photolysis rates, are sourced from the various satellite campaigns that have supported the TOMS and now OMI instruments.

3. Results

CAMx hourly surface ozone output was compared to data from monitoring stations to assess system performance. Year 2006 was chosen due to data availability and the fact that the emissions inventory was designed for simulations of 2006. Table 1 shows comparison statistics using each of four Eskom run monitoring stations with data available for this study.

Table 1: Statistics for comparison of CCAMCAMx with observed data

	Data %	Stdev Obs	Stdev CAMx	Av Bias	Correl
Camden	86	16.15	9.07	-7.03	0.27
Elandsf	42	13.33	8.74	-15.28	0.19
Kendal 2	67	16.27	8.63	-9.34	0.08
Verkykop	70	10.97	9.59	-5.35	0.01

The Camden station shows best data completeness. Standard deviation for observed data is comparable across stations, while similar can be said of the CAMx output. However CAMx does not capture variability seen in observed data, which is expected due to the relatively coarse model cell size (12kmx12km) when compared to a point on the ground which is the monitoring station. The average bias shows that CAMx under-estimates ozone at all stations; a possible indication of an incomplete emissions inventory. Correlations also show low similarity between observed and simulated. However it should be noted this may be due to a time misalignment with emissions and model time. Indeed shifting simulated output two hours ahead improves correlation.

Comparison with observed data not withstanding, this study aims to show change and the response of surface ozone levels to a changing climate. Discrete ozone concentrations are then not as relevant as trends between time periods, which show increase or decrease. Figure 2 shows the average inter-annual trend over the modelled years.

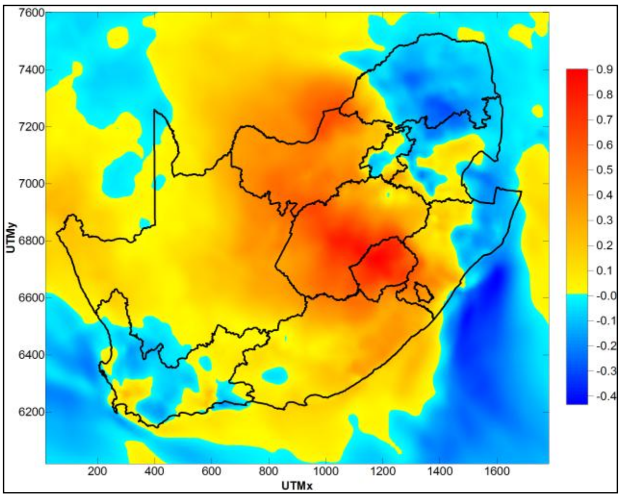

Figure 2: Averaged inter-annual trend (ppb/yr) as simulated by CCAMCAMx system

Trend is considered to be the linear slope between annual averages, and this is averaged for the entire modelled period (excluding 1995 and 1996). In Figure 2, highest average inter-annual change is 0.9 ppb/year seen over central region of South Africa and interior Western Cape. It should be noted that this is based on annual averages, and so represents more accurately the long term large scale transport of ozone over the model domain for the baseline period. Figure 3 shows the Spring trend, calculated similar to Figure 2, but with only Spring months (September, October, November).

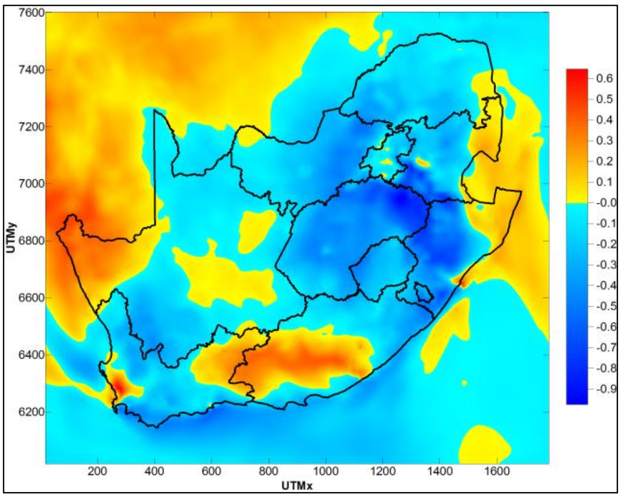

Figure 3: Averaged Spring trend (ppb/yr) as simulated by CCAMCAMx system

Inter-annual Spring trends show lower increase and a general decrease over the country. Maximum increases of 0.6 ppb/year are seen particularly around the coastal refineries in Durban and Cape Town. Minor dispersed increases are also seen over the Gauteng region.

4. Conclusion

The mechanisms of these changes are still to be investigated and an analysis of the changing meteorology will reveal much more (particularly over a longer timescale and with more complete inter-annual model output); noting that the emissions inventory remains static, leaving meteorology as the major driver. However, while this study will be able to show various photochemical responses to a changing climate, it is still limited by the lack of biomass burning in the emissions inventory; a further possibility to decreases seen in the Limpopo province.

The current baseline of 1989-2009 (20 years) may be seen as a fairly limited view in terms of the effect of long term climate variability on surface ozone concentrations. Due to the inherent “shorter” time scale variability, due to phenomena such as El Niño/La Niña, any effect of global climate change on the regional atmosphere is more clearly seen for periods greater than 20 years. Additionally, the global warming signal is more apparent later in the century (Engelbrecht 2013). Therefore current baseline created by these model runs provide a starting point for comparison with CAMx simulations forced with CCAM climate change projection data over southern Africa within the context of the IPCC AR4 emission scenarios.

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