CAUL Project 1: Milestone 16: Annual Report on Air Quality Modelling

Introduction

There have been substantial efforts in the past five years to better characterise the sources of particulate pollution in the Sydney basin and surrounding areas, and to establish robust air quality modelling capabilities as well as quantify health effects of exposure to air pollution. This work has been led by the NSW Office of Environment and Heritage (OEH), NSW Environment Protection Authority (NSW EPA), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australian Nuclear Science and Technology Organisation (ANSTO) plus Universities, including the University of Wollongong. CAUL has worked in partnership with these organisations, to undertake a substantial modelling intercomparison and to build a model ensemble that can provide a greater understanding of the drivers of poor air quality and health outcomes in the Western Sydney region and beyond.

In this report we describe the research efforts over the last year to implement state-of-the-science air quality modelling to assess particle pollution in Western Sydney. The report briefly lists the activities that have been undertaken in 2016 and then lists the papers being prepared. The draft paper outlines are then given as appendices.

Overview of Activities in 2016

- A model validation framework has been developed under a collaborative UOW-OEH postdoctoral research project and used as a starting point for the model intercomparison
- Five separate model runs have been undertaken covering the dates of each of the measurement campaigns. These include WRF-Chem and CMAQ set-up and tailored for the greater Sydney region for the first time. Other models include two versions of the CSIRO-CTM run at OEH and CSIRO. Also the ANSTO radon-only WRF –Chem simulation. Data has been sent to UOW for collation and statistical analysis.
- Further analysis of the LIDAR data from SPS2 and MUMBA has been undertaken in collaboration between ANSTO and UOW to derive a final dataset of boundary layer heights for the campaigns.
- The SPS1 and SPS2 datasets have been finalised and published so that they are publically available.
- A description paper is being prepared for submission to the journal Earth System Science Data

- The MUMBA dataset is being finalised and a description paper for ESSD is near completion
- Additional papers on Marine, biogenic and urban influences are in the early stages of preparation.
- The first round intercomparison of models and observations is complete and model refinements are underway. All data will be sent to UOW to collate and run comparison statistics in R.
- The scientific outcomes of this intercomparison study will be published in a series of papers that are currently in outline stage (and are included as appendices to this report)

List of Scientific Papers planned from Air Quality Modelling work:

1. Paper 1 on model intercomparison (UOW - Elise) – criteria pollutants
2. Paper 2 on model intercomparison (OEH- Khalia) – meteorology (Divide between papers 1 & 2 tbd)
3. Paper 3 on model intercomparison (UM- Steve) – Air Quality on hot days (MUMBA)
4. Paper 4 on model intercomparison (UOW- Jeremy) – AOD

In order to present a more detailed idea of the work progressing in this aspect of the project, the outlines of these four scientific papers are presented as appendices.

Appendix 1: Paper 1: Evaluation of regional air quality models over Sydney, Australia: surface ozone and PM2.5

Abstract

Introduction

Air quality models are valuable tools to investigate the complex and dynamic interactions between meteorology and chemistry leading to poor air quality episodes

This inter-comparison exercise was designed to promote policy-relevant research on regional air quality modelling in Australia, specifically over the greater Sydney area (similar to AQMEII but our models are not operational – except OEH and we are modelling a much smaller region)

Models were run for three periods for which detailed characterisation of atmospheric composition is available with the aims to:

- Determine ability of models to reproduce observed surface concentrations of criteria pollutants, especially ozone and PM2.5, on an hourly basis (and on a rolling 4-hour average basis for ozone and on a daily basis for PM2.5)
- Investigate causes of discrepancies between models and observations and in between models (e.g. biogenic emissions/mixing ratios, chemistry?)
- Discuss implications for modelling framework to test policy scenarios
-

Methods

The modelling has been conducted for the same geographical domains, grid resolution and measurement campaign periods

2.1 Description of models

For AQ evaluation: 3 modelling groups, three models, 4 configurations (UoM: CMAQ, WRF-Chem, CSIRO, OEH)

Domain/grid

Schemes

Emissions – not covered by Khalia

**Need a table – sum over the domain for CO, NOx, etc + range of total emissions over the domain for isoprene (as in Im et al 2015)

Also, map of NOx emissions overlaid with stations that measure O3 and map of PM2.5 emissions overlaid with stations that measure PM2.5 (as per Im et al 2015)

Boundary conditions

Table 1: Overview of the configuration of the air quality models (the meteorological models were described in Monk et al)

Model specifications	Model	WRF-Chem	WRF-CMAQ	CCAM-CTM (CSIRO)	CCAM - CTM (OEH)
	Model Version				
Domain	Number of nests				
	Horizontal resolution (for each nest)				
	Number of x grid points (per nest)				
	Number of y grid points (per nest)				
	Number of vertical layers				
	Height of first layer				
Initial & Boundary conditions	Chemical BCs				
Emissions	Anthropogenic				
	Biogenic				
	Sea salt				
	Dust				
Chemical parameterisations	Gas-phase mechanism				
	Aerosol modules				
	Phytolysis schemes				

2.2 Description of observations

OEH network – ozone, (NOx), PM2.5

PM2.5 speciation?

Campaigns (SPS1 and 2, MUMBA) – detailed characterisation of surface atmospheric composition, including VOCs

- SPS1 and 2
    - When and why was this campaign held – Table 2 for dates
    - References: SPS report
    - Data sources:
        - http://doi.org/10.4225/08/57903B83D6A5D
        - http://doi.org/10.4225/08/5791B5528BD63
- MUMBA
    - When and why was this campaign held
        - Table 2
    - References: MUMBA overview paper – ESSD – in progress
    - Data sources: PANGAEA – in progress

we have two locations with detailed measurements within our domain - this is an advantage (despite the fact that we have two summer campaigns – less relevant for met, but might be useful for AQ parameters)

Table 2: Overview of measurement campaigns

Campaign	Period	Data source	Publication
SPS1	02/2011 - 03/2011		
SPS2	04/2012 - 05/2011		
MUMBA	21/12/2012 – 15/02/2013		

2.3 Statistical analyses

(include equations)

2.3.1 Ozone

r, RMSE, NMSE and NMB as per Im et al 2015 Part 1: Ozone

2.3.2 PM2.5

r, RMSE, MFE and MFB as per Boylan and Russell 2006

"The mean fractional bias (MFB) and mean fractional error (MFE) normalize the bias and error for each model-observed pair by the average of the model and observation before taking the average (does not assume the observations are the absolute truth)

$$\mathrm{MFB} = \frac{1}{N}\sum_{i=1}^{N}\frac{(C_\mathrm{m} - C_\mathrm{o})}{(C_\mathrm{o} + C_\mathrm{m}/2)},$$

$$\mathrm{MFE} = \frac{1}{N}\sum_{i=1}^{N}\frac{|C_\mathrm{m} - C_\mathrm{o}|}{(C_\mathrm{o} + C_\mathrm{m}/2)}.$$

...the mean fractional error and bias are the least biased and most robust of the various performance metrics“

But also test NMSE and NMB as per Im et al 2015 Part 2: PM

$$\mathrm{NMSE} = \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N \times \overline{P} \times \overline{O}} \times 100$$

PCC (r) is a measure of associativity and allows gauging whether trends are captured, and it is not sensitive to bias; RMSE is a measure of accuracy and, because it is squared, is sensitive to large departures

Table 3: Benchmarks for model performance for air quality parameter – THIS TABLE NEEDS UPDATING

Species	Metric	Criteria	Goal	Source
$PM_{2.5}$	MFE	75%	50%	Boylan and Russell (2006), US-EPA (2007)
	MFB	±60%	±30%	
O_3	MFE	35%		
	MRB	15%		
NO_x, CO, PM_{10}	FAC2	Half points within -0.3<FB<0.3		Chang and Hanna (2004)
	FB			
	NMSE	<4		

Model evaluation results

3.1 Ozone

<u>3.1.1 Region/domain-wide analysis</u>

Table with r, RMSE, NMSE and NMB for each model for ozone (hourly and rolling 4-hour average, also max daily ozone?)

Diurnal cycles

- is timing of max ozone right?
- Is amplitude OK? It tends to be larger in models that simulate a more stable and shallow nocturnal boundary layer (Im et al 2015 Part 1)

Box plots (overall and by campaign, or by campaign only? 4 vs. 3 plots – no big deal)

Taylor diagrams (one for each campaign -or all campaigns on one – if legible):

- How spread are the results?
- Are there any outliers?
- How do they vary between campaigns?
- Are there any obvious seasonal differences?

(Note: Taylor plot only show random errors, not systematic bias – Boylan and Russell 2006)

check how the model biases vary with ozone levels – bin ozone (quartiles?) and check NMB for each bin– do this for both time bases (Im et al 2015 Part 1) -all campaigns combined?

Investigate role of boundary conditions for ozone – does the global model overpredicts/underpredicts over the greater Sydney region?

(I will need these boundary conditions from the modellers)

3.1.2 Spatial analysis

Bubble plots of statistical parameters: r, RMSE, NMSE, NMB for each model for each campaign

(hourly only? Or rolling 4-hour and max also? – plot them all, maybe don't include them all)

CMAQ		
WRF-Chem		
OEH		
CSIRO		
SPS1	SPS2	MUMBA

Figure 1: Spatial evaluation of model performance – bubble plot – correlation coefficient

CMAQ		
WRF-Chem		
OEH		
CSIRO		
SPS1	SPS2	MUMBA

Figure 2: Spatial evaluation of model performance – bubble plot – RMSE

CMAQ		
WRF-Chem		

OEH		
CSIRO		
SPS1	SPS2	MUMBA

Figure 3: Spatial evaluation of model performance – bubble plot – NMSE

CMAQ		
WRF-Chem		
OEH		
CSIRO		
SPS1	SPS2	MUMBA

Figure 4: Spatial evaluation of model performance – bubble plot – NMB

3.2 PM2.5

3.2.1 Region/domain-wide analysis

Table with r, RMSE, NMSE and NMB (or MFE and MFB) for each model for PM2.5 (hourly and calendar day average)

FOR PM, daily means a calendar day average - so it makes sense to look at the data on that basis - there is no hourly standard, and no clear diurnal cycle in most cases - but you can check - obs vs. models might let you know whether the timing of emissions is off/weird/wrong

Box plots (overall and by campaign, or by campaign only?)

Taylor diagrams:

- How spread are the results?
- Are there any outliers?
- How do they vary between campaigns?
- Are there any obvious seasonal differences?

3.2.2 Spatial analysis – less relevant, only 5-6 stations

Daily averages only

CMAQ		
WRF-Chem		

OEH		
CSIRO		
SPS1	SPS2	MUMBA

Figure 5…: Spatial evaluation of model performance – bubble plots

3.3 PM2.5 speciation?

Same stats as for PM2.5

Species and time-basis will depend on observations:

- we have OC and EC at MUMBA, OC and EC, SO_4^{2-}, NO_3^- and NH_4^+ for SPS1 and SPS2 (filters: 5- or 8-hour resolution)

Plot timeseries

Table with stats

Discussion

- Do models meet benchmarks for performance? Overall? Site-by site?
- Do models capture exceedances, if any?
- Are there City vs rural? / Inland vs coastal? biases

- What drives the differences between models / with the observations? (look at other parameters such as NOx, isoprene, etc.)
- dry deposition rate (or totals) for each model for ozone? Chemistry schemes?
- NO_2 levels (to interpret ozone)
- Refer back to meteorological analysis – wind speed, mixing height

- Can model reproduce intensive campaign results (anthropogenic VOCs, biogenic tracer, PM2.5 composition)?
- What does this tell us about the models/inputs/etc?
- What is the influence of natural sources vs. anthropogenic sources?
- Also, how do our models fare compared to AQMEII, etc

Summary and conclusions

- Does one model outperform the others?
- Main reason(s) for biases
- Going forward – modelling air quality in the Greater Sydney area – implications for policy/modelling framework

Appendix 2: Paper 2:

Evaluation of regional air quality models over Sydney, Australia: Meteorological models

1.1 Introduction

- The ability of the meteorological models to accurately characterise the regional meteorology plays a crucial part in the performance of photochemical simulations of air pollution.
- The models compared are part of an inter-comparison exercise that was designed to promote policy-relevant research on regional air quality modelling in Australia, specifically over the greater Sydney area.
- Models were run for three periods and detailed characterisation of meteorology is available with the aims to:
    - Determine ability of meteorological models to reproduce observed features of the local meteorology that drives poor air quality episodes on hourly basis
    - Investigate causes of discrepancies between models and observations and in between models
- Why are we doing this study
    - Where is the study focused – Sydney
        - Why is it of importance to focus on this region
            - Population growth
            - Greater impact on airshed
            - Mesoscale meteorological features that drive air pollution
            - Want to provide modelling framework to test policy scenarios
- What other intercomparison/model evaluation studies have been conducted for the purpose of met models into AQMs
    - AQMEII, DEFRA model intercomparison
- How we have conducted this study
    - This study is a collaboration between four different modelling groups using 3 different modelling systems
    - There are five different model configurations

1.2 Methods

The modelling has been conducted for the same geographical domains, grid resolution and measurement campaign periods.

- Description of models - CCAM and WRF (for CMAQ and WRF-Chem)

- Domain/horizontal resolutions/vertical resolution/first layer
- Physics schemes/parametrisations comparison
- Boundary conditions comparisons

Figure 2: Modelling domains (3 nests), station locations

A summary of the configuration of the different meteorological models included in the intercomparison is presented in Table 4.

Table 4: Overview of the configuration of the meteorological models

Model specifications	Model	WRF (Chem)	MCIP (WRF)	CCAM (OEH)	CCAM (CSIRO)	WRF (RADON ANSTO)
	Model Version					
Domain	Number of nests					
	Horizontal resolution (for each nest)					
	Number of x grid points (per nest)					
	Number of y grid points (per nest)					
	Number of vertical layers					
	Height of first layer					
Initial & Boundary conditions	Met input/BCs					
	(Analysis and initialization AI), integration (IN), data assimilation (DA)					
Parameterisations	Microphysics					
	LW radiation					
	SW radiation					
	Land surface					
	PBL/turbulence					
	Convection					
	Aerosol feedbacks					

- Description of observations

- Variables to be examined: Temperature, relative humidity, wind speed wind direction, u and v, precipitation and PBL height
  - Why are these specific variables being looked at
    - Following on from other intercomparison and model evaluation studies of Brunner et al 2015 and Vautard et al 2012
- BoM sites justifying not using OEH for met analysis
  - Note may include more stations.
- Campaigns (SPS1 and 2, MUMBA)
  - SPS1 and 2
    - When and why was this campaign held
    - Discussion on significant meteorological features that may have driven poor air quality during these periods
    - References: SPS report
    - Data sources:
      - http://doi.org/10.4225/08/57903B83D6A5D
      - http://doi.org/10.4225/08/5791B5528BD63
  - MUMBA
    - When and why was this campaign held
      - Table 2
    - Discussion on significant meteorological features that may have driven poor air quality during these periods
    - References: MUMBA overview paper (s) ??
    - Data sources:???

Table 5: Measurement campaigns

Campaign	Period
SPS1	02/2011-03/2011
SPS2	04/2012-05/2011
MUMBA	21/12/2012-02/2013

- Statistical analyses
  - Description of statistical metrics for comparisons
  - Why have we chosen to only show these metrics
    - Dennis et al 2010, Thunis et al 2012, Brunner et al 2015 and Vautard et al 2012
  - MB (positive or negative deviation from the mean), MGE (overall deviation from mean), RMSE (or CRMSE – magnitude of the deviation), R (linear agreement) , IOA, Mean and STDDEV (spread of the data)
  - Benchmark values. See Table 6.

Table 6: Meteorological parameter benchmarks

Variable	Statistical Metric	Units	Benchmark	Terrain type	Source
Wind speed	RMSE	m/s	≤ 2	Simple	(Emery, Tai et al. 2001)
			≤ 2.5	Complex	McNally (2009) , (Kemball-Cook, Jia et al. 2005)
	Bias		≤ ± 0.5	Simple	(Emery, Tai et al. 2001)
			≤ ± 1.5	Complex	McNally (2009) , (Kemball-Cook, Jia et al. 2005)
	IOA	-	≥ 0.6		(Emery, Tai et al. 2001)

Wind direction	MAE/Gross Error	degrees	≤ 30	Simple	(Emery, Tai et al. 2001)
			≤ 55	Complex	McNally (2009), (Kemball-Cook, Jia et al. 2005)
	Bias		≤ ±10		(Emery, Tai et al. 2001)
Temperature	MAE/Gross Error	degrees K	≤ ±2	Simple	(Emery, Tai et al. 2001)
			≤ ±3	Complex	(McNally 2009) , (Kemball-Cook, Jia et al. 2005)
	Bias		≤ ±0.5	Simple	(Emery, Tai et al. 2001)
			≤ ±1	Complex	(McNally 2009) , (Kemball-Cook, Jia et al. 2005)
	IOA	-	≥ 0.8		(Emery, Tai et al. 2001)
Mixing ratio	MAE/Gross Error	g/kg	≤ 2		(Emery, Tai et al. 2001)
	Bias		≤ ± 1		(Emery, Tai et al. 2001)
	IOA	-	≥ 0.6		(Emery, Tai et al. 2001)

1.3 Model Evaluation Results

Averaging across all site (by owner) and presenting comparisons between models.

1.3.1 Region wide analysis

1.3.1.1 Temperature

- Brunner et al 2015: Temperature is of prime importance for atmospheric chemistry as it controls the rate of chemical reactions and also alters the gas particle phase partitioning, thus altering the aerosol concentrations.
- Diurnal cycles comparisons
    - How do each of the models compare
    - How well do the models do during the day where they will be associated with a maximum impact on air quality models because of photochemical processes

SPS1	SPS2	MUMBA

Figure 3: Campaign average diurnal cycle for temperature for each model and campaign (averaging over all BoM stations)

- Performance statistics
    - Which models have the smallest bias and error?
    - Do they meet benchmarks (Emery et al 2005,)
    - How well do they correlate
    - Does the IOA meet benchmarks
    - Taylor diagrams
        - Which models are closest to the reference (comparison of R, CRMSE and STDDEV)

Table 7: Summary of statistics for temperature for each model

	Mean Obs	Mean Model	Stddev	MB	MGE	CRMSE	R	IOA
CMAQ								
WRF-Chem								
OEH								
CSIRO								

WRF-RADON 1								
WRF-RADON 2								

- Taylor Diagrams
    - How spread are the results
    - Are there any outliers
    - How do they vary between campaigns
    - Are there any obvious seasonal differences

Figure 4: Taylor diagrams for temperature comparing models and campaign (averaging over all BoM stations)

- Vertical profiles comparisons (Mascot)
    - What is the mean bias throughout the atmosphere
    - How do they vary between models

MB	MB	MB
CRMSE	CRMSE	CRMSE
R - SPS1	SPS2	MUMBA

Figure 5: Vertical profile plots for temperature averaged all measurement comparing models and campaign

1.3.1.2 Relative Humidity

- How will this parameter impact on chemical process in AQ model
- Diurnal cycles comparisons
    - How do each of the models compare
    - How well do they during the day where they will be associated with a maximum impact on air quality models because of photochemical processes

SPS1	SPS2	MUMBA

Figure 6: Campaign average diurnal cycle for relative humidity by model and by campaign (averaging over all BoM stations)

- Performance statistics
    - Which models have the smallest bias and error?
    - Do they meet benchmarks (Emery et al 2005,)
    - How well do they correlate
    - Does the IOA meet benchmarks
    - Taylor diagrams
        - Which models are closest to the reference (comparison of R, CRMSE and STDDEV)

Table 8: Summary of statistics for relative humidity for each model

	Mean Obs	Mean Model	Stddev	MB	MGE	CRMSE	R	IOA
CMAQ								
WRF-Chem								
OEH								
CSIRO								

WRF-RADON 1								
WRF-RADON 2								

- Taylor Diagrams
  - How spread are the results
  - Are there any outliers
  - How do they vary between campaigns
  - Are there any obvious seasonal differences

Figure 7: Taylor diagrams for relative humidity comparing models and campaign (averaging over all BoM stations)

- Vertical profiles comparisons (Mascot)
  - What is the mean bias throughout the atmosphere
  - How do they vary between models

MB	MB	MB
CRMSE	CRMSE	CRMSE
R - SPS1	SPS2	MUMBA

Figure 8: Vertical profile plots for relative humidity averaged all measurement comparing models and campaign

1.3.1.3 Wind

- Look at wind speed or u and v or both?
  - Brunner et al 2015: Wind speed and direction control the horizontal transport and thereby the spatial distribution of pollutants. Wind speed is a particularly important parameter as it influences the volume of air into which emissions are diluted, determines the transport time between sources and receptor locations, and also controls the emission of sea salt and dust
- Wind direction
  - Brunner et al 2015: Wind direction is not evaluated. While the evaluation of wind directions at single stations (e.g. by comparing wind roses) is useful, a statistical evaluation of wind directions is complicated by the fact that wind direction errors typically become large at low wind speeds (Jimenez and Dudhia, 2013). Furthermore, an average wind direction for a given subregion would provide little useful information and other statistics such as correlations or RMSE would not be useful at all.

1.3.1.3.1 Wind speed

- Diurnal cycles comparisons
  - How do the models compare
  - How do they vary between campaigns
  - What are going on with the overnight wind speeds as this are will directly influence the dispersion of pollutants overnight.

SPS1	SPS2	MUMBA

Figure 9: Campaign average diurnal cycle for wind speed by model and by campaign (averaging over all BoM stations)

- Performance statistics
  - Which models have the smallest bias and error?
  - Do they meet benchmarks (Emery et al 2005,)
  - How well do they correlate
  - Does the IOA meet benchmarks
  - Taylor diagrams
    - Which models are closest to the reference (comparison of R, CRMSE and STDDEV)

Table 9: Summary of statistics for wind speed for each model

	Mean Obs	Mean Model	Stddev	MB	MGE	CRMSE	R	IOA
CMAQ								
WRF-Chem								
OEH								
CSIRO								
WRF-RADON 1								
WRF-RADON 2								

- Taylor Diagrams
  - How spread are the results
  - Are there any outliers
  - How do they vary between campaigns
  - Are there any obvious seasonal differences

Figure 10: Taylor diagrams for wind speed comparing models and campaign (averaging over all BoM stations)

- Vertical profiles comparisons (Mascot)
  - What is the mean bias throughout the atmosphere
  - How do they vary between models

MB	MB	MB
CRMSE	CRMSE	CRMSE
R - SPS1	SPS2	MUMBA

Figure 11: Vertical profile plots for wind speed averaged all measurement comparing models and campaign

1.3.1.3.2 Meridional and Zonal winds (u and v)

- Diurnal cycles comparisons
  - How do the models compare
  - How do they vary between campaigns
  - What are the overnight wind magnitudes as this will directly influence the dispersion of pollutants overnight.

U		
V SPS1	SPS2	MUMBA

Figure 12: Campaign average diurnal cycle by model and by campaign for (top) meridional and (bottom) zonal winds (averaging over all BoM stations)

- Performance statistics
  - Which models have the smallest bias and error?
  - Do they meet benchmarks (Emery et al 2005,)
  - How well do they correlate
  - Does the IOA meet benchmarks
  - Taylor diagrams
    - Which models are closest to the reference (comparison of R, CRMSE and STDDEV)

Table 10: Summary of statistics for meridional winds for each model

Variable	Model	Mean Obs	Mean Model	Stddev	MB	MGE	CRMSE	R	IOA
U	CMAQ								
	WRF-Chem								
	OEH								
	CSIRO								
	WRF-RADON 1								
	WRF-RADON 2								
V	CMAQ								
	WRF-Chem								
	OEH								
	CSIRO								
	WRF-RADON 1								
	WRF-RADON 2								

- Taylor Diagrams
  - How spread are the results
  - Are there any outliers
  - How do they vary between campaigns
  - Are there any obvious seasonal differences

U
V

Figure 13: Taylor diagrams for (top) meridional and (bottom) zonal winds comparing models and campaign (averaging over all BoM stations)

- Vertical profiles comparisons (Mascot)
  - How do the model results vary through the atmosphere
  - Are there any regions with higher biases, CRMSE or R

MB	MB	MB

CRMSE	CRMSE	CRMSE
R - SPS1	R - SPS2	R - MUMBA

Figure 14: Vertical profile plots for meridional winds averaged all measurement comparing models and campaign

MB	MB	MB
CRMSE	CRMSE	CRMSE
R - SPS1	SPS2	MUMBA

Figure 15: Vertical profile plots for zonal winds averaged all measurement comparing models and campaign

1.3.1.4 Precipitation

- Brunner et al 2015: Wash-out of water soluble species by precipitation is an important sink of pollutants from the atmosphere. Pollutants are scavenged in-cloud by cloud droplets growing to sizes large enough to form precipitation, or below-cloud by precipitation falling through layers of air below the cloud.
- Time series of accumulated precipitation
    - How do each of the models compare
    - Are they getting the precipitation at the correct times

SPS1	SPS2	MUMBA

Figure 16: Time series of accumulated precipitation by each model and for each campaign (averaging over all BoM stations)

1.3.1.5 PBLH

- Brunner et al 2015: Vertical mixing by atmospheric turbulence controls the dilution of air pollutants released at the surface into the vertical column and thereby critically determines near-surface concentrations.
- Depending on methodology for computation of this variable – if two measurements are available from radiosondes or from LIDAR derived dataset
    - CSIRO may provide airplane based measurement dataset.
    - Note may compute based on a smaller period where more complete?
    - Performance statistics
- Diurnal cycle
    - How do the models compare
    - How do they vary between campaigns

SPS2	MUMBA

Figure 17: Diurnal profile plots for PBLH at Westmead comparing models and campaign (possibly add in Sydney airport sonde PBLH)

1.3.2 Spatial analysis

- Bubble plots:
    - Temperature, Tmin, Tmax, relative humidity, wind speed, precip?
- statistics (MB, RMSE, R)

CMAQ		
WRF-Chem		
OEH		
CSIRO		
WRF-RADON1		
WRF-RADON1 - SPS1	SPS2	MUMBA

Figure 18: Bubble plots for MB of temperature comparing models and campaign

CMAQ		
WRF-Chem		
OEH		
CSIRO		
WRF-RADON1		
WRF-RADON1 - SPS1	SPS2	MUMBA

Figure 19: Bubble plots for CRMSE of temperature comparing models and campaign

CMAQ		
WRF-Chem		
OEH		
CSIRO		
WRF-RADON1		
WRF-RADON1 - SPS1	SPS2	MUMBA

Figure 20: Bubble plots for R of temperature comparing models and campaign

Etc???

1.4 Discussion

- Are there City vs rural? / Inland vs coastal? OEH/BoM? biases
- Do the models capture the strength and timing of the sea breeze
- How well is the PBL characterised
- Do models meet benchmarks for performance? Overall? Site-by site?
- What drives the differences between models?
- What does this tell us about the models/inputs/etc?

1.5 Summary and Conclusions

- Does one model outperform the others?
- Main reason(s) for biases
- How will this impact on modelling air quality in the Greater Sydney area?

Appendix 3: Paper 3:

Hot summers: impact of elevated temperatures on air quality in Sydney, NSW

Utembe et al

December 20, 2016

1 Introduction

- Impact of air quality on health
- Impact of extreme weather events on air quality
- Incidences of elevated temperatures

Aims of paper are:

- to study air quality during elevated temperatures in Sydney 2013 and contrast with air quality under normal temperature conditions
- to examine statistical correlations between measured elevated biogenic, ozone concentrations and hot temperature days?
- to conduct sensitivity studies on the impact of temperature on air qual- ity

2 High Temperatures events during Summer of 2013 in Sydney

Here we present observed extreme temperatures in Sydney in January 2013

3 Methodology and Results

3.1 Description of models

- domain
- chemistry schemes
- aerosol schemes

3.2 Simulation of meteorology by the different models

Comparison with observations

3.3 Simulation of gas and aerosol species concentrations by the different models

Compare with observations

3.4 Sensitivity studies (WRF-Chem only)

The plan is to hack wrfchem so that there is another temperature variable T_high = T + offset where T is the normal temperature from the model and T_high is only used (instead of T) to calculate new reaction rates for chemistry and biogenics so that we can look at temperature sensitivity studies by:

- increasing temperature by 2 degrees
- increasing temperature by 5
- increasing temperature by 10

4 Discussion

4.1 Using observed temperatures

For hot vs normal days analyse and discuss the effect of temperature on:

- biogenic concentration (ozone precursors)

- ozone concentration
- particulate concentration
- exceedances

4.2 Sensitivity studies

Compare as above

5 Conclusions

Hopefully we will conclude that:

- Extreme (hot) days compound air quality problems via
- Effect of temperature on generation of biogenics so that
- Climate change is expected to result in poor air quality in cities like Sydney
- Any other conclusions

Appendix 4: Paper 4:

Aerosol Optical Depth around Sydney, Australia

Jeremy Silver

1 Introduction

Points to make:

- Aerosols harmful for health
- Air quality in Australia is generally good, but may be getting worse in cities

- AOD offers us a long-term spatial average and allows us to work out trends, spatial hot-spots, incidents, etc.
- AOD can provide spatial validation of the models

Aims of paper:

- Test whether AOD is a decent proxy for $PM_{2.5}$ in the GMR
- Test models' spatial skill for aerosols via AOD, throughout each campaign
- Identify some high AOD days, and hot-spots during the period - relate them to case studies
- Look at long-term spatial averages and tends across the GMR

2 Methods and results

2.1 Surface PM and remotely-sensed AOD

Introduce:

- Satellite AOD datasets + any processing
- Surface AOD datasets
- Surface $PM_{2.5}$ datasets
- Also, potentially, the region (topographic +

population maps) Examine:

- Relationship between surface-based AOD and $PM_{2.5}$ at any collocated sites
  - Scatter-plots at sites, possibly examining the relationship for different seasons, wind-sectors, wind- speed bins
- Relationship between surface-based AOD and satellite-based AOD
  - Same as for surface-based AOD vs. $PM_{2.5}$

- Relationship between satellite-based AOD and surface $PM_{2.5}$
  - Same as for surface-based AOD vs. $PM_{2.5}$

For this I will need:

- All surface $PM_{2.5}$ obs in the region
- All surface-based AOD obs in the region
- Collocated satellite-based AOD time-series

2.2 Model skill for AOD during campaigns

Introduce:

- The models
- The campaign periods
- Any averaging procedures

Examine:

- Spatially averaged AOD for each campaign
  - Gridded modelled, gridded retrieved maps
  - Look at bias, correlation, standard deviation ratio (other metrics ??)
- Modelled surface PM vs AOD
  - Is the relationship strong? Scatterplots modelled AOD vs modelled PM
  - Is the midday/snapshot AOD representative for daily AOD - for daily PM? Scatterplots of snapshot vs daily average.
  - Under what conditions is the relationship strong? ie. wind sectors, wind speed bins, times of day? Plots of correlations of the above conditional on the wind speed/direction, hour-of-day.
- Incidents/episodes
  - Any smoke events? Plots of MODIS fires, plots of surface PM and AOD.
  - Representative examples of on-shore or off-shore flow. Plots of PM and AOD for these times.

For this I will need:

- Gridded hourly AOD from each model
- Gridded AOD from the satellite products
- Gridded hourly surface PM from each model
- MODIS fire product for the region

2.3 Trends and patterns in AOD across the region

Examine:

- Long-term averages
  - Maps of averages
- Trends

- Maps of trends
- Time-series of trends at specific locations/regions
- Possibly averaging across the area using an exposure proxy (e.g. weighting by population/gridcell)

• Seasonal patterns

- Time-series: monthly median 10%, 90% quantiles for specific locations/regions

For this I will need:

• Gridded AOD from the satellite products, over as long a time-series as possible

3 Discussion

Points to make:

• The models were able to reproduce these trends... but not these ...

• The models detected some events (...) but not others (...)

• Relationship between AOD and surface PM is weak/strong in the GMR

• Gridded AOD shows an increasing/decreasing trend across t

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