Proceedings for the 6th International Fire Behavior and Fuels Conference
April 29 – May 3, 2019, Sydney, Australia
Published by the International Association of Wildland Fire, Missoula, Montana, USA

DEVELOPMENT AND EVALUATION OF A SMOKE EMISSION MODULE IN NSW OPERATIONAL AIR QUALITY FORECAST MODELLING SYSTEM

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Introduction

Smoke from wildfires and planned burns can impact regional air quality and expose people to fine particulate matter with diameter of less than 2.5 µm ($PM_{2.5}$). Exposure to smoke can have adverse health impacts, ranging from eye and throat irritation and asthma symptoms to hospitalisations and premature deaths.

The NSW Office of Environment and Heritage (NSW OEH) operates a comprehensive air quality monitoring network to provide the community with accurate and up-to-date information about regional air quality. NSW OEH also issues a daily air quality forecast for the Greater Sydney region, and has a formal role working with NSW Health to issue Air Pollution Alerts. Under the umbrella of the NSW OEH Air Quality Forecast Framework (AQFF) (NSW OEH, 2015), the coupled Conformal Cubic Atmospheric Model (CCAM) and the Chemical Transport Model (CTM) (the CCAM-CTM) modelling system (Cope et al, 2009 and 2014) has been configured by NSW OEH to conduct operational air quality forecast modelling for the NSW Greater Metropolitan Region.

While committed to carrying out hazard reduction burning as a public safety tool, NSW OEH is investigating ways to better manage smoke impacts and greenhouse gas emissions from hazard reduction burning and wildfires in NSW. In 2017, a Smoke Emission Module (SEM) which can be run in-line within CTM for landscape fire smoke modelling was developed through a collaboration with CSIRO. This smoke module was further refined and tested by NSW OEH in 2018.

In this study, the performance of the operational CCAM-CTM modelling system with an in-line SEM was evaluated for selected Hazard Reduction Burns (HRB) in 2018. The modelled meteorology and air pollution ($PM_{2.5}$) were compared with the observations across the Sydney Basin as part of an operational evaluation. Statistical metrics provide an indication on the accuracy of the forecasting system and highlighted some of the model biases and their implications on forecasting skill.

The NSW Operational Air Quality Modelling System

The CCAM-CTM modelling system has been configured by NSW OEH to conduct operational air quality forecast modelling for the NSW Greater Metropolitan Region. The performance of the modelling system has been evaluated prior to being operationalised to support daily air quality forecasting (Chang et al, 2018). The schematic diagram of the modelling system is illustrated in Figure 1.

The operational CCAM-CTM modelling is undertaken using three nested domains, comprising the outermost New South Wales (NSW) domain at 60-km x 60-km resolution, the Greater Metropolitan Region (GMR) at 8-km x 8-km and the innermost domain covering Sydney regional airshed (GSYD) at 1-km x 1-km resolution. Model domain configurations are shown in Figure 2. The CTM is initiated by CCAM at 12 UTC (22 AEST) on each day and runs for 96-hours for the 60-km, 8-km and 1-km domains. The first 24 hours of the CTM forecast is normally skipped in the analysis to allow the model to be spun up.

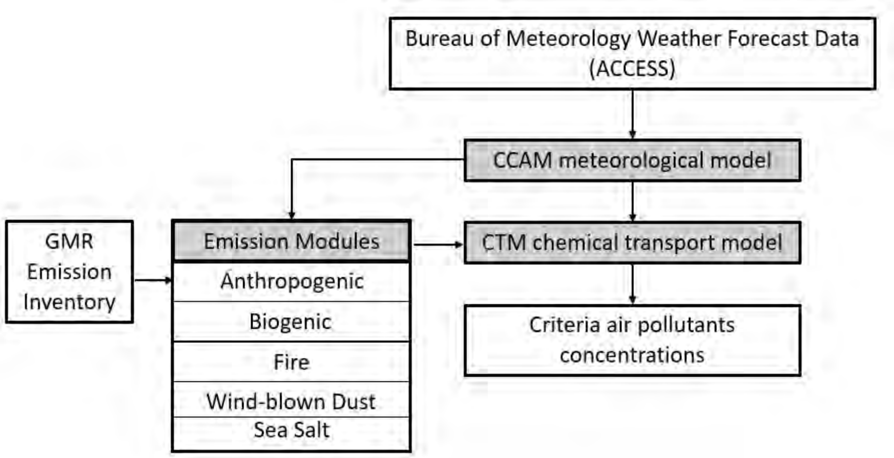


Figure 1: Schematic diagram of the operational CCAM-CTM modelling system

Figure 2: Domain configuration of the operational CCAM-CTM

Development of the smoke emission module

The SEM currently implemented in the NSW OEH operational CCAM-CTM modelling system simulates the emission of various pollutant species from HRBs and bush fires. The module was developed by CSIRO and the fire emissions are estimated using the approach developed by Seiler and Crutzen (1980). The total smoke emissions are from both fine fuel flaming and smouldering. Flaming is quick, hot and rising loftily with fine fuels such as leaf litter consumed quickly emitting gaseous and aerosol species that are carried over a distance. Smouldering emit aerosols mainly above ground level due to coarse fuel slow burning. The burning efficiency (BEF) of the fine fuels, which pyrolyse through flaming, will be higher than the BEF for the coarse woody debris (fallen branches, boughs and toppled stems) in which pyrolysis occurs through smouldering.

An "Ensemble" approach (as illustrates in Table 1) with four fires scenarios embedded was developed by NSW OEH and implemented for daily operational CCAM-CTM modelling since April 2018. The option 1 - "Base case" runs automatically every morning regardless of fires or HRBs incidents; option 2- "Basecase + Bushfire" runs automatically every morning whenever there is bushfire incident data available through the automated feeds from NSW RFS; option 3- "Basecase + HRB" runs when the major planned HRBs are identified and this scenario requires manual extraction of HRBs scar information from Bush Fire Risk Information Management System (BRIMS); and the last option 4 – "Basecase + Bushfire + HRB" runs for both bushfires and HRBs incidents occurring during the same forecast time window.

Table 1: Ensemble approach in NSW OEH operational CCAM-CTM modelling

Scenarios	Anthropogenic emissions	Smoke emissions		Daily simulation
		Bushfire	HRB	
1 – Base case	2008 NSW GMR Air Emissions Inventory	No	No	Auto
2 – Basecase + Bushfire		Yes	No	Auto
3 – Base case + HRB		No	Yes	Semi-auto
4 – Base case + Bushfire + HRB		Yes	Yes	Semi-auto

Evaluation of the smoke emission module

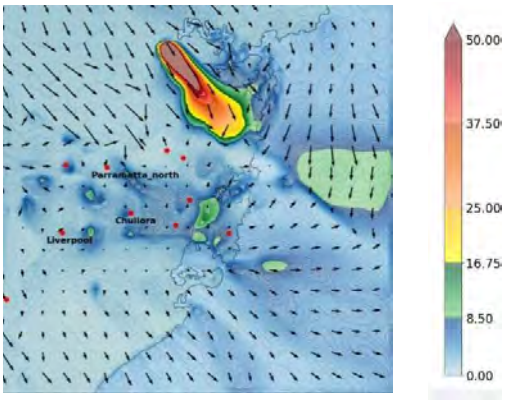
In this section, three HRB cases are selected from autumn 2018 to evaluate the performance of the smoke emission module and the potential smoke impact on predicted air quality. The detail descriptions of the three HRB cases are listed in Table 2.

Table 2: Selected HRBs case in autumn 2018 for evaluation

Case	Event Name	LGA	Date	Estimated total area burnt
1	Coba Creek HR	Hornsby	11-14 April 2018	2,000 ha
2	Mount Solitary HR	Blue Mountains	8-9 May 2018	2,700 ha
3	State Forest West HR	Hawkesbury Colo Heights	26-27 May 2018	1,973 ha

Smoke Plum Transport

The plots in left-hand column of Figure 3 are CCAM-CTM predicted hourly $PM_{2.5}$ concentrations from each of the three HRB cases. The right-hand column of Figure 3 are MODIS satellite images showing the smoke plume transport on the same day. The presence of smoke related to HRBs is generally correctly captured in the CCAM-CTM modelling, with reasonable agreement between observed satellite images and model predicted plume location.

<table>
<tr><td>CCAM-CTM predicted hourly $PM_{2.5}$ (µg/m^3)</td><td>MODIS satellite imagery</td></tr>
<tr><td colspan="2">(a) Case 1 - Coba Creek HR</td></tr>
<tr><td>20180413 1200 AEST</td><td>20180413</td></tr>
<tr><td>
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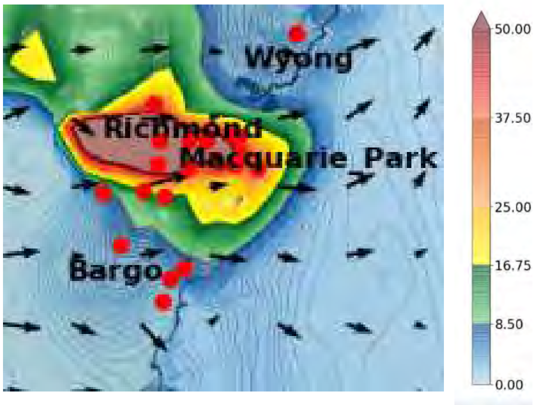
<tr><td colspan="2">(b) Case 2 - Mount Solitary HR</td></tr>
<tr><td>20180509 1900 AEST</td><td>20180509</td></tr>
<tr><td>
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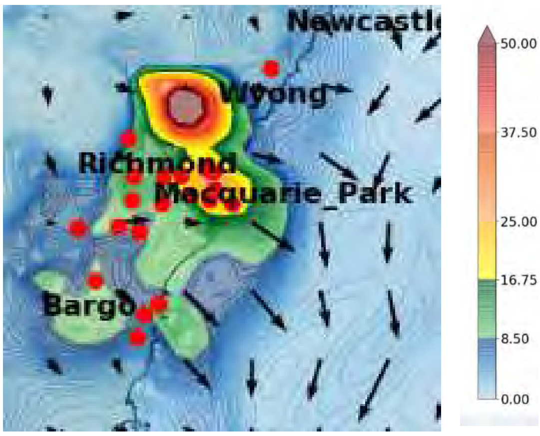
<tr><td colspan="2">(c) Case 3 - State Forest West (Colo Heights) HR</td></tr>
<tr><td>20180527 2200 AEST</td><td>20180527</td></tr>
<tr><td>
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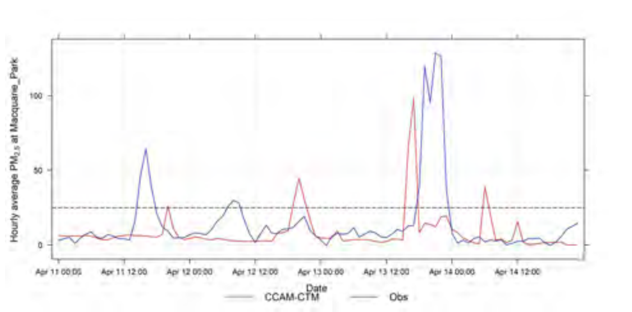
Figure 3: Comparisons of the CCTM-CTM predicted hourly $PM_{2.5}$ (µg/m3) and MODIS observed smoke plums in selected three HRB cases.

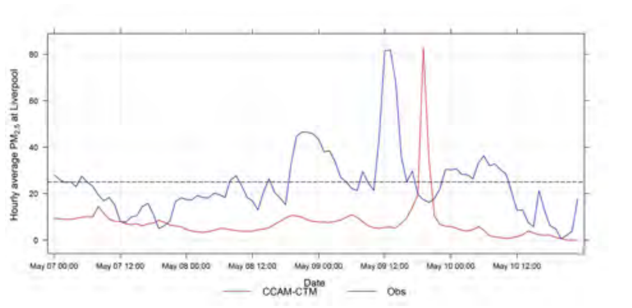
$PM_{2.5}$ Evaluation

Time series plots of $PM_{2.5}$ concentrations comparing observations and predictions from the CCAM-CTM at one OEH monitoring site per case are presented in Figure 4. The model generally captures the magnitude of the peak $PM_{2.5}$ concentrations, however they do miss some of the smaller peaks. It is evident from the time series plots that there are limitations in capturing the exact timing of these peaks which is due in part to the complexity involved in accurately modelling the mesoscale meteorology, e.g., the difficulties in predicting accurate boundary layer evolution during late night to early morning, which often relates to the occurrences of strong inversions and light winds in the Sydney basin.

(a) Case 1 - Coba Creek HR



(b) Case 2 - Mount Solitary HR



(c) Case 3 - State Forest West (Colo Heights) HR

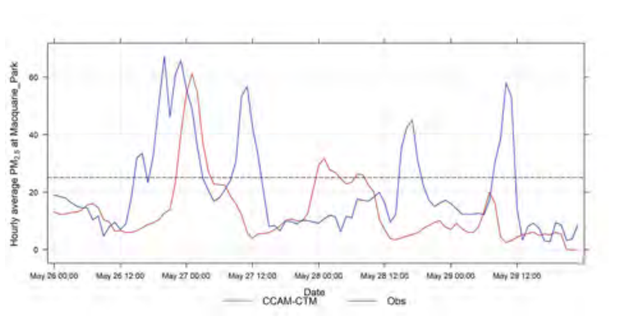


Figure 4: Predicted and observed $PM_{2.5}$ concentrations ($\mu g/m^3$) at (a) Macquarie Park, (b) Liverpool and (c) Macquarie Park for each case.

The forecasts that the OEH provide are focused on the entire Sydney domain and therefore having the correct amount injected into the atmosphere in this region will allow for reasonable forecast skill. A selection of statistics (mean bias (MB), mean error (ME), mean fractional bias (MFB), mean fractional error (MFE), root mean square error (RMSE), correlation coefficient (R) and index of agreement (IOA)) averaged over the Sydney region for each case are provided in Table 3. The model tends to underestimate the $PM_{2.5}$ concentrations across the Sydney region with mean biases between -14.7 and -4.4. The MFB and MFE statistics are the least biased of the statistical metrics provided. The simulations do not meet the more stringent performance goal for MFB (±30%), however the performance criterion is met for MFB (±60%), during the Coba Creek and Colo heights cases. Neither the MFE performance goal (50%) or performance criteria (75%) is met for these three cases.

The preliminary results of predicted $PM_{2.5}$ as shown in this section suggest that the amount of smoke emitted into the model is correct, but more investigations need to be done to understand the general limitations of the smoke predictions in the CCAM-CTM modelling system.

Table 3: Quantitative performance statistics for predicted hourly $PM2_{.5}$ concentrations (μg/m^3) against observations for the Sydney region

Case	Mean (obs)	Mean (model)	MB	MGE	RMSE	R	MFB*	MFE*	IOA
Ideal value	-	-	0	0	0	1	-	-	1
Coba Creek	9.2	4.8	-4.4	6.7	11.8	0.2	-50 %	80 %	0.4
Mt Solitary	15.9	8.3	-7.6	12.5	19.0	0.02	-70 %	90 %	0.4
Colo Heights	24.9	10.2	-14.7	17.7	31.8	0.04	-40 %	110 %	0.3

* The performance criteria for MFB is ± 60% and the performance goal for MFB is ±30%. The performance goal for MFE is 50% and the performance criteria for MFE is 75%.

Conclusion

The performance of the operational CCAM-CTM modelling system with an in-line SEM was evaluated for selected HRBs in 2018. An operational evaluation was conducted for predicted and observed the $PM_{2.5}$ concentrations across the OEH air quality monitoring network across the Sydney Basin. Three HRB cases are selected from autumn 2018 to evaluate the performance of the SEM.

The presence of smoke related to HRBs are generally correctly captured in the CCAM-CTM modelling, showing reasonable agreement between the observed satellite images and the simulated plume. Time series comparisons of observations and predictions highlighted the model's ability to capture the magnitude of peak $PM_{2.5}$ concentrations from smoke plumes. The statistical metrics averaged over the region indicated that there is a tendency for the models to underpredict the regional $PM_{2.5}$ concentrations which is taken into consideration when this tool is used for forecasting in the region. The modelling system has some skill forecasting the potential impacts of smoke from HRBs and bushfires, however there are some biases in the model which need further investigations.

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