Report

ENERGY FROM WASTE FACILITY – OZONE IMPACT ASSESSMENT

THE NEXT GENERATION

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EXECUTIVE SUMMARY

The Next Generation NSW Pty Ltd (TNG NSW) proposes to construct and operate an Energy from Waste (EfW) facility on land adjacent to the Genesis Xero Waste facility in Eastern Creek. Pacific Environment has been engaged by TNG NSW to prepare an Ozone Impact Assessment for the facility.

At present there are no regulatory documents or policies in the public domain that prescribe the preferred methodology for ozone impact assessment in NSW. Pacific Environment has discussed the broad assessment approach with the EPA and the following sections are based on our understanding of a proposed ozone assessment framework. As is stands, this project is the first project in NSW to be assessed under the ozone assessment framework.

A review of maximum 1-hour and 4-hour ozone concentrations within the region has been completed. Based on this analysis, the Sydney region is classified as an ozone non-attainment area. This classification thus determines the applicable assessment pathway within the ozone assessment framework.

The annual oxides of nitrogen (NO_x) emissions for the TNG EfW facility have been estimated based on the facility meeting an in-stack concentration limit of 200 mg/Nm^3, expressed as a daily average. Assuming the EfW facility emits NO_x at this limit for ~8,000 hours of the year, the annual NO_x load to the Sydney airshed would be in the region of 800 tonnes/year. At this level, ozone assessment is triggered and the next step in the framework is a Level 1 screening assessment.

However, given that projected emissions from the facility exceed the ozone assessment threshold by >8 times, the approach for this assessment has been to proceed directly to a Level 2 refined assessment. The approach to the level 2 refined assessment has been discussed with both the NSW Environmental Protection Authority (EPA) and Office of Environment and Heritage (OEH).

As agreed with the EPA and OEH, the photochemical grid model (PGM) used in the assessment is the CSIRO's The Air Pollution Model (TAPM), with chemical transport module (TAPM-CTM).

TAPM-CTM has been widely adopted in Australia and has also been used and evaluated in the United States, New Zealand, Thailand and Europe.

Under the ozone refined assessment approach, emissions data are required for two scenarios. A "Base Case" scenario assesses model performance without the emissions from the EfW facility. In other words, all existing emissions sources are modelled and compared to monitoring data for the same period. A "Test Case" scenario then assesses the impact from the addition of the EfW facility.

For the Base Case scenario, TAPM-CTM ready gridded GMR emissions inventory data (for anthropogenic sources of ozone precursors) were provided by EPA for January and February 2008.

The selection of this time period for modelling is based on a review of ozone monitoring data, which was then used to identify an "ozone season" or period when ozone concentrations were elevated. Selected days within this "ozone season" have subsequently been selected for detailed analysis based on:

- High measured ozone concentrations.
- High modelled ozone concentrations.
- Days when the model performs well (predicted comparable to observed).
- Ozone impact occurs over land.

We have reviewed five years of ambient ozone monitoring data across the GMR and Illawarra to identify "ozone seasons" for modelling – i.e. summer months which contain a number of consecutive days of high (comparable to NEPM standards) 1-hour and 4-hour ozone concentrations.

The days selected for analysis of impact are:

- 28 January 2009
- 30 January 2009
- 31 January 2009
- 6 February 2009
- 7 February 2009
- 8 February 2009

It is highlighted that during the last four days (6 to 9 February) bushfires were recorded in the Sydney region. It may be expected that the performance of the TAPM-CTM model will not be optimal during these days without accurate characterisation of this important source of ozone precursors. However, it was agreed, through consultation with both OEH and EPA that these days would be included in the assessment for evaluation purposes.

Model performance for the Base Case was evaluated against the measured 1-hour ambient concentrations and found to perform with an acceptable degree of accuracy. A general observation is that the model tends to over predict when ambient concentrations are low and under predict peak O_3 concentrations.

An important consideration in any photochemical modelling exercise is the degree of accuracy that can be expected of the model outputs in comparison with observations. Photochemical modelling is an evolving field. Such wide degrees of uncertainty in photochemical modelling are typically a function of the uncertainty of the inputs, for example the complexity and variability in the nature of biogenic emissions.

Uncertainties in the model were identified to include the 2008 GMR inventory, the influence of bushfire events, boundary layer height predictions and the role of biogenic emissions.

The significance of impact on ground-level ozone in the GMR is assessed based on the screening impact level (SIL) of 0.5 ppb and maximum allowable increment of 1 ppb.

Analysis of the TAPM-CTM model outputs shows that the difference between the maximum 1-hour and 4-hour O_3 for the Base Case and Test Case, across the region, may be above the maximum allowable increase of 1 ppb on specific occasions and at locations.

However, while incremental O_3 concentrations are predicted to be greater than 1 ppb on particular hours at particular locations, these do not relate to periods of time or locations where the maximum concentrations are occurring, nor at concentrations that are predicted to exceed the NEPM ambient O_3 criteria. In other words, while the value of 1 ppb is predicted to occur on occasion under the Test Case scenario, this ozone formation is predicted to occur during periods when ambient ozone is low (and thus of lesser concern).

It is noted that a reasonable worst case Test Scenario assumes that both stacks are continuously operating at the EU IED daily emission limit. Typically during normal operations of the plant, the emission levels are anticipated to be lower. The facility will employ Best Available Technology (BAT) in the form of Selective Non-Catalytic Reduction (SNCR) for reducing emissions of NO_x, the dominant ozone precursor released from the facility. VOCs will be minimised through combustion control with additional controls afforded from activated carbon injection as part of the flue gas treatment.

The EPA's proposed ozone assessment framework states that if the maximum ozone increment is below the Screening Impact Level (SIL; 0.5 ppb), the project must demonstrate that best management practice (BMP) is implemented for the emission source and all Reasonably Available Technology (RAT) should be considered. Further, it states that if the maximum ozone increment is above the SIL but below

the maximum allowable increment (1 ppb), the project must demonstrate best management practice (BMP) for the emission source and consider Best Available Technology (BAT) and/or emissions offsets.

If the maximum ozone increment is above the maximum allowable increment, the EPA may consider the impact of the source on local and regional air quality having regard to the following:

i. The outcomes of the BMP determination
ii. The frequency and duration of ground-level ozone impacts
iii. Any pollution reduction programs established or agreed to
iv. Any control equipment installed or agreed to
v. Any load reduction agreement entered into
vi. The principles of ecologically sustainable development.

It is considered that the current report provides the regulator with adequate information to inform the likely source impact in the above terms.

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1 INTRODUCTION

The Next Generation NSW (TNG) propose to construct and operate an Energy from Waste (EfW) facility on land adjacent to the Genesis Xero Waste facility, located at Honeycomb Drive, Eastern Creek, Sydney. The EfW will accept between 900,000 to 1,350,000 tonnes of waste per annum (tpa) for thermal conversion and generation of electrical power.

Pacific Environment has been engaged by TNG to prepare an Ozone Impact Assessment as part of an Environmental Impact Statement (EIS), required under State Significant Development provisions under Section 78A(8A) of the *Environmental Planning and Assessment Act* 1979 (EP&A Act).

1.1 Background

The NSW Environment Protection Authority (NSW EPA) has provided '*Agency Requirements*' for the Environmental Assessment of the proposed The Next Generation (TNG) Energy from Waste facility (EfW) at Eastern Creek, including a photochemical smog assessment, as follows:

> *Include a quantitative photochemical smog assessment in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (2005)*

The Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (The Approved Methods; (**NSW EPA, 2005**)) state that advice should be sought from the EPA prior to undertaking a quantitative photochemical smog[a] assessment. In accordance with the Approved Methods, Pacific Environment has consulted with the EPA and NSW Office of Environment and Heritage (OEH) (refer **Table 1-1**).

[a] The terms photochemical smog and ozone are used interchangeably. Ozone is a secondary pollutant formed in a chemical reaction when precursor emissions of oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) react in the presence of sunlight.

Table 1-1: Outcomes of consultation

Agency	Date	Discussion Point / Outcome
NSW EPA (Air Policy)	28/02/2014	The EPA Level 1 screening tool for ozone assessment was not publicly available. The project was likely to need a Level 2 detailed assessment (based on Western Sydney being an ozone non-attainment area and the emissions threshold being exceeded).
NSW EPA (Air Policy)	6/03/2014	The Level 2 assessment requirements were discussed and formal consultation (teleconference between EPA, OEH and Pacific Environment) was arranged to discuss the approach to the assessment
OEH (Climate and Atmospheric Science Branch)	20/03/2014	Detailed discussion of approach to the assessment. Agreement on the use of TAPM-CTM with CB05 chemical mechanism, 2008 emissions data from EPA GMR air emissions inventory, and methodology to select scenario days. It was suggested by OEH that a method paper is prepared for review by CSIRO
NSW EPA (Air Policy),	17/2/2015	Preliminary discussion of the reported results. EPA indicated that OEH should also be given opportunity to provide additional comment.
NSW EPA (Air Policy), OEH (Climate and Atmospheric Science Branch) and CSIRO	10/03/2015	Discussion around additional analysis of NO_2 and NO_x predictions prepared by Pacific Environment, in consultation with CSIRO, in advance of this meeting. Discussion identified that an updated version of TAPM-CTM and OEH emission inventory inputs files had become available since the original modelling and should be incorporated into the modelling.
NSW EPA (Air Policy), OEH (Climate and Atmospheric Science Branch) and CSIRO	1/04/2015	Teleconference to discuss outcomes of revised modelling incorporating the above updated model inputs.
CSIRO	10/04/2015	Completion of CSIRO peer review role, as summarised within letter report provided as **Appendix F**.

2 PROJECT DESCRIPTION AND STUDY AREA

2.1 Overview

The development involves the construction and operation of an electricity generation plant, which will allow for unsalvageable and uneconomic residue waste from the Genesis Xero Material Processing Centre (MPC) and Waste Transfer Station (WTS) to be used for generation of electrical power.

This development site is part of a proposal to construct and operate NSW's largest EfW facility using as fuel, residual waste which would otherwise be land filled, to allow for a "green" electricity generation facility. The plant, powered by burning non-recyclable combustible waste material, will have a capacity for up to 1.35 million tonnes of waste material per annum, as follows:

- 850,000 tonnes per annum (tpa) from waste already being received at the neighbouring Genesis Xero Waste Facility.
- Up to 500,000 tpa from external (new) sources.

2.2 Proposed technology

The facility will operate a well-established technology known as a moving grate furnace. Waste is gravity fed onto the incinerator grate. The grate is continually moving thus promoting continuous mixing of the waste with the combustion air, extracted from the tipping hall and introduced from beneath the

grate into the heart of the fire. Further air is injected just above the fire to promote mixing and complete combustion of the gases.

Fuel gas burners are installed for start-up and to maintain the furnace temperature, if required. However, during normal operation no support fuel is required to maintain the minimum 850°C.

Ash from the grate is discharged into a water filled quench bath from where it is moved by conveyor to the enclosed ash storage bunkers prior to being transported off site. All incinerator bottom ash is sent to the adjoining Genesis facility or other licenced facilities for aggregate and road base production. Residue ash from the pollution control system is collected into sealed storage tanks and transported off-site for further treatment or disposal via sealed tanker vehicle.

Hot gases from the combustion of the waste pass through a heat recovery boiler. The temperature of the gases is reduced from over 850°C to around 150°C. The energy from the hot gases is transferred to the boiler to produce high pressure steam. This steam is fed to the steam turbine driven generator capable of generating around 150 MW, which, after supplying the site electrical load is exported to the National Grid.

The facility will operate 24 hours a day, 7 days a week, with occasional offline periods for maintenance. Over the entire year, it is assumed that the facility would be operational for 8,000 hours as an annual average.

Some wastes would be delivered directly to the facility (by truck) with the remaining transferred from the existing Genesis Xero Waste facility either via a covered electrically powered conveyor or by truck. The EfW facility will have capacity between 900,000 to 1,350,000 tonnes of waste per annum. The following waste fuel types are considered as the main sources of fuel for the facility.

- Chute Residual Waste (CRW) from the Genesis Facility.
- Commercial and Industrial (C&I) Waste.
- Construction and Demolition waste (C&D).
- Flock waste fuel supply from car and metal shredding.
- Other organic waste.

2.2.1 Flue gas treatment

The proposed technology for the EfW facility is based on existing facilities in the UK and rest of Europe and will incorporate best available technology (BAT) for flue gas treatment. The flue gas treatment is designed to meet the in-stack concentrations limits for waste incineration set by the European Union's Industrial Emissions Directive (IED) (2010/75/EU). The flue gas treatment system includes:

- Selective Non-Catalytic Reduction (SNCR) for reducing emissions of oxides of nitrogen.
- Dry lime scrubbing for reducing emissions of acid gases, including hydrogen chloride (HCl) and Sulfur Dioxide (SO_2).
- Activated carbon injection for reducing emissions of dioxins and mercury.
- Fabric filters for reducing emissions of particles and metals.
- Following flue gas treatment, dispersion via two 100m tall stacks.

2.3 Study area

The proposed Energy from Waste Facility is located at Eastern Creek, approximately 36 km west of the Sydney CBD, in the Western Suburbs of Sydney, as shown in **Figure 2-1:** . The site is surrounded by the residential areas of Minchinbury, Mt Druitt and Rooty Hill to the north, Erskine Park to the east and Colyton to the northwest. The project is located within the Greater Metropolitan Region (GMR) that comprises the Sydney, Illawarra and Newcastle regions. The extent of the GMR is shown in **Figure 2-2**.

Figure 2-1: Project location

Figure 2-2: GMR (EPA, 2012a)

3 OZONE ASSESSMENT FRAMEWORK

3.1 Overview

At present there are no regulatory documents or policies in the public domain that prescribe the preferred methodology for ozone impact assessment in NSW. Pacific Environment has discussed the broad assessment approach with the EPA and the following sections are based on our understanding of a proposed ozone assessment framework, which is outlined in **Environ, 2011**. As is stands, this project is the first project in NSW to be assessed under the ozone assessment framework.

An overview of the framework is shown in **Figure 3-1**. The proposed EfW facility requires consideration of ozone impacts as it satisfies all the following:

- It is an activity listed under Schedule 1 of the *Protection of the Environment Operations Act 1997*.
- It will release ozone precursors as part of the project's proposed operations.
- It is located within the NSW Greater Metropolitan Region (GMR) as defined within the *Protection of the Environment Operations (Clean Air) Regulation 2010*.
- It is a requirement of the DGRs.

An assessment of ozone impact follows the steps outlined in the framework (**Figure 3-1**) and discussed in the sections below.

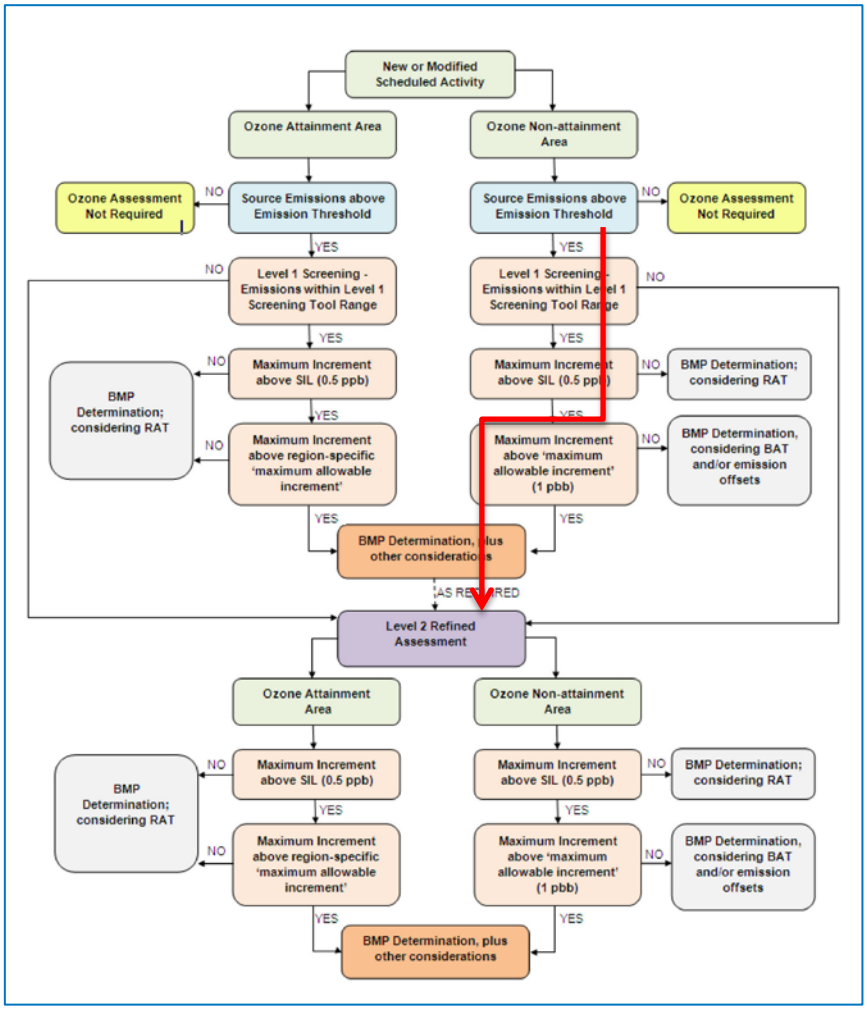


Figure 3-1: Ozone impact assessment procedure and current assessment pathway

3.2 Step 1 - Classification of region as ozone attainment or ozone non-attainment area

The first step in the process is to determine if the project is located within an "attainment area" or "non-attainment area". Ozone attainment and non-attainment areas are defined based on comparison with the ambient air quality (NEPM[b]) goals. The average of five years of monitoring data for the region is compared against an "acceptance limit" which is expressed as 82% of the NEPM goal (**NEPC, 2007**).

A review of maximum 1-hour and 4-hour ozone concentrations within the region has been completed, with aggregated average for the Sydney monitoring stations presented in **Table 3-1**. Based on this analysis, the Sydney region is classified as an ozone non-attainment area. The right hand side of the ozone assessment framework flow chart (**Figure 3-1**) becomes the applicable pathway. Further analysis of the ozone concentrations across the Sydney region is provided in **Section 7.2.**

Table 3-1: Annual maximum 1-hour and 4-hour ozone concentrations in Sydney

Year	Annual 1-hour maximum ozone concentration (ppm)	82% of the NEPM (ppm)	Annual 4-hour maximum ozone concentration (ppm)	82% of the NEPM (ppm)
2009	0.154		0.112	
2010	0.119		0.103	
2011	0.136		0.122	
2012	0.095		0.084	
2013	0.117		0.110	
Average	**0.124**	**0.082**	**0.106**	**0.056**

Notes: NSW EPA monitoring Station include: Chullora, Earlwood, Lindfield, Randwick, Rozelle, Prospect, Richmond, St Marys, Vineyard, Bargo, Bringelly, Campbelltown West, Liverpool, Macarthur and Oakdale.

3.3 Step 2 - Emissions threshold

The second step evaluates the annual NO_x and VOC emissions from the project and compares them with the emission thresholds, shown in **Table 3-2**. Scheduled activities that trigger the relevant emissions threshold are required assess the significance of the incremental ozone contributions.

Table 3-2: Emission thresholds for Schedule 1 activities located in non-attainment areas

Regulatory requirement	Source type	NOx / VOC Emission rates (tonnes/year)
Any scheduled activity listed in Schedule 1 of the *POEO Act* (2007)	New	>90
	Modified	>35

The annual NO_x emissions for the TNG EfW facility have been estimated based on the facility meeting an in-stack concentration limit of 200 mg/Nm^3, expressed as a daily average. Assuming the EfW facility emits NO_x at this limit for 333 days a year (or 8,000 hours of the year), the annual NO_x load to the Sydney airshed would be in the region of 800 tonnes/year. At this level, ozone assessment is triggered and the next step in the framework is a Level 1 screening assessment.

The Level 1 screening tool is currently not available. Given that projected emissions from the facility exceed the threshold by >8 times, the approach for this assessment is to proceed directly to a Level 2 refined assessment. The approach to the level 2 refined assessment has been discussed with the EPA and OEH and is outlined the sections below.

[b] National Environment Protection Measures for Ambient Air Quality (referred to as the Ambient Air-NEPM) (**NEPC, 1998**)

4 OZONE ASSESSMENT CRITERIA

Ozone (O_3) is a secondary pollutant formed in a chemical reaction when emissions of NO_x and VOCs react in the presence of sunlight (as follows):

$$NO + VOCs \xrightarrow{sunlight} NO_2 + O_2 \xrightarrow{sunlight} NO + O_3$$

Ozone is the principal component of photochemical smog, which is typically formed several hours after the precursors (NO_x and VOCs) are emitted. This means that the highest concentrations of ozone normally occur on summer afternoons in areas downwind of major sources of the precursors. The dominant ozone precursor released from the facility is NO_x.

Ground-level ozone continues to be a problem in Sydney during summer months. Unlike many other pollutants, ozone levels in Sydney are not decreasing and may actually be on a slight upward trend (**NSW DECCW, 2009**).

At ground level, elevated ozone concentrations can cause health and environmental problems. As well as affecting vegetation growth and damaging materials such as rubber, fabric, masonry, and paint, it can also reduce visibility. Ozone (O_3) is a strongly oxidising gas. Human exposure to ground-level ozone damages lung tissue and reduces lung function. High concentrations of ozone affect not only people with respiratory problems such as asthma, but also healthy adults and children **(NSW DECCW, 2010a)**.

Ambient air quality standards for ozone are contained in the National Environment Protection Measure (NEPM) for ambient air quality (**NEPC, 1998**) and are summarised in **Table 4-1**.

Table 4-1: Air quality standards for ozone

Pollutant	Standard	Averaging Period
Ozone	100 ppb	1-Hour
	80 ppb	4-Hour

In addition, the proposed ozone assessment framework defines criteria for assessment of increments to ground level ozone concentrations in the GMR.

The framework defines a screening impact level (SIL) and maximum allowable increment as follows:

- Screening impact level (SIL) of 0.5 ppb
- Maximum allowable increment of 1 ppb

5 MODELLING APPROACH

As agreed with the EPA and OEH, the photochemical grid model (PGM) used in the assessment is the CSIRO's The Air Pollution Model (TAPM), with chemical transport module (TAPM-CTM).

5.1 TAPM-CTM

A literature review was completed as part of the **Environ (2011)** assessment guidance and evaluated a number of photochemical models from the United States, Europe and Australia including:

- CAMx
- CMAQ
- CHIMERE
- TAPM/TAPM-CTM
- CIT

Rather than providing detailed information on each of the above models, we have limited this high level review to the findings of **Environ (2011)** that specifically relate to TAPM-CTM.

TAPM-CTM has been widely adopted in Australia and has also been used and evaluated in the United States, New Zealand, Thailand and Europe.

TAPM-CTM makes use of integrated prognostic meteorological fields, unlike its competitors, and is limited to urban scale modelling. All models include comprehensive gas-phase photochemical mechanisms (e.g. CB4, CB05, MELCHIOR1 and MELCHIOR2) in addition to inorganic and secondary organic aerosols.

An important consideration in any photochemical modelling exercise is the degree of accuracy that can be expected of the model outputs in comparison with observations. Moreover, it is reasonable to expect that correlations of 0.7 are considered a reasonable result and that time lags and minor geographical offsets are expected. Photochemical modelling is an evolving field. Such wide degrees of uncertainty in photochemical modelling are typically a function of the uncertainty of the inputs, for example the complexity and variability in the nature of biogenic emissions. The main sources of uncertainty for the current project are discussed in **Section 9.1**.

A number of validation studies have been completed for the use of TAPM-CTM in photochemical modelling, specifically addressing ozone in the urban air shed. In 2008 CSIRO **(Galbally, 2008)** completed a study involving the measurement and modelling of levels of ozone and their precursors in Sydney. The purpose of the study was to verify and identify changes that can be made in the inventories and modelling systems to improve the robustness of ozone modelling. In-situ measurements collected at Randwick and Bringelly from 2007 were compared with three emissions inventories[c] that utilised the CB05 chemical mechanism, among others. Key outcomes of the study highlighted the important role of biogenic VOCs, such as isoprene, which was initially found to have been underestimated. The adoption of a revised isoprene inventory was found to improve model performance in ozone predictions.

A concurrent study by CSIRO **(Cope, 2008)**, investigated a methodology for determining the impact of climate change on ozone levels in Sydney. The objective of this study was to demonstrate a methodology that can robustly predict ozone concentrations under climate change conditions for any period or location in Australia, and specifically to give an insight into the impact of climate change on ozone levels in Sydney in 20 and 50 years' time. The study focussed on Sydney, with TAPM-CTM

[c] Inventories included the DECC 2007 Inventory, National Pollutants Inventory, Model Inventory.

demonstrated to perform well in the prediction of historic ozone climatology, mesoscale meteorology and peak ozone concentrations. The study also identified that typically the highest concentrations of photochemical smog in the GMR are observed to develop under north-easterly sea breezes after 4–6 hours of photochemical activity, and subsequently observed many kilometres downwind of the source regions (i.e. at the monitoring stations at Bringelly, Oakdale and Bargo).

Works completed as part of the *Sydney particle Study – Stage 2* **(Cope et al., 2014)** also adopted the use of TAPM-CTM and CCAM-CTM to complete a comprehensive study into fine particles (with an aerodynamic diameter of less than 2.5µm) in the Sydney region. The study included an ambient air quality monitoring program in addition to the development of a modelling framework encompassing emissions inventory development and chemical transport modelling subsequently used for calculating population exposure and health impacts. Both models were assessed to have good agreement with the observations **(Cope et al., 2014)**.

5.2 Chemical mechanism

The Carbon Bond 05 (CB05) mechanism was adopted for this assessment. CB05 is a lumped and structured photochemical smog mechanism which links to regional precursor inventories (such as the EPA GMR inventory) however requires correctly speciated VOC emissions (**Cope et al, 2009a).**

The CB05 mechanism comprises 51 chemical species and 156 chemical reactions. It supersedes the CB4 mechanism, providing improvements in performances for aldehyde and olefin species in addition to oxidant species involved in particulate matter sulfate formation and improves the simulation of hydrogen peroxide under low NOx conditions (**Yarwood et al., 2005**). The CB05 has been evaluated against measured data generated at the Universities of North Carolina and California at Riverside smog chamber. A full technical description of the CB05 reaction mechanisms is available in **Yarwood et al. (2005)**.

5.3 Meteorology

The TAPM prognostic meteorological model has been used to simulate meteorology within the study area. Wind data from the OEH monitoring stations located within the modelling domain were included in the study, where available[d]. The inclusion of surface observation data as an observation input file provides real-world observations and improves the accuracy of the resultant wind field.

The meteorological data obtained from the OEH monitoring sites was given preferential treatment over the potential use of meteorological data from the Bureau of Meteorology (BoM). This approach was adopted as the OEH datasets are more representative of built up areas, and thus were deemed to provide more representative assimilation files to nudge the model. It is noted this approach is consistent with the worked example provided in **Environ (2011)**. BoM data are considered optimal closest to airports where there are large open spaces. However, data from BoM Bankstown Airport should be broadly representative of OEH's Liverpool and Chullora sites. Similarly, BoM Camden Airport may be representative of OEH Macarthur and BoM Sydney Airport reflective of OEH Randwick. Therefore, if BoM airport stations are included, further refinement of the meteorological modelling may not necessarily be achieved.

In addition, BoM data are often provided in 10° increments for wind direction, resulting in inaccurate representation within the meteorological model resulting in potential 'stepping' effects. It is noted that the from year to year OEH weather stations may not be compliant with the Australian Standard (AS 2923-1987 Guide for Measurement of Horizontal Wind for Air Quality Applications). During the year of modelling (2009) OEH weather stations non-compliant with the standard were noted as Earlwood,

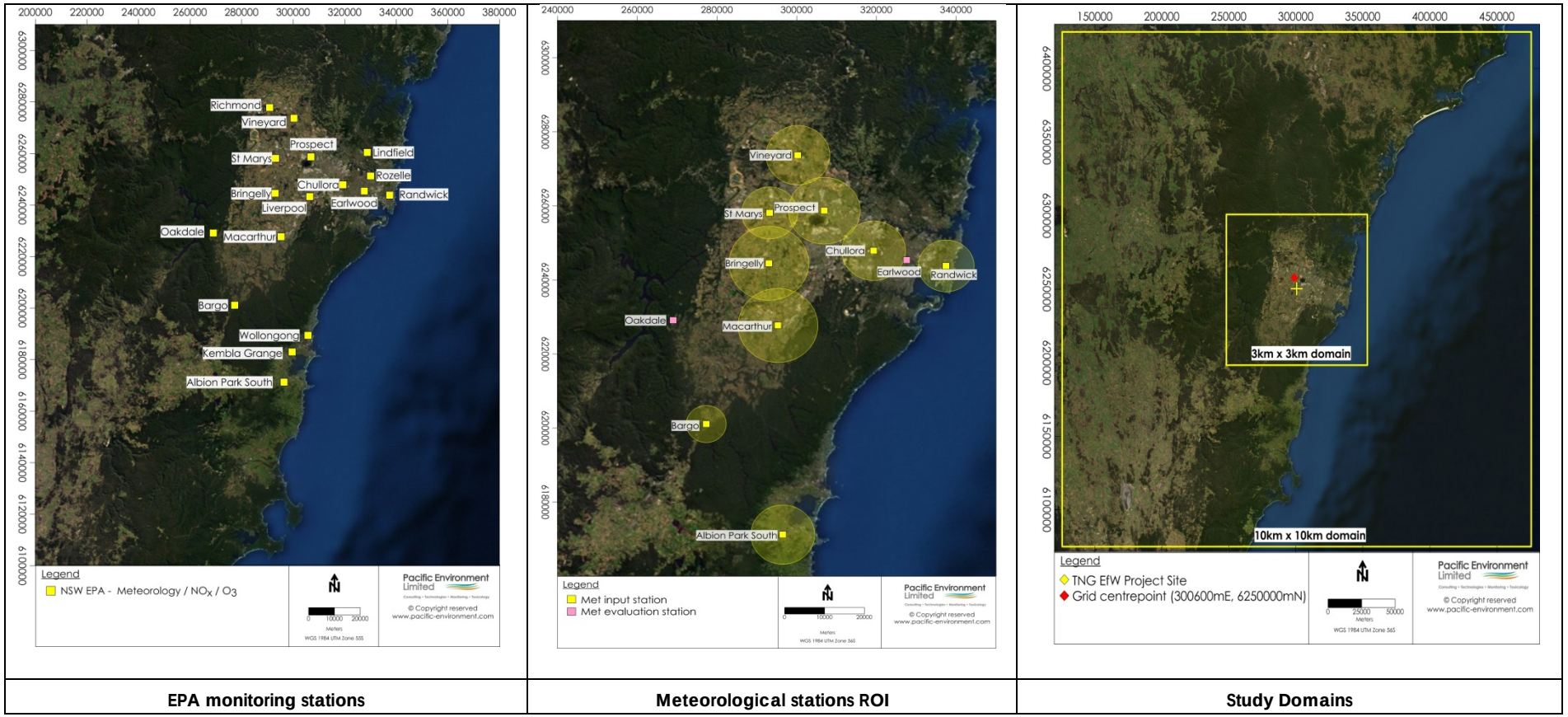
[d] Available sites with sufficient data capture rates for the period of interest. Some sites will be excluded and used for model evaluation purposes.

Liverpool and Rozelle. For all three sites siting requirements were not met due to tree growth / obstruction since station establishment **(NSW DECCW, 2010b)**.

There are 11 OEH weather stations that have been selected for this study, of which two have been excluded from the observation input file and used to evaluate model performance (Oakdale and Earlwood). The location of the monitoring sites is shown in **Figure 5-1**. The selected observation sites provide reasonable spatial distribution across the model domain. It is noted that the sites Richmond, Liverpool, Rozelle and Lindfield were not able to be used due to poor data retrieval.

The nine stations selected as observation sites to 'nudge' the TAPM meteorological module are shown in **Figure 5-1** and summarised in **Table 5-1**. Also shown is the radius of influence of the surface meteorology of each site that will also be included in the meteorological modelling. A smaller radius of influence and number of vertical levels to assimilate into the model was selected for sites located closer to terrain so as to allow the model to capture localised terrain influences.

The performance of the model in predicting wind speed, wind direction and temperature at the evaluation sites, is summarised in **Section 8,** including simple visual analysis (comparison of wind roses, time series and percentile / quantile-quantile plots), simple statistical descriptors and statistical evaluation of performance based on benchmarks set for mesoscale model evaluation by **Emery et. al (2001)**.



EPA monitoring stations	Meteorological stations ROI	Study Domains

Figure 5-1: OEH monitoring sites, observations sites and radius of influence and CTM domain

Table 5-1: Summary of meteorological observation files

Monitoring site	Easting (mE UTM 56)	Northing (mN UTM 56)	Evaluation site	Radius of influence (m)
Bargo	277,300	6,201,100	Observation	5,000
Bringelly	293,000	6,244,500	Observation	10,000
Prospect	306,900	6,258,700	Observation	9,000
Randwick	337,500	6,243,800	Observation	7,000
St Marys	293,200	6,258,100	Observation	7,000
Vineyard	300,300	6,273,700	Observation	8,000
Macarthur	295,300	6,227,700	Observation	10,000
Chullora	319,300	6,247,900	Observation	8,000
Oakdale [a]	269,000	6,229,100	Evaluation	n/a
Earlwood [a]	327,600	6,245,400	Evaluation	n/a
Albion Park South	296,500	6,171,230	Observation	8,000

Notes: (a) This is an evaluation site and was note included in the TAPM assimilation files.

5.4 Modelling domain

TAPM was run with three nested grids with grid spacing of 30km x 30km, 10km x 10km and 3km x 3km with 35 vertical levels. The number of grid points (35 x 40) was selected to ensure that the inner most grid (3km x 3km) covers the main area of interest for the study (e.g. western and south western Sydney).

TAPM-CTM is run with two nested grids, a master grid resolution of 10km x 10km and inner grid resolution of 3km x 3km. The master grid (10km x 10km) covers the GMR and corresponding to area covered by emissions in the NSW EPA air emissions inventory (**NSW EPA, 2012**).

The inner CTM grid (3 km x 3 km) covers the main area of interest for this study, encompassing western and south-western Sydney. It is not considered necessary to use higher resolution in-line grids, meaning the final resolution for chemical transport calculations will be at the 3 km resolution. This is a resolution typically used for urban scale photochemical modelling.

5.5 Boundary conditions

Boundary conditions or initial concentrations were included in the form of a two dimensional, constant boundary concentration file, for each relevant species. The boundary conditions are most important for species with long atmospheric lifetimes and significant background concentrations (NO_x and CO) (**Environ, 2011**). Ozone background is typically in the range of 20-30 ppb and for the Sydney area a background of 20 ppb is appropriate (**Environ, 2011**) and is adopted for this assessment.

Boundary concentrations for other species are based on a sample boundary file provided by CSIRO and are provided in **Appendix A**. Based on subsequent discussions with Dr Martin Cope of CSIRO this is considered to provide a reasonable indication of background concentrations of other species.

6 EMISSIONS DATA

Emissions data are required for two scenarios. A "Base Case" scenario will assess model performance without the emissions from the EfW facility. In other words, all existing emissions sources are modelled and compared to monitoring data for the same period. A "Test Case" scenario will assess the impact from the addition of the EfW facility.

6.1 Base case emissions

TAPM-CTM ready gridded GMR emissions inventory data (for anthropogenic sources of ozone precursors) were provided by EPA for January and February 2008. The selection of this time period is discussed in detail in **Section 7**.

The emission files were provided at a 1km x 1km resolution and were input directly into the TAPM-CTM master grid which covers the GMR.

The EPA emissions inventory data includes point source emissions from commercial and industrial sources, area source emissions for on-road mobile, commercial, industrial, domestic and off-road sources. The emissions files included in the modelling are:

- aems_1km - Area emission files for 1km grid.
- mvems_1km – motor vehicle emission files for 1km grid.
- pems_1km – elevated point source emission files for 1km grid.

The emission files are provided from the NSW EPA as weekday and weekend emissions files for January and February 2008. The weekday and weekend emission files are combined into a full 7 day period of emissions for January and February.

The modelling domain includes areas of dense eucalypt forest that form part of the Blue Mountains national parklands. VOC emission contribution from these biogenic sources is an important inclusion in the modelling. Options for inclusion of biogenic emissions include:

- Using NSW EPA inventory data (based on monthly average temperature profiles)
- Generate emission estimates using a model such as MEGAN *(Model of Emissions of Gases and Aerosols from Nature)*.
- Generate 'on-the-fly' emissions within the TAPM-CTM model.

It is our understanding that biogenic emissions can differ significantly depending on the option used. It is also understood that CSIRO have recently used TAPM-CTM for a regional particles study (the Sydney Particles Study) where TAPM-CTM was used to generate biogenic emissions using data generated directly by TAPM-CTM. For example, VOC emissions from forest canopies can be estimated based on leaf area index, canopy height, leaf biomass and leaf level VOC emission rates (**Cope et al, 2009b**). By taking into account time of the day and temperature, emissions can be varied more accurately than those based monthly average temperature profiles.

This approach has been adopted for this study, however it is acknowledged that model predictions may be particularly sensitive to variations in this emission source and an evaluation of the model performance is presented in **Section 9**.

6.2 Test case emissions

The test case emissions include all sources in the base case scenario with the addition of emissions from the EfW facility. Emissions from the EfW facility are released from two 100m stacks and the emissions are therefore added to the elevated point source emissions file.

The dominant ozone precursor released from the facility is NO_x (oxides of nitrogen, expressed here in terms of NO and NO_2). Speciated emissions of reactive organic compounds are not available for inclusion and based on a review of monitoring data from a similar facility in the UK, emissions of total organic compounds (TOC) are expected to be low **(Pacific Environment, 2015)**. It is assumed that at the point of release, NO comprises approximately 95% of total NO_x emissions **(Janssen et al., 1998).** The emission rates (g/s) for each stack are presented in **Table 6-1**.

The emission rates and all other modelled stack parameters are taken from the local air quality assessment **(Pacific Environment, 2015)**. Given the timescales of photochemical activity and subsequent ozone formation the EU Industrial Emissions Directive (IED; Directive 2010/75/EU) dally NO_x emission limit, rather than half hourly limit has been adopted for this assessment. This is considered to provide a reasonable worst case emissions scenario for assessment purposes.

Table 6-1: Modelled emission rates

Parameter	Value
Stack location (m, MGA, Zone 56)	298633 (E), 6257734 (N)
	298575 (E), 6257741 (N)
Base elevation (m, AHD)	~65
Stack Height (m)	100
Stack Diameter (m)	2.5
Temperature (°C)	120
Flue Gas Flow (Nm^3/s)	139.3
Gas Exit Flow Rate (Am^3/s)	175.8
Gas Exit Velocity (m/s)	35.8
NO emission rate (95% of NO_x) (g/s)	26.5
NO_2 emission rate (5% of NO_x) (g/s)	1.4

It is noted that the Test Scenario assumes that both stacks are continuously operating at the daily emission limit (i.e. the maximum allowable emission concentration averaged over the day). Typically during normal operations of the plant, the emission levels will be lower. A review of continuous emissions monitoring system (CEMS) reports for the Riverside EfW facility in the United Kingdom, which employs similar technology and flue gas treatment, demonstrates that the facility is consistently lower than the maximum allowable daily limit. The Riverside EfW CEMS reports can be reviewed here (http://www.coryenvironmental.co.uk/energy-from-waste/riverside-resource-recovery-facility/). A sample report is provided in **Appendix E** of **Pacific Environment (2015)**.

6.2.1 Comparison of test case emissions with other NO_x sources in air shed

Other significant NO_x sources in the Sydney and Greater Metropolitan Region (GMR) air sheds are primarily sourced from shipping, passenger vehicles, fuel production and heavy duty diesel vehicles, in addition to power generation facilities **(NSW EPA, 2015)**.

The annual NO_x emissions from the TNG EfW facility have been compared against other significant NO_x sources, as extracted from the NSW EPA GMR 2008 emissions inventory. A comparison of the top ten man-made NO_x emission sources within the Sydney air shed, as well as how the TNG EfW projected emissions, are shown in **Figure 6-1**. The TNG EfW facility ranks seventeenth compared to other grouped emission sources in the Sydney air shed. Relative to man-made sources within the GMR, where most electrical power generation sources are located, the TNG EfW facility would be placed significantly lower in ranking.

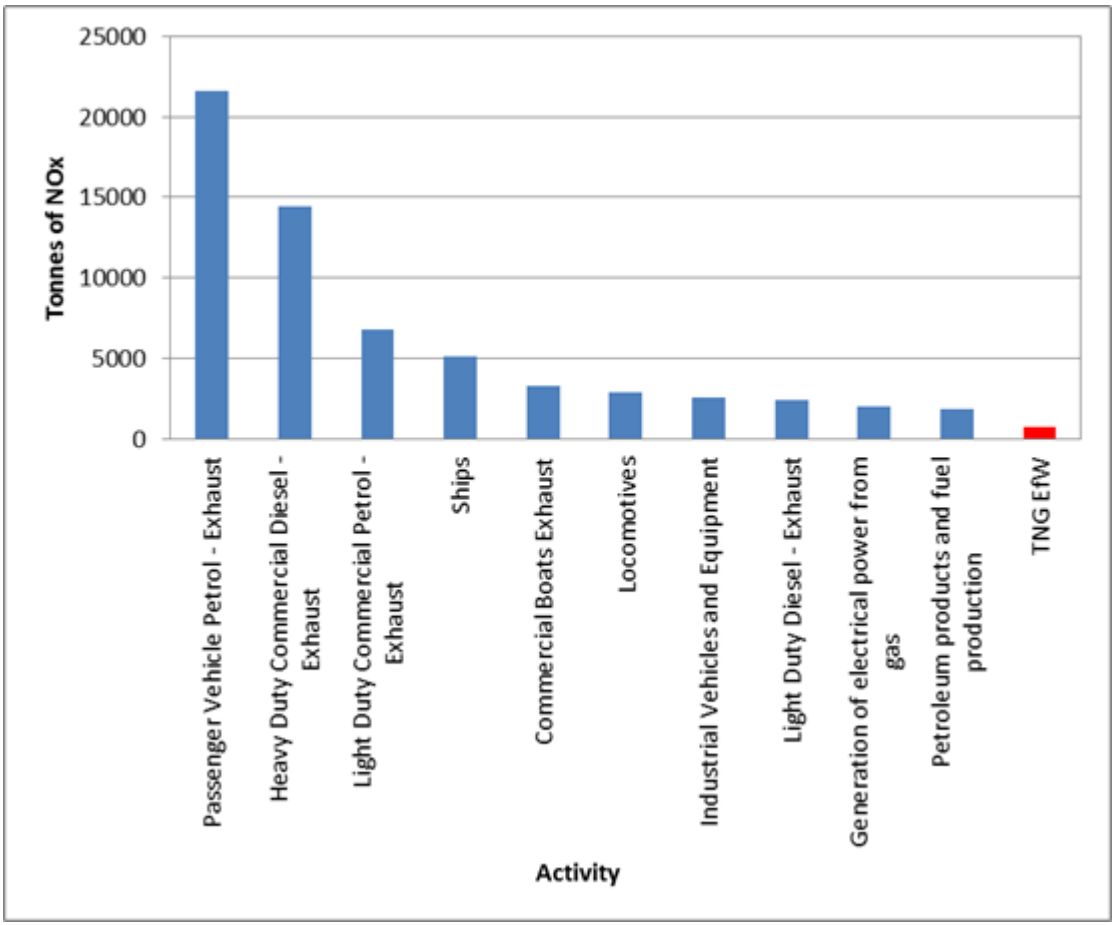


Figure 6-1: Top ten NO_x emission sources in the Sydney air shed compared with projected TNG EfW emissions

6.2.2 Upset conditions

Upset operating conditions can occur for a number of reasons (**Fichtner, 2015**) including:

- Reduced efficiency of:
  - selective Non-Catalytic Reduction (SNCR) system as a result of blockages or failure
  - particulate filtration system due to bag failure and inadequate isolation, leading to elevated particulate emissions and metals in the particulate phase.
  - lime injection system such as through blockages or failure of fans leading to elevated acid gas emissions.
- Complete failure of
  - lime injection system leading to unabated emissions of hydrogen chloride. (Note: this would require the plant to have complete failure of the bag filter system. As a plant of modern design, the plant would have shut down before reaching these operating conditions).
  - the activated carbon injection system and loss of temperature control leading to elevated concentrations of metals and dioxin reformation and their unabated release.

In accordance with the EU IED (Directive 2010/75/EU), such events shall under no circumstance occur for more than 4 hours uninterrupted where the emission values exceed the limits and no more than 60

hours per year. Under such circumstances the operator shall reduce or shut-down operations as soon as practicable until normal operations can be restored.

There are no monitoring data available from existing facilities during 'upset operations'. In the absence of monitoring data worst-case assumptions have been made based on consultation with the UK Environment Agency based on their knowledge of plausible upset emissions for key pollutants (**Fichtner, 2015**). Plausible emissions during upset conditions for NO_x would equate to a mass emission rate of 76.2 g/s.

When considering upset operating conditions it is always a matter of balance between stated upset emission level, the probability of reaching this level and the duration of emission at the elevated level. Very high emission levels would occur rarely and for short time because plant shutdown would likely be an imminent consequence, whereas slightly elevated levels could occur occasionally and for some length of time until the necessary actions are put into place. In view of the limited number of hours (no more than four consecutive hours) that the plant would have the potential to release emissions during upset conditions, such a scenario has not been explicitly modelled. This is particularly in view that the likelihood that such upsets may occur during days of potentially high ozone formation is, cumulatively, extremely low.

In the event of upset conditions strict management measures should be followed to ensure that elevated emissions are minimised.

7 MODELLING SCENARIOS

The Base Case emissions scenario assesses model performance without the emissions from the EfW facility. The Test Case scenario assesses the incremental ground level concentrations of ozone resulting from emissions from the facility.

The first step in the modelling is the selection of the appropriate period to model. This chapter provides a review of the ozone monitoring data in the Sydney airshed that has been used to inform this process.

7.1 Modelling period

A review of ozone monitoring data is used to identify an "ozone season" or period when ozone concentrations were elevated. Selected days within this "ozone season" (minimum of 3 days) has been selected for detailed analysis based on:

- High measured ozone concentrations.
- High modelled ozone concentrations.
- Days when the model performs well (predicted comparable to observed).
- Ozone impact occurs over land.

We have reviewed five years of ambient ozone monitoring data across the GMR and Illawarra to identify "ozone seasons" for modelling – i.e. summer months which contain a number of consecutive days of high (comparable to NEPM standards) 1-hour and 4-hour ozone concentrations.

7.2 Review of ozone monitoring data – selection of ozone season

7.2.1 Exceedances of the impact assessment criteria

Ozone concentration data has been reviewed across 19 monitoring sites located in Sydney's Central-East, Sydney North-West, Sydney South-west and Illawarra between 2009 and 2013. The data set has been analysed by region, with the maximum number of days that measured an exceedance of the 1-hour and 4-hour impact assessment criteria for each region shown in **Figure 7-1** and **Figure 7-2**, respectively.

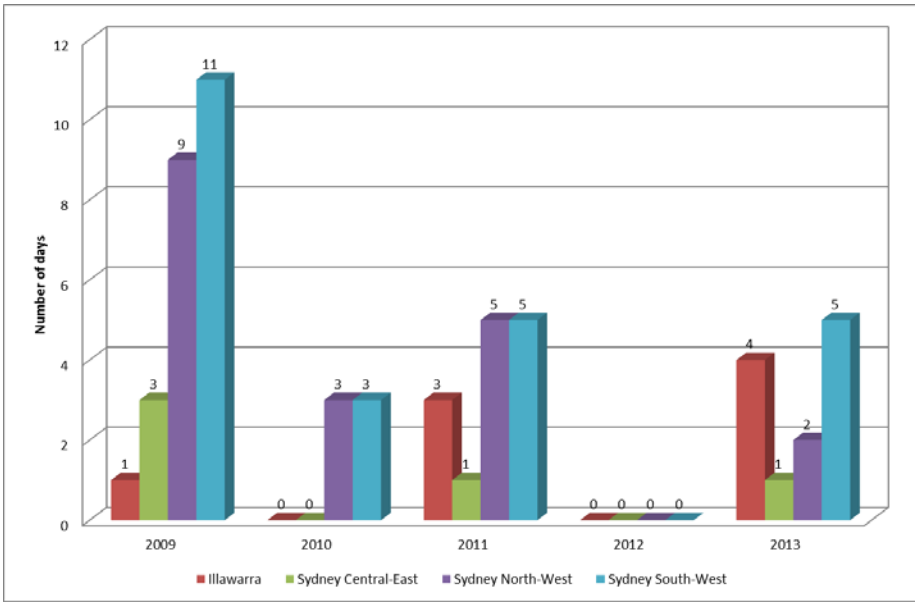


Figure 7-1: Annual number of days of above the 1-hour O_3 criteria by region

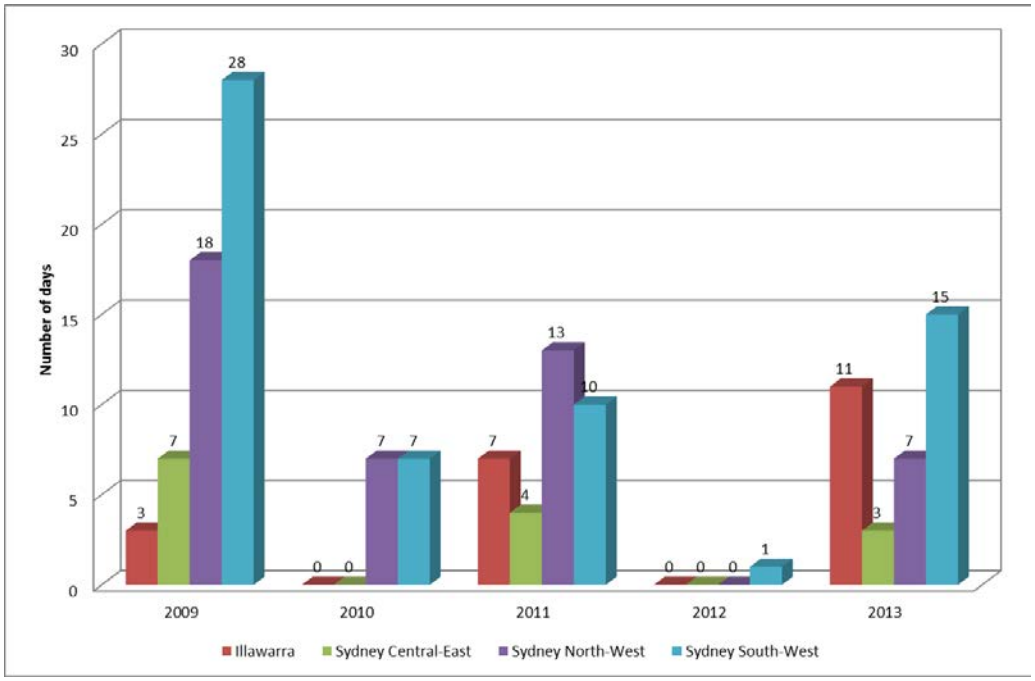


Figure 7-2: Annual number of days of above the 4-hour O_3 criteria by region

The greatest number of exceedances of the NEPM 1-hour criterion of 100ppb within a calendar year was 24 during 2009 across the Sydney region, followed by 2011 with 14 and 2013 with 12 events respectively.

There are more exceedances of the NEPM 4-hour criterion (80 ppb) than the 1-hour criterion, approximately by a factor of two. For both the 1-hour and 4-hour averaging periods the calendar years that have experienced the highest number of exceedances correspond to 2009 (56 events), 2011 (34 events) and 2013 (36 events) respectively.

During 2010 and 2012 there were significantly less exceedances of the both the 1-hour and 4-hour criteria. It is also noted that ozone concentrations in the Sydney region have exceeded either one or both of the NSW EPA ozone criteria every year since 1994.

For both the 1-hour and 4-hour averaging periods the Sydney South-West region experiences the most days above the ozone impact assessment criteria. This is followed by the Sydney North-West region. Both the Sydney Central-East and Illawarra regions have recorded the fewest number of exceedances of the ozone criteria over the last decade.

7.2.2 Ozone concentration data

The daily maximum ozone concentration data for the past five complete years (2009 – 2013) have also been reviewed on a monthly basis. The monthly maximum 1-hour and 4-hour ozone concentrations measured across the 19 sites that comprise the OEH monitoring network in the GMR is shown in **Figure 7-3**. There is a strong seasonal trend in the ozone concentration, with the highest values for both the 1-hour and 4-hour averaging periods generally occurring between November and February. Between 2009 and 2013, all exceedances of the impact assessment criteria occurred between October and March.

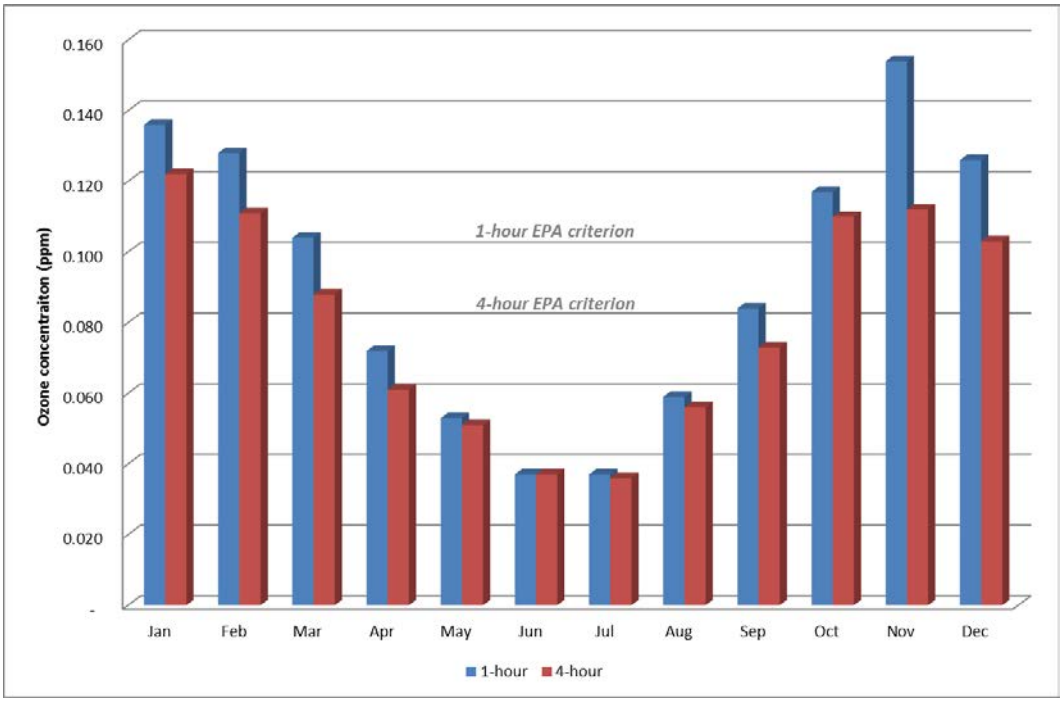


Figure 7-3: Monthly maximum O_3 concentration

7.3 Selection of high ozone days for detailed analysis

The greatest number of exceedances of both the 1-hour and 4-hour ozone concentrations occurred in the summer of 2008-2009. Rather than present detailed information for all 19 sites, we have focused on three sites. The Prospect monitoring station is the closest monitoring station to the proposed EfW facility, approximately 7.5 km east of the site. Both the Macarthur and Bargo sites are located in the South-West Sydney region where the highest number of exceedances of the ozone 1-hour and 4-hour criteria occurred during this period.

Table 7-1 presents a summary of the number of exceedances at these sites during 2009. The greatest number of exceedances occurs during January and February.

Table 7-1: Monthly number of exceedances of the 1-hour and 4-hour EPA criteria during 2009

Month	1-hour average			4-hour average		
	Prospect	Macarthur	Bargo	Prospect	Macarthur	Bargo
January	1	2	1	4	7	5
February	1	8	6	4	10	16
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	0	0	0	0	0	0
July	0	0	0	0	0	0
August	0	0	0	0	0	0
September	0	0	0	0	0	0
October	0	0	0	0	0	0
November	2	2	2	8	3	5
December	0	1	0	2	3	2
Total	**4**	**11**	**11**	**18**	**23**	**28**

Times series plots of the maximum daily 1-hour and 4-hour concentration for January and February 2009 are shown in **Figure 7-4** and **Figure 7-5.** There are a number of consecutive days when the ozone impact assessment criteria are exceeded for both 1-hour and 4-hour averages.

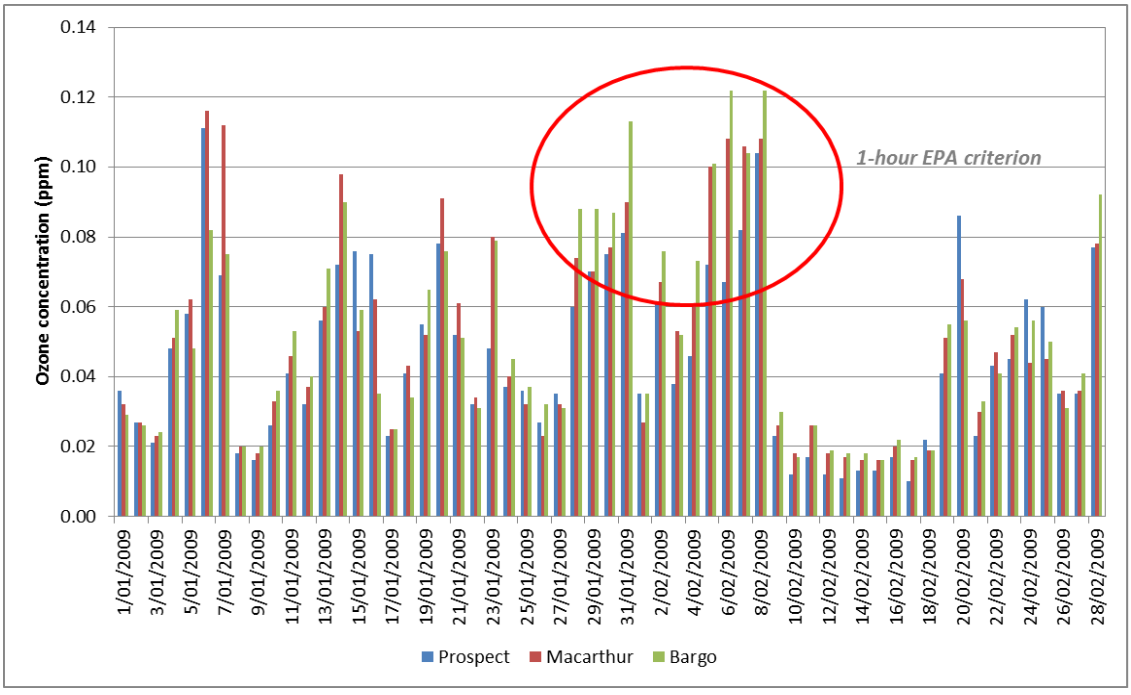


Figure 7-4: Daily maximum 1-hour O_3 concentration December 2009 - January 2010

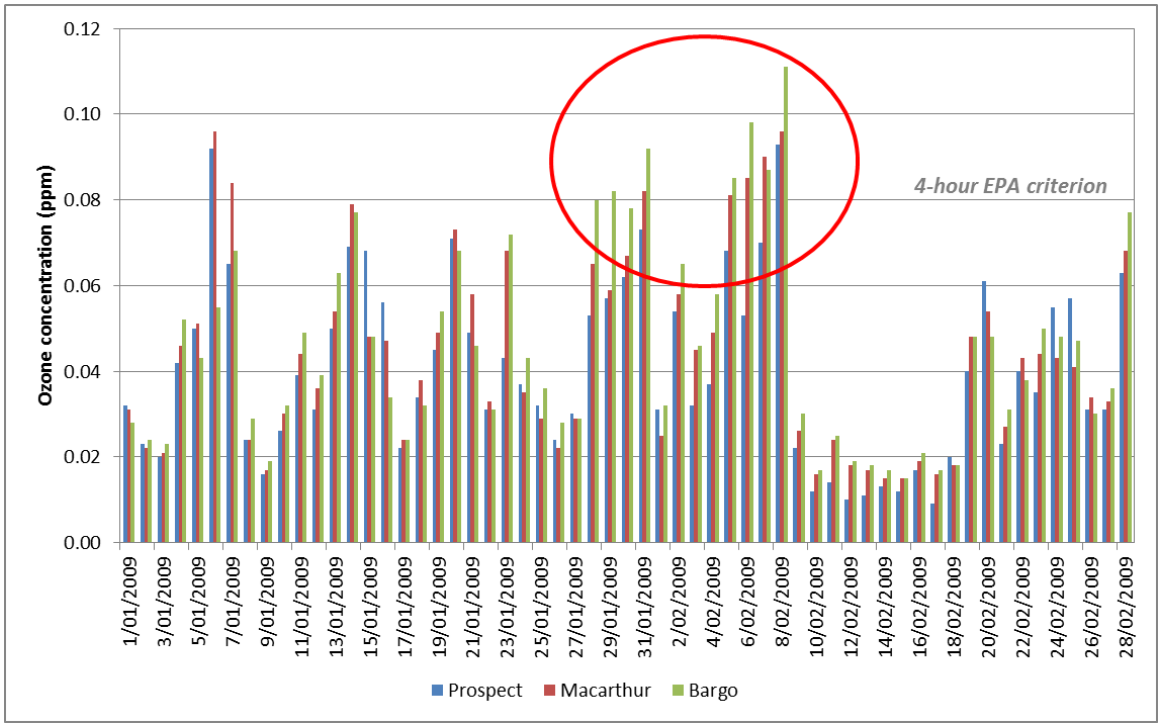


Figure 7-5: Daily maximum 4-hour O_3 concentration during January and February 2009

Based on the analysis presented, the period of January to February 2009 has been selected as an appropriate period for modelling. The majority of the exceedances of both the 1-hour and 4-hour ozone criteria occur between the last week of January and first week of February. Due to time constraints in modelling an extended period (all of January and February), we have focused on this two week period for base model evaluation.

8 EVALUATION OF METEOROLOGICAL MODELLING

An evaluation of the meteorological model has been completed for two sites that were not included in the TAPM modelling (Earlwood and Oakdale). One-hour data for wind speed, wind direction and temperature are evaluated visually as time series and wind roses and analytically using linear regression and percentile plots. The period of evaluation was January and February, 2009.

In addition to the sites that were excluded from the modelling, the analysis is also presented for two sites that were included as observation sites in the modelling, referred to as the assimilation sites (Macarthur and St Marys).

It is expected that due to model nudging the assimilation sites will evaluate better, within the radii of influence presented in **Figure 5-1**.

8.1 Wind speed

Wind speed determines the initial dilution rates of the precursor emissions and the wind vector determines where, and how quickly, a photochemical precursor plume is transported to regions away from the point of emission **(Cope, 2008)**. Therefore the accurate prediction of peak ozone concentrations relies on the accurate prediction of the wind fields, both at the surface and aloft.

Figure 8-1 compares predicted and observed wind speed at the evaluation sites (Earlwood and Oakdale) and **Figure 8-2** compares predicted and observed wind speed at the assimilation sites (St Marys and Macarthur). At the two assimilation sites, as expected, the regression analysis shows a stronger correlation between predicted and observed, as follows:

- Earlwood wind speed $R^2 = 0.61$
- Oakdale wind speed $R^2 = 0.32$
- Macarthur wind speed $R^2 = 0.82$
- St Marys wind speed $R^2 = 0.76$

Wind speeds are generally underestimated at the Earlwood and Oakdale sites although percentile plots demonstrate a slight over-prediction of low wind speeds.

The regression analysis shows only a weak correlation between the predicted and observed wind speeds at the Oakdale site. Review of the land-use categories for the Oakdale site (immediate area) shows that these were set to 'forest-mid dense' with soils set to 'sandy clay loam' and leaf area index (LAI) of 3.2 for both January and February within the model. On review of the land-use in the Oakdale area, the adopted land-use categories appear reasonable.

The poor performance of the meteorological model at Oakdale may be more likely a result of the Oakdale site being located at the foothills of the Blue Mountains where the complex wind regimes that interact with the terrain may not be fully captured due model resolution.

The varying level of correlation is not unexpected as the wind field simulations are subject to potential inaccuracies. The observed wind field vectors will generally be more spatially inhomogeneous compared to, for example, the temperature. Wind field vectors will be responsive to local variation in surface roughness (i.e. due to the presence of building and trees within the vicinity of the observation sites) which is not readily resolvable by the model at a 3 km grid spacing **(Cope 2008)**. This then has implications for the accurate prediction of stability and vertical profiles **(Cope et al., 2014)**.

Compared with the evaluation sites, the two assimilation site percentile plots show a better model performance, particularly in the higher wind speed categories.

8.2 Wind direction

Annual wind roses for both the evaluation sites and the two selected assimilation sites are presented in **Figure 8-3** and compare against the predicted winds from TAPM. The wind directions for predicted wind roses for the Earlwood site compare reasonably well with the observed measurements and reflect well in terms of dominant wind directions. The predicted wind directions for this site show a higher frequency of winds originating from the northeast, supplementing a decrease in the frequency of winds from the south-easterly direction.

The observed and predicted wind roses for the Oakdale site compare between the two datasets. The model has captured the prevailing wind directions reasonably well, with a general shift of the wind rose by 22.5° in an anti-clockwise direction for the predicted compared to the observed.

The observed and predicted wind roses for the Macarthur site compare well. The frequency distributions of the predicted data perform well across the grid, with the exception of the south-western quadrant, where the TAPM has under predicted winds originating from the southwest. The subtle changes are likely due to the minor difference in location between the actual weather station and the TAPM grid extraction point. Potential inaccuracies in the model prediction for wind directions are similar to those already discussed for wind speed (see **Section 8.1**).

The wind directions for predicted wind roses for the St Marys site compare reasonably well with the observed measurements and reflect well in terms of dominant wind directions.

8.3 Temperature

Temperature is critical for determining the temperature dependent precursor emission fluxes (natural and anthropogenic), the rate of chemical transformation, vertical dispersion rates and sea breeze **(Cope, 2008)**.

Figure 8-1 compares predicted and observed temperature at the evaluation sites (Earlwood and Oakdale) and **Figure 8-5** compares predicted and observed temperature at the assimilation sites (St Marys and Macarthur). For all sites, regression analysis shows general agreement between predicted and observed, as follows:

- Earlwood wind speed $R^2 = 0.82$
- Oakdale wind speed $R^2 = 0.88$
- Macarthur wind speed $R^2 = 0.84$
- St Marys wind speed $R^2 = 0.81$

The percentile plots general show a gradient close to unity although a slight over-prediction of low temperatures and slight under prediction at higher temperatures for all four sites investigated for this analysis. This may have some implications for the ozone predictions as peak photochemical smog production is correlated with high ambient temperatures **(Cope, 2008)**.

As the slight over-prediction of low temperatures and slight under prediction at higher temperatures occurs across all sites it is anticipated that the source of error is most likely to systematic, rather than site specific, such as the case for wind speed predictions at Oakdale (see **Section 8.1**). A similar bias was also observed in the temperature predictions by TAPM-CTM in the Sydney Particle Study **(Cope et al., 2014)**, however, no explanation for this model behaviour was provided.

Additional summary statistics for all sites are presented in **Appendix B**. Model performance is also evaluated against statistical benchmarks (or ideal scores) for a variety of statistical tests and presented in **Appendix B**.

In conclusion, key shortfalls in the meteorological model performance include:

- Poor agreement in wind speed predictions at the Oakdale monitoring site
- Under prediction of maximum temperatures across multiple sites

However, on the basis of the above evaluations, the meteorological model is considered appropriate for use in the photochemical modelling. Overall, it is considered that the TAPM model simulates the meteorology of the region with an acceptable degree of accuracy.

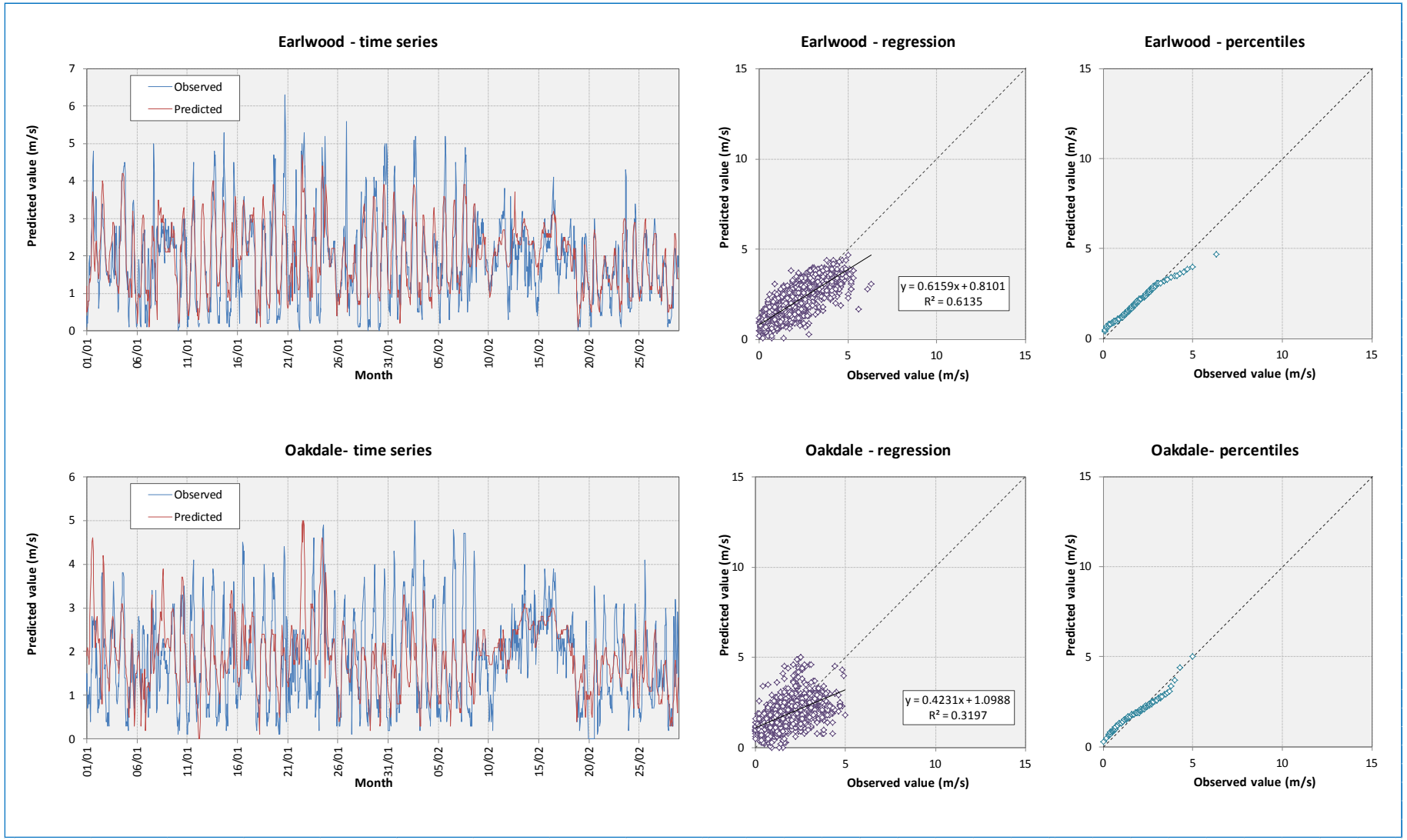


Figure 8-1: TAPM evaluation sites - predicted and observed hourly average wind speed (time series, regression plot and percentile plot)

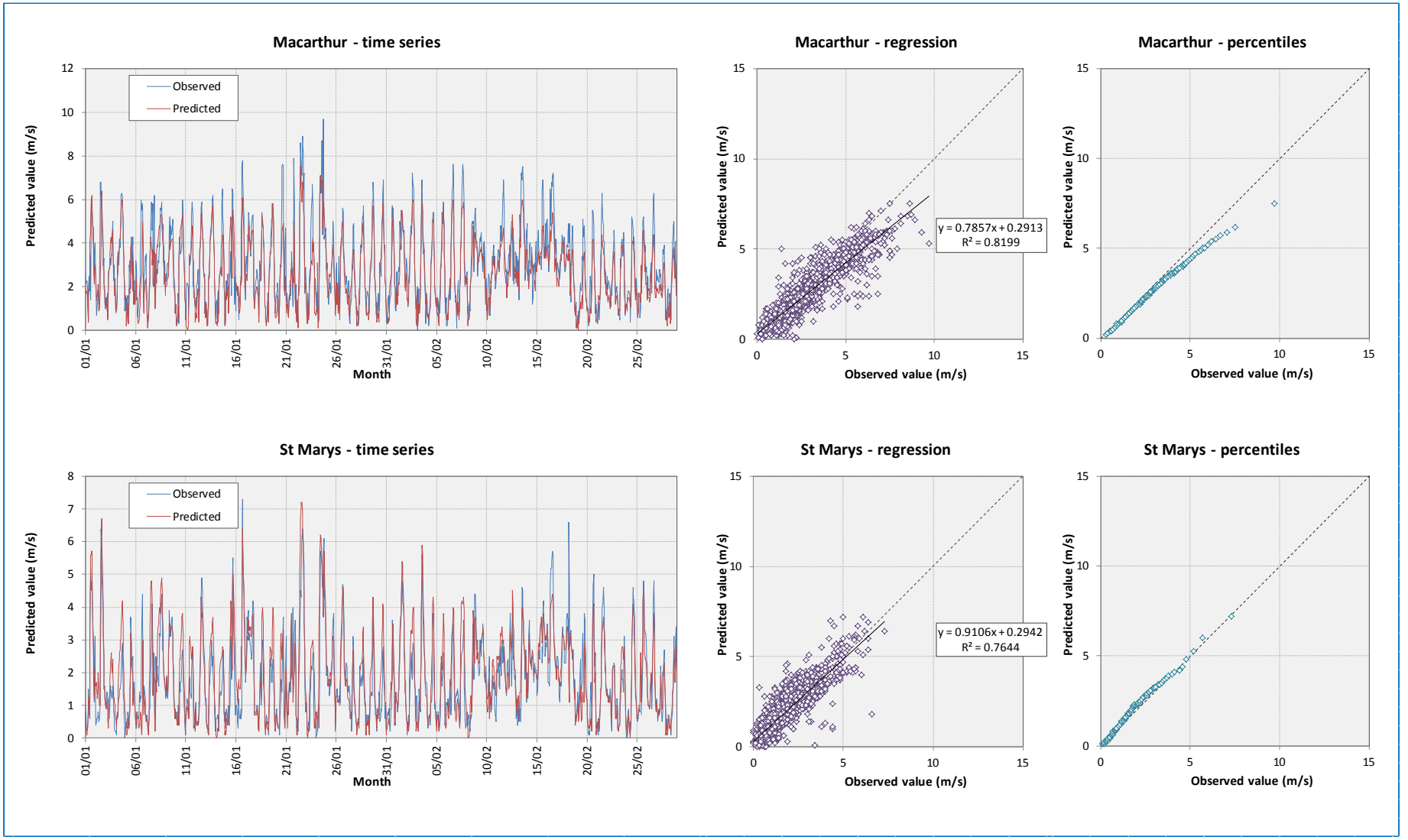


Figure 8-2: TAPM assimilation sites - predicted and observed hourly average wind speed (time series, regression plot and percentile plot)

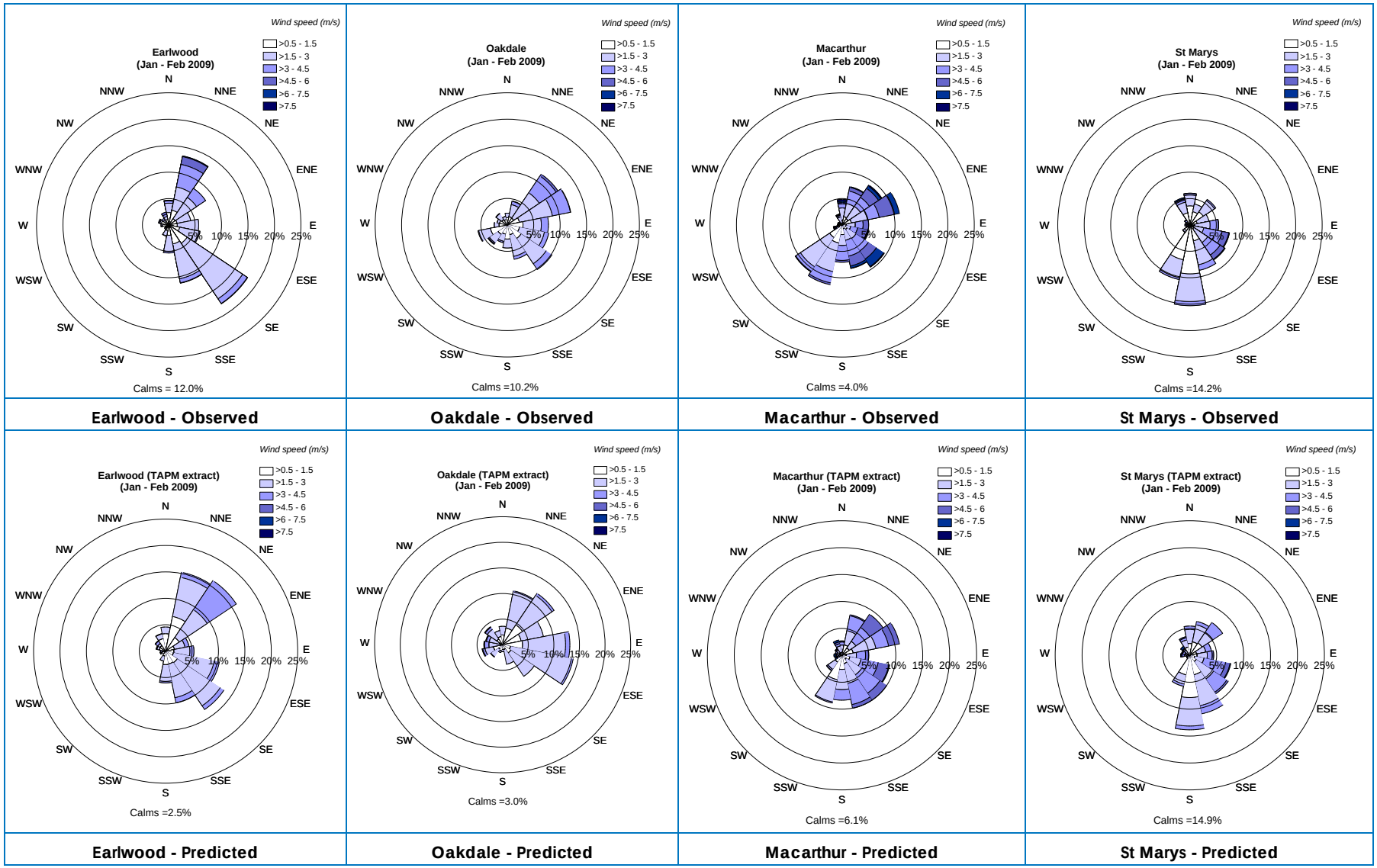


Figure 8-3: Wind roses for observed and predicted meteorological analysis sites

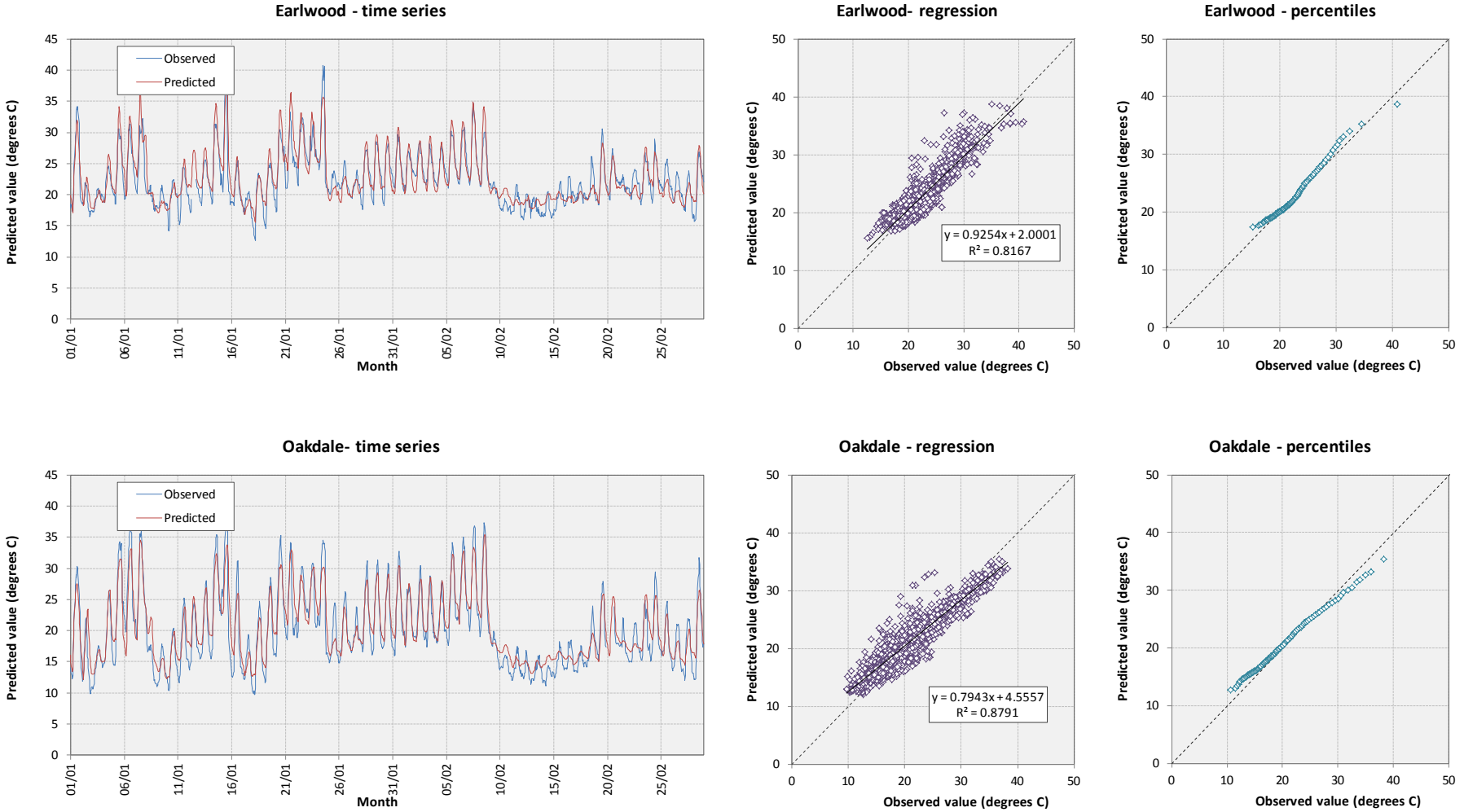


Figure 8-4: TAPM evaluation sites - predicted and observed hourly average temperature (time series, regression plot and percentile plot)

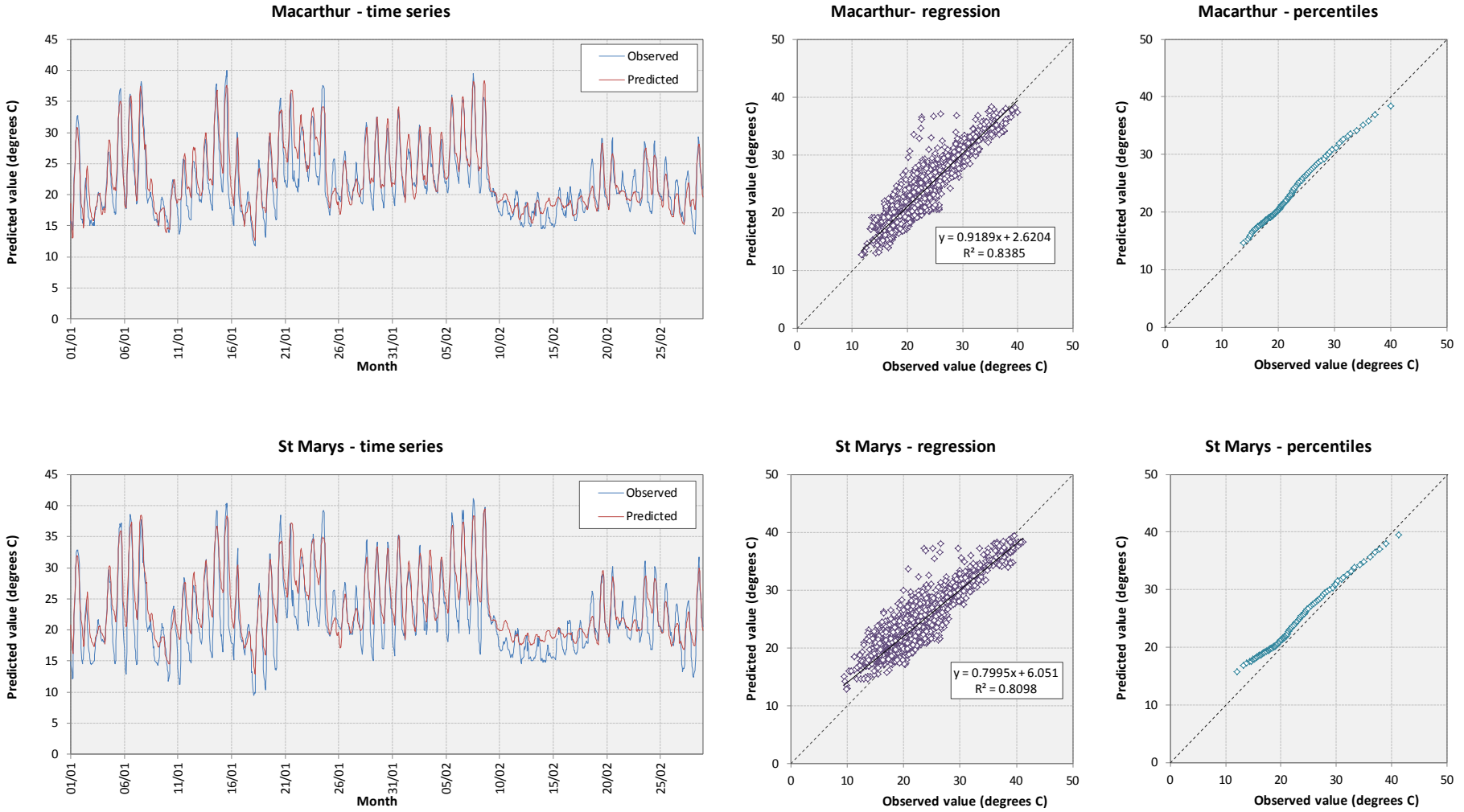


Figure 8-5: TAPM assimilation sites - predicted and observed hourly average temperature (time series, regression plot and percentile plot)

9 MODEL EVALUATION - BASE CASE SCENARIO

Model performance for the base case is evaluated against the measured 1-hour ambient concentrations. Outputs from TAPM-CTM validation software are presented for a number of sites where O_3 measurements are available. Not all monitoring sites had data available for the modelled period (between 27 January 2009 and 9 February 2009). Sites with monitoring data available include:

- Bargo
- Macarthur
- St Marys
- Chullora
- Earlwood
- Prospect
- Randwick
- Vineyard

Time series of observed and predicted 1-hour O_3 concentration for St Marys, Oakdale, Macarthur and Bargo are presented in **Figure 9-1**, through **Figure 9-4**. Time series are also presented for meteorological parameters measured at each site.

The time series for the St Marys site shows reasonable correlation between observed and predicted. The peak 1-hour O_3 concentration for the period is measured on 8/02/2009 (14:00), followed by the 6/02/2009 (16:00) and the 31/01/2009 (16:00). The predicted O_3 concentration for these hours is comparable although slightly lower.

The time series for the Oakdale site shows reasonable correlation between observed and predicted. The peak 1-hour O_3 concentration for the period was measured on 8/02/2009 (16:00) followed by the hours preceding and following. The predicted O_3 during this period captures this peak in concentration, however the absolute concentrations predicted for these hours are lower than those observed.

The time series for the Macarthur site also shows reasonable correlation between observed and predicted. The peak 1-hour O_3 concentrations for the period are measured between 5/02/2009 and 8/02/2009 (occurs on either 13:00 or 14:00). The predicted O_3 concentration for these hours is comparable although slightly lower again.

A similar pattern emerges at Bargo. The peak 1-hour O_3 concentration for the period is measured on 8/02/2009 (16:00), followed by the 6/02/2009 (15:00) and the 31/01/2009 (16:00). The predicted O_3 concentration on the 8/02/2006 is close to observed.

Data for other sites are presented in **Appendix C**. The 1-hour observed and predicted O_3 concentration at the other sites also correlates reasonably well, with the model predictions performing best in the western Sydney area. This is especially prominent when reviewing the central Sydney sites such as Randwick. However, the poorer performance is mostly associated with NO_x and NO_2 predictions (**Appendix C**) rather than O_3. Another general observation is the model tends to over predict when ambient concentrations are low and under predict the peak O_3 concentrations. These under predictions are considered to be largely a function of uncertainty in the model and are discussed in detail in **Section 9.1**. Further comments on model performance are provided within the peer review letter accompanying this report as **Appendix F**.

The normalised mean bias (NMB) and normalised mean error (NME) for each day across the modelling period are statistical metrics that have been used to identify those days were the model has effectively captured observations. Such days are considered most suitable for ozone impact evaluation. In reviewing these results for St Marys, Oakdale, Macarthur and Bargo the following dates show reasonable statistical model performance: 27/01/2009 – 31/01/2009, 02/02/2009, 03/02/2009, 05/02/2009, 06/02/2009, 09/02/2009.

Also presented in **Figure 9-5** through **Figure 9-8** are statistical evaluations for St Marys, Oakdale, Macarthur and Bargo. It is generally recommended that an air quality model is acceptable at a screening level if more than half of the short-term model predictions lie within a factor of two of the observations (**DEFRA, 2010**). The scatter plots presented show the observed and predicted paired in time. At each of the three sites, the majority of the predictions fall within a factor of two of the observations. A reasonable correlation is seen in the scatter plots at all sites, as follows:

- St Marys - $R^2 = 0.78$
- Oakdale - - $R^2 = 0.76$
- Macarthur - $R^2 = 0.81$
- Bargo - $R^2 = 0.76$

As discussed in **Section 5.1** a correlation of 0.7 is considered a 'good' degree of accuracy in the model predictions compared with observations.

The quantile-quantile plots present the same data ranked (not paired in time) and show reasonable correlation.

9.1 Sources of uncertainty in the modelling

For the purposes of this modelling exercise, it is considered that the principal performance issue is related to the under-prediction of peak ozone by the model. Potential uncertainties within the modelling that may contribute to this include:

- Uncertainty in the 2008 GMR inventory, which is relatively new and as such has not been robustly validated.
- The inability of the model to represent real-world, hour-by-hour emissions. For example, the 2008 GMR emission inventory comprises 1 km by 1 km grid cells that account for hourly changes in emissions based on week days and weekend conditions only. The model then treats the aggregated emissions within each grid cell as a uniform emission.
- Out of necessity, the influence of individual bushfire events have not been characterised within the modelling. The OEH notes that there was bushfire activity in the Sydney region between 6 and 9 February, 2009 (simulation days used within the current modelling). It is noted that, given the inherent uncertainties in developing an emission inventory for a given bushfire event, bushfires are rarely dealt with explicitly in photochemical modelling for impact assessment purposes. Rather, such modelling is typically confined to research applications. In not including bushfires within the modelling, an additional degree of uncertainty for the model predictions for 6 – 9 February is acknowledged.
- The under prediction of peak temperatures noted in **Section 8.3** can have an effect on the reaction rate of the photochemistry and therefore peak ozone concentrations. This issue was discussed within **Cope, 2008**. Discrepancies over only a few degrees can have an effect on model predictions. In this case the limits in the model configuration need to be considered, whereby the model inner domain represents 3 km by 3 km grid cells. In reality, measurements of temperature at different locations within such an area are likely to be subject to some degree of variability.
- Investigations by **Cope et al. (2014)** into TAPM's performance at simulating boundary layer heights showed that, under some circumstances, the model has some difficulty in accurately characterising boundary layer heights. Further, the ability of the model to capture the timing of the changeover from convective to stable conditions has the potential to effect pollutant concentrations. Such effects are considered a potential uncertainties within the current assessment.
- Underestimation of the role of biogenic emissions. **(Galbally, 2008)** identifies the important role of biogenic isoprene and its impact on model performance. Given the complexity associated with

biogenic emissions and photochemistry it is anticipated that the accuracy of such simulations can be limited.

Notwithstanding the above acknowledgement of model uncertainties, a review of the model performance and consultation with the model developers, it is concluded that the overall model performance is appropriate for subsequent analysis for ozone impact assessment. Further discussion on model performance and uncertainty is provided within the technical peer review letter provided as **Appendix F**.

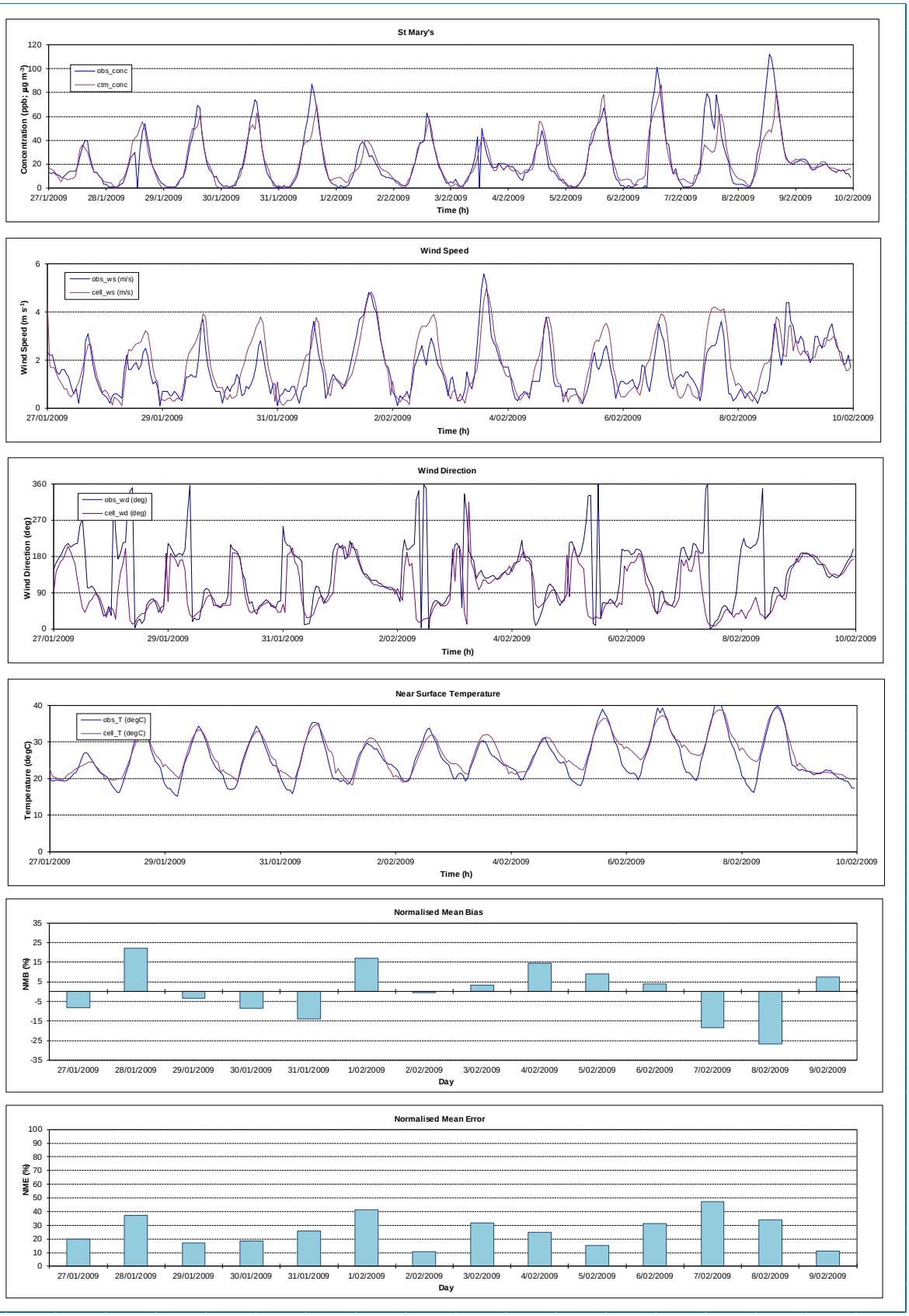


Figure 9-1: Time series of observed and predicted O_3 concentration, wind speed, direction and temperature – St Marys

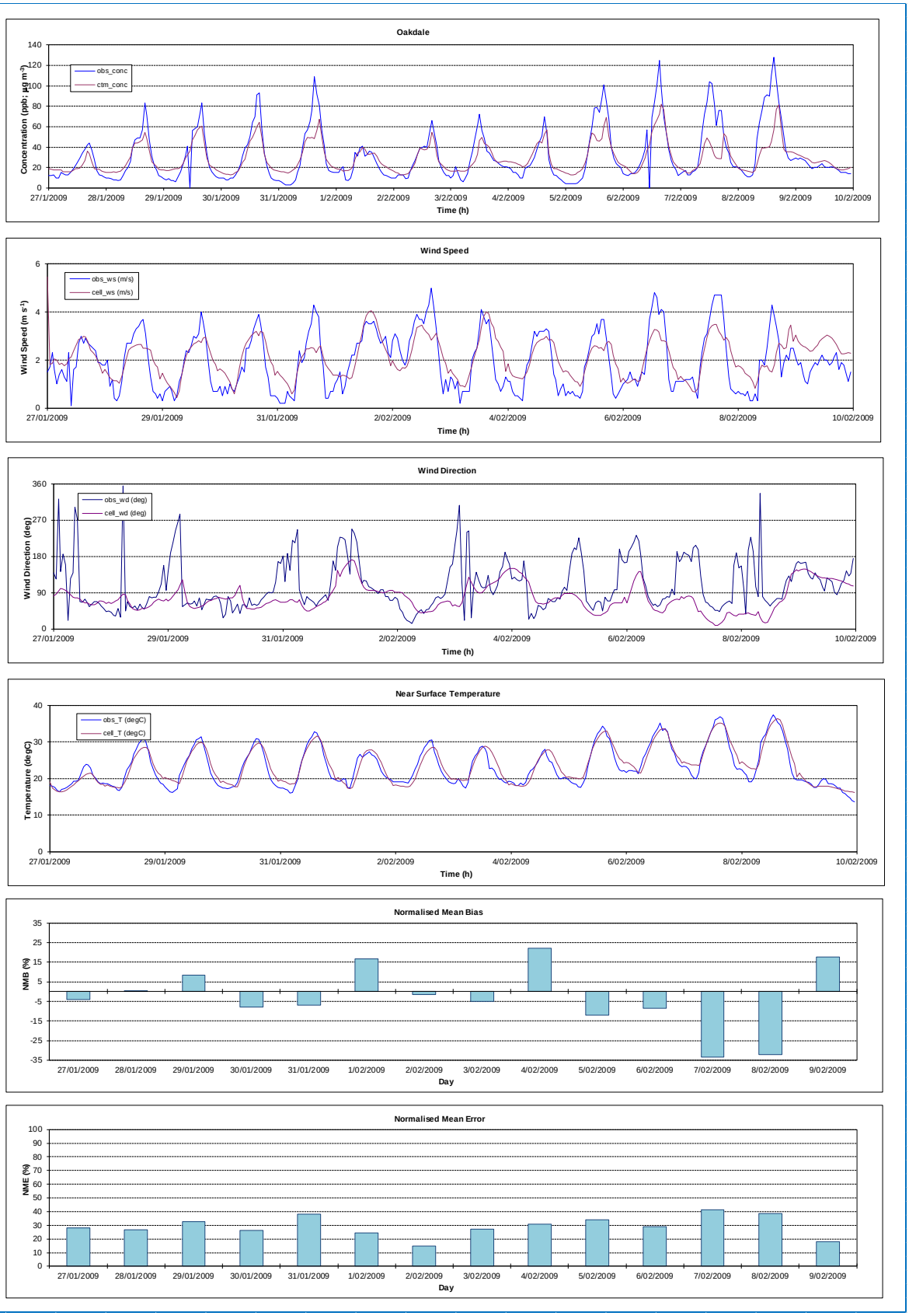


Figure 9-2: Time series of observed and predicted O_3 concentration, wind speed, direction and temperature – Oakdale

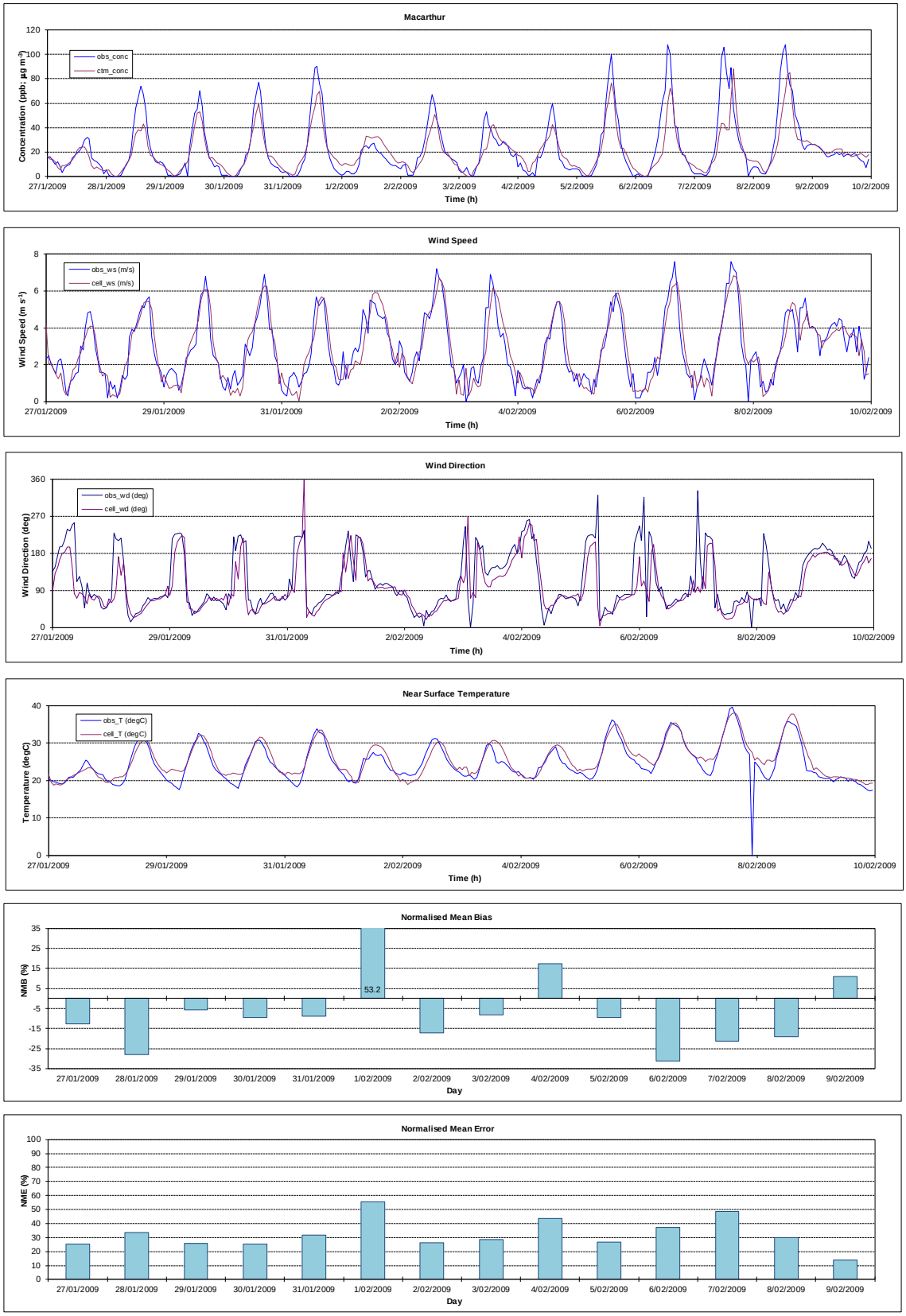
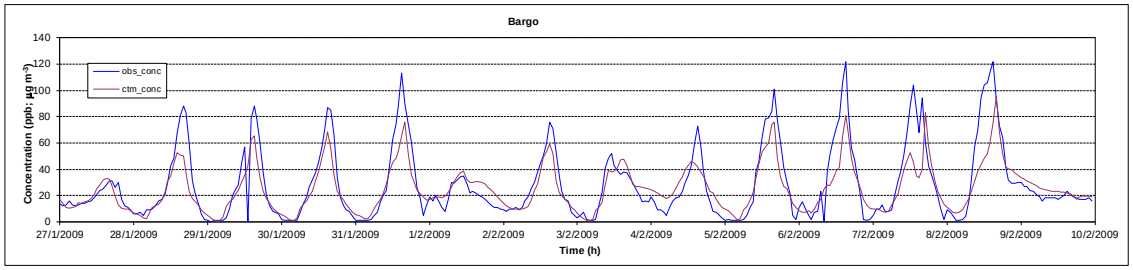
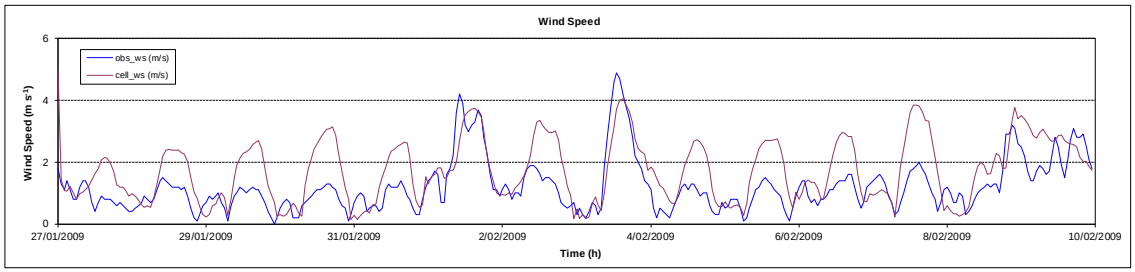
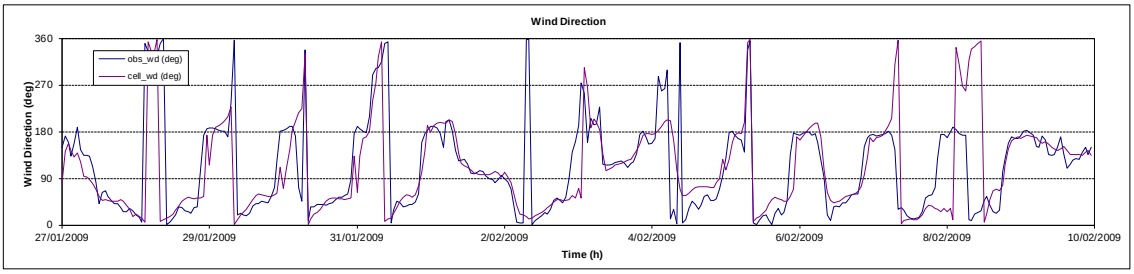
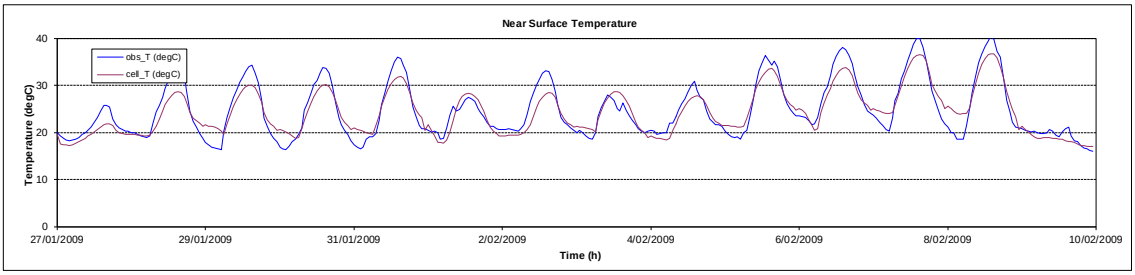


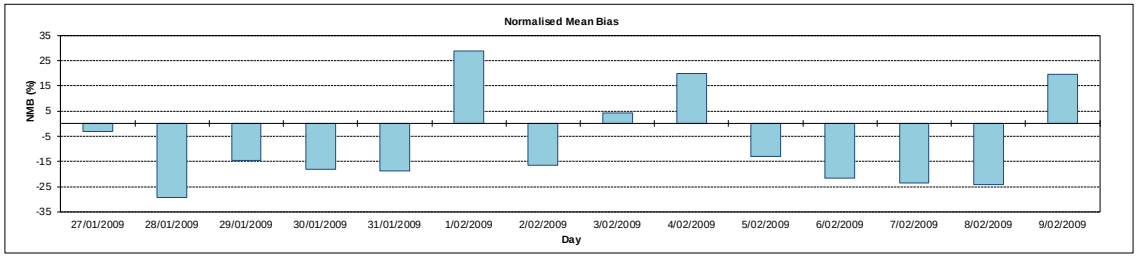
Figure 9-3: Time series of observed and predicted O_3 concentration, wind speed, direction and temperature – Macarthur


Bargo
obs_conc
ctm_conc
Concentration (ppb; µg m-3)
Time (h)


Wind Speed
obs_ws (m/s)
cell_ws (m/s)
Wind Speed (m s-1)
Time (h)


Wind Direction
obs_wd (deg)
cell_wd (deg)
Wind Direction (deg)
Time (h)


Near Surface Temperature
obs_T (degC)
cell_T (degC)
Temperature (deg C)
Time (h)


Normalised Mean Bias
NMB (%)
Day

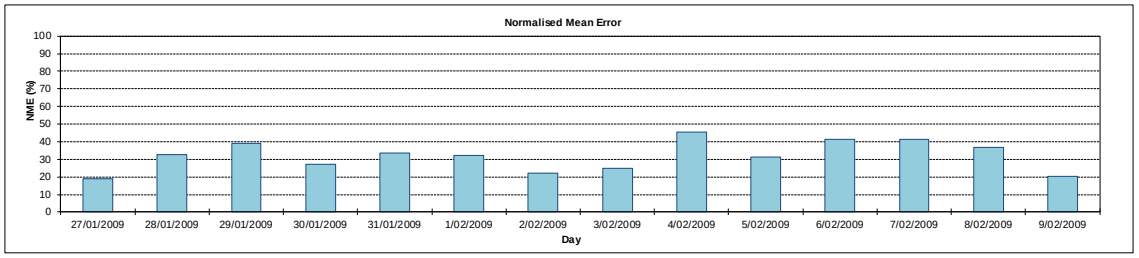

Normalised Mean Error
NME (%)
Day

Figure 9-4: Time series of observed and predicted O_3 concentration, wind speed, direction and temperature – Bargo

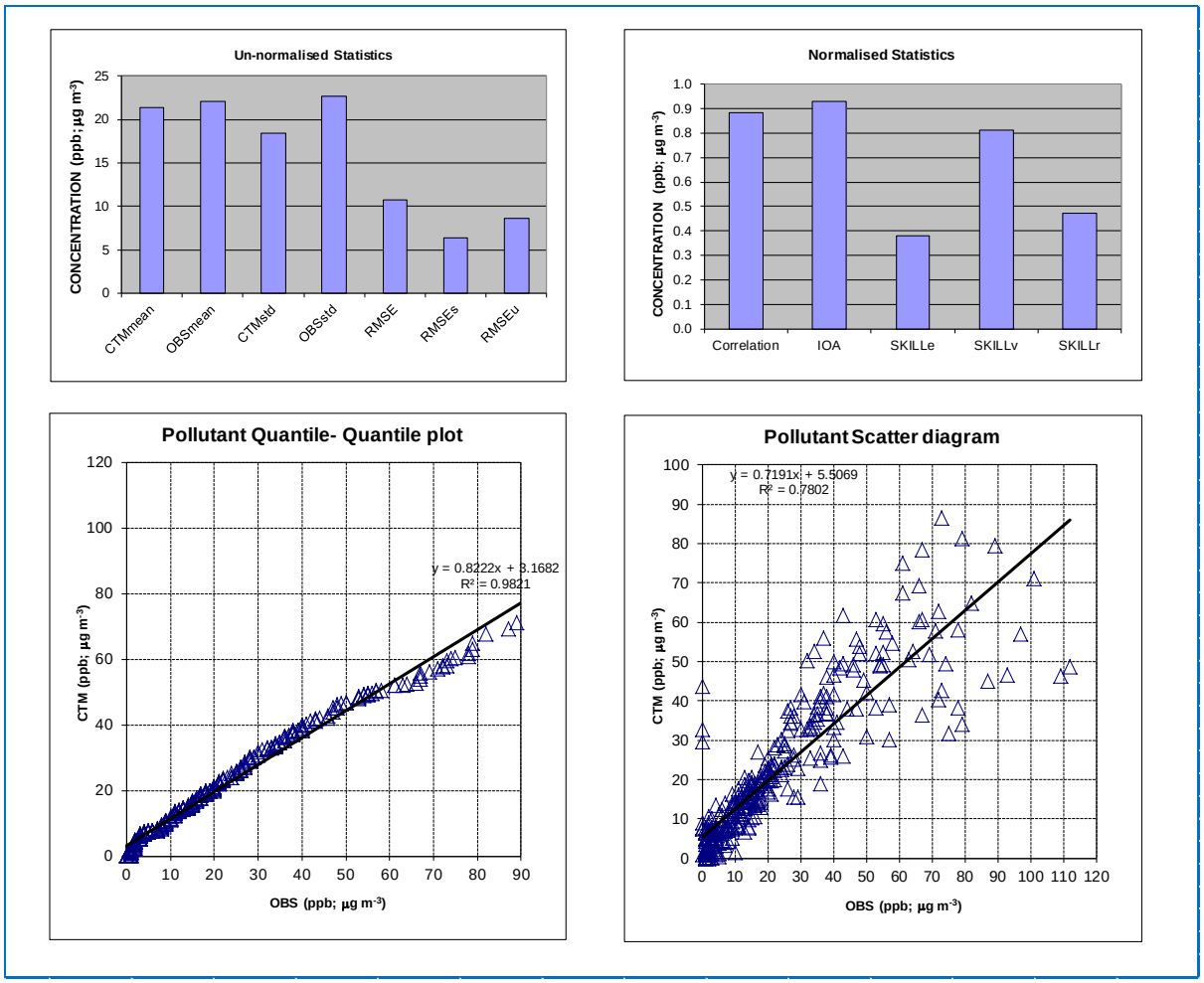


Figure 9-5: Statistical evaluation of observed and predicted O_3 concentration – St Marys

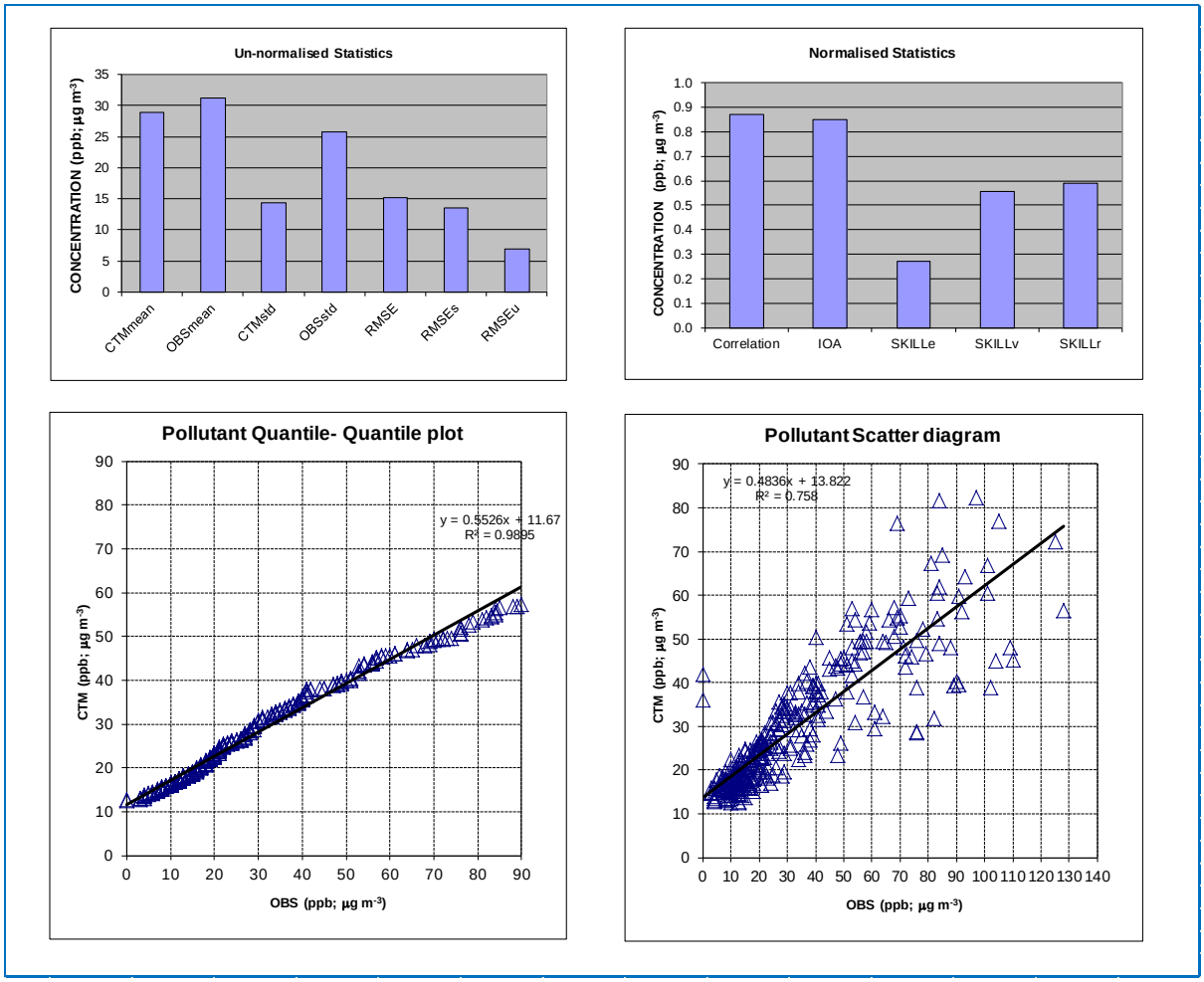


Figure 9-6: Statistical evaluation of observed and predicted O_3 concentration – Oakdale

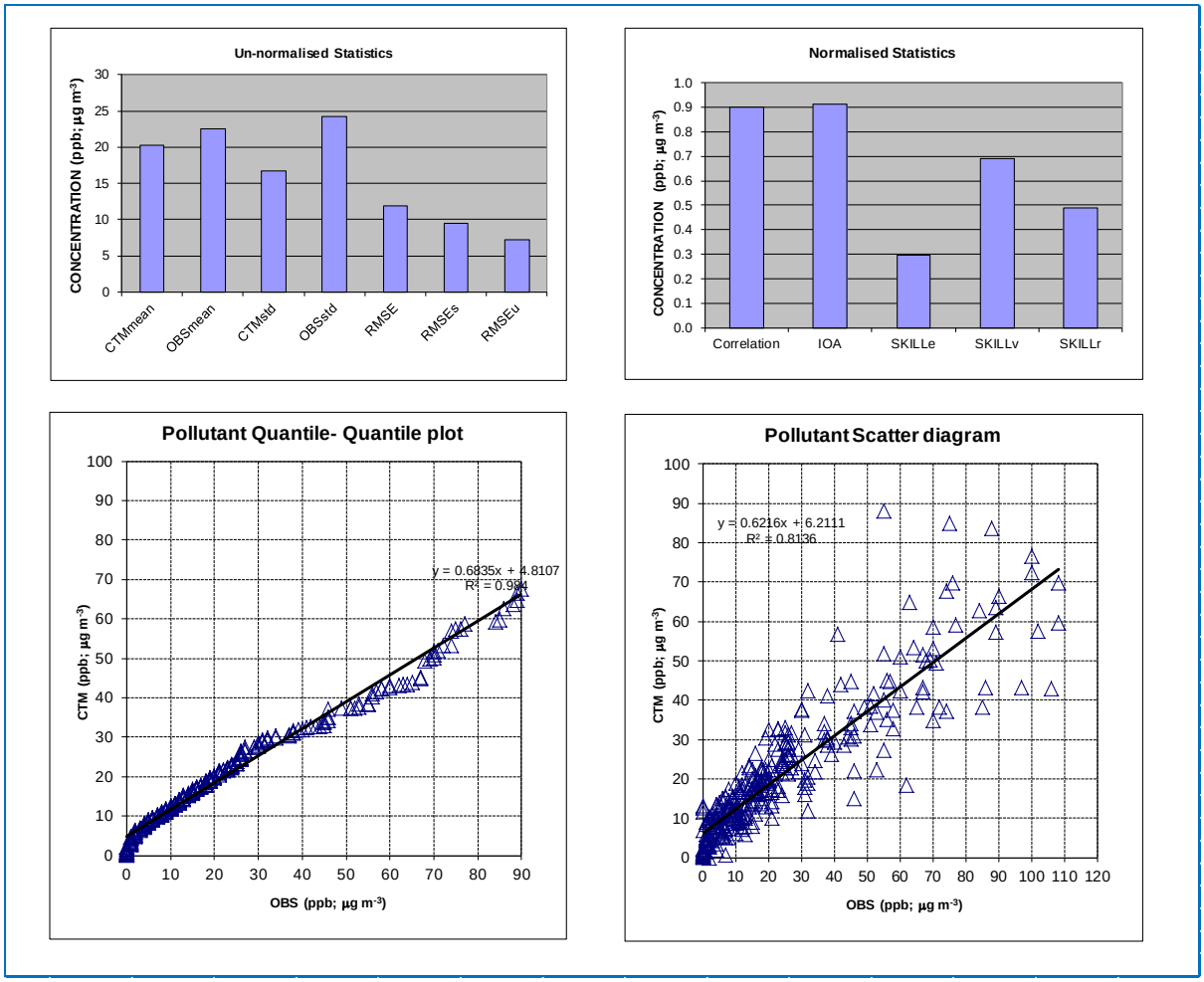


Figure 9-7: Statistical evaluation of observed and predicted O_3 concentration – Macarthur

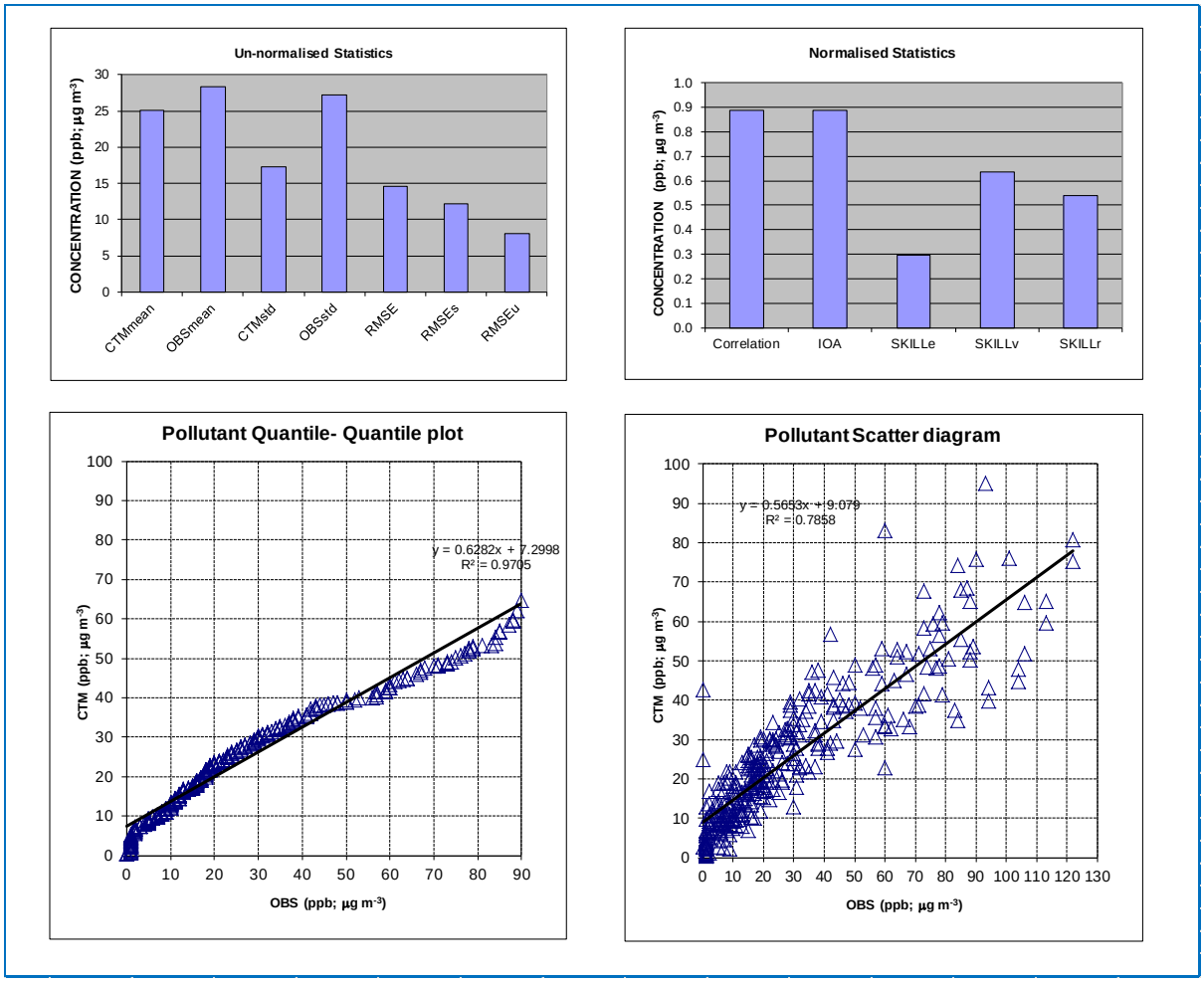


Figure 9-8: Statistical evaluation of observed and predicted O_3 concentration – Bargo

10 EVALUATION OF IMPACT

10.1 Selection of days

The days selected for analysis of impact are:

- 28 January 2009
- 30 January 2009
- 31 January 2009
- 6 February 2009
- 7 February 2009
- 8 February 2009

These days fit the selection criteria outlined in **Environ (2011)**, namely:

- High measured ozone concentrations
- High modelled ozone concentrations
- Days when the model performs well (predicted comparable to observed)
- Ozone impact occurs over land.

It is highlighted that during the last four days (6 to 9 February) bushfires were recorded in the Sydney region. As noted in **Section 9.1**, it may be expected that the performance of the TAPM-CTM model will not be optimal during these days without accurate characterisation of this important source of ozone precursors. However, on these days elevated O_3 observations were measured in addition to high O_3 predictions. On that basis, it was agreed, through consultation with both OEH and EPA, that these days would be included in the assessment for evaluation purposes.

Accurate inclusion of bushfire emissions within TAPM-CTM is not anticipated to be practicable, since the emissions files for bushfires were not readily available at the time of modelling and are still considered to be a research application only (M. Cope. Personal communications. 13 February, 2015). Secondly it is acknowledged that the prevailing bushfire conditions during this period are not representative of typical conditions experienced during normal operations of the Project.

Time series of the observed and predicted (Base Case and Test Case) O_3 concentrations for the above selected days at four OEH ambient air quality monitoring locations (St Marys, Oakdale, Macarthur and Bargo) are presented in **Figure 10-1** and **Figure 10-2**. A time series of O_3 predictions for the two week modelling period[e] is provided in **Appendix D**, along with the corresponding NO_2 and NO_x predictions.

Of the six selected investigation days, the time series show:

- Peak O_3 concentrations measured on these days. The observed concentrations are indicated on the plot as boxes.
- Peak O_3 concentrations predicted on these days under Base Case (BC) and Test Case (TC) scenarios. The Base Case and Test Case predictions are shown as the green and red lines, respectively.

Evaluation of the time series indicates that:

- Predicted O_3 concentrations track well with the measured O_3 concentrations; however the peak observed concentrations are generally under predicted.
- There is little difference in predicted O_3 concentration between the Base Case and Test Case.

[e] Day 1 of the modelling period corresponds to 27 January 2009.

The Test Case scenario has assumed reasonable worst-case operations of the TNG EfW facility (all four lines operational and two stacks operating at the EU IED daily stack emission limits) and is used to compare the incremental change in O_3 concentration as a result of operation of the TNG EfW facility. As discussed in in **Section 6.2.2**, upset conditions have not been explicitly modelled. This is due to their anticipated short duration, combined with the low likelihood that an upset event would combine with a day of high ozone generating potential.

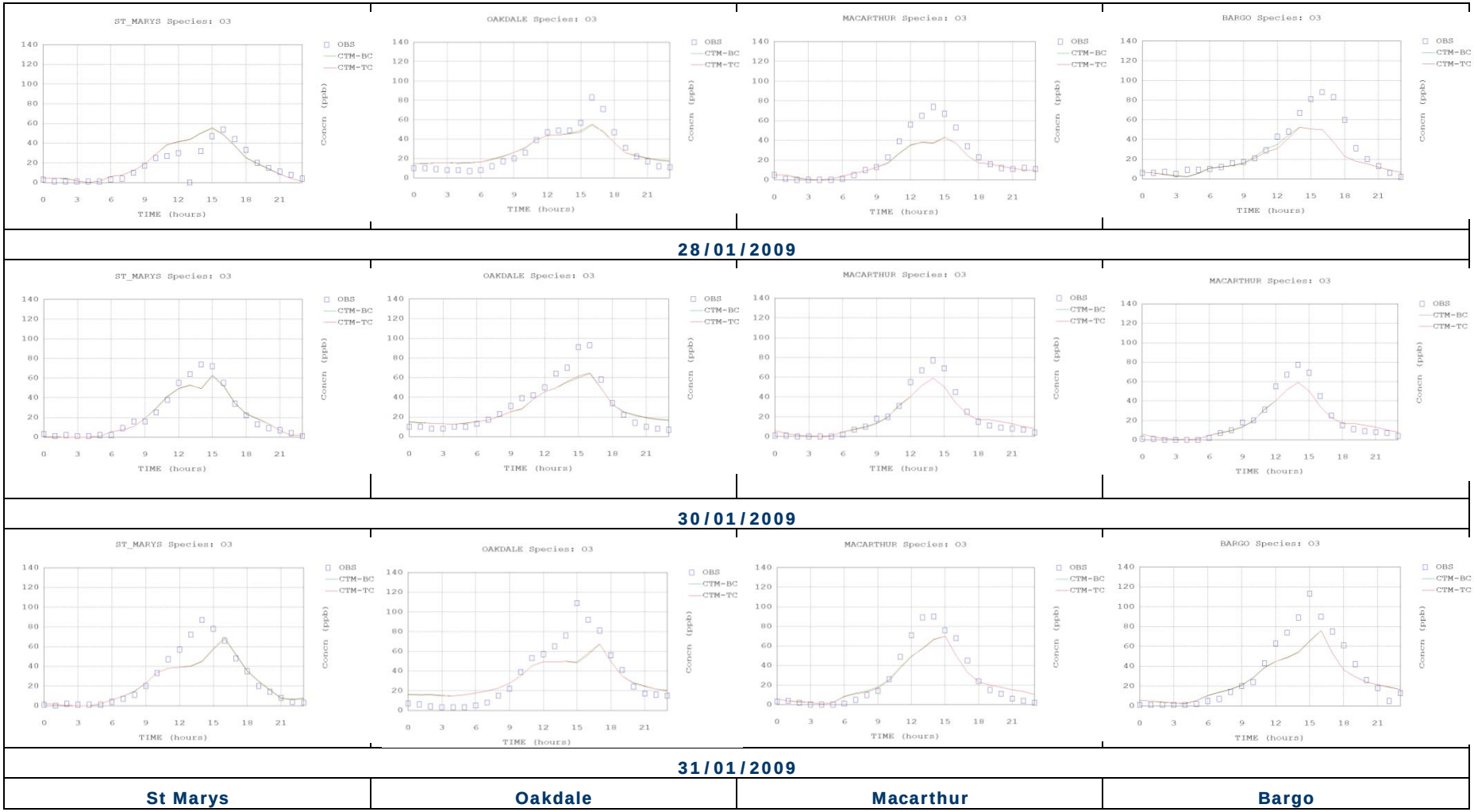


Figure 10-1: Time series of observed and predicted ozone concentrations on 28/01/2009, 30/01/2009 and 31/01/2009

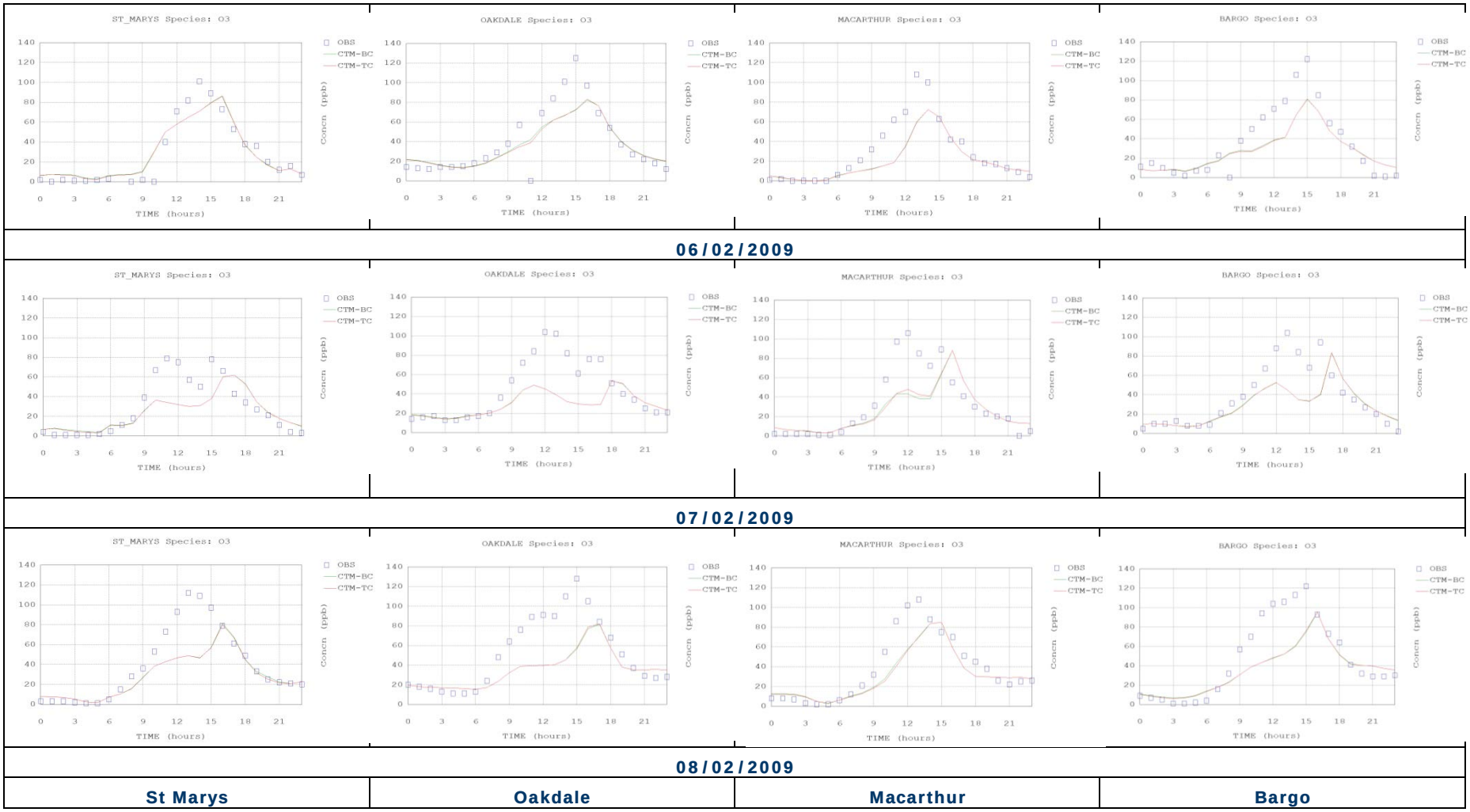


Figure 10-2: Time series of observed and predicted ozone concentrations on 06/02/2009, 08/02/2009 and 09/02/2009

10.2 Maximum predicted O_3 concentrations

The maximum predicted 1-hour and 4-hour O_3 concentration across the modelling grid for each day is presented in **Table 10-1**. Also shown is the maximum O_3 increase (difference between the Test Case and Base Case) at any given grid cell within the model domain (i.e. results paired in space and time).

The results indicate that the maximum change between predicted O_3 concentrations during Base Case and Test Case scenarios may be in excess of 1 ppb at any given grid cell under worst-case ozone formation conditions, for both the 1-hour and 4-hour averaging periods.

Table 10-1: Maximum predicted 1-hour and 4-hour O_3 concentration (ppb) for selected days across the model domain

Date	Maximum O_3 prediction across grid for each day		Results paired in space and time			
	Base case (ppb)	Test Case (ppb)	Maximum difference (ppb)	Hour of maximum difference	Base case (ppb)	Test Case (ppb)
1-hour						
28/01/2009	61.9	61.6	2.2	16:00	51.2	53.5
30/01/2009	66.8	66.1	2.2	14:00	45.4	47.6
31/01/2009	77.2	77.2	2.5	15:00	50.7	53.2
06/02/2009	88.0	88.0	1.7	14:00	67.3	69.1
07/02/2009	78.9	78.9	4.7	12:00	43.0	47.8
08/02/2009	86.6	86.6	5.7	13:00	60.8	66.5
4-hour						
28/01/2009	57.2	56.8	1.1	16:00	49.0	50.1
30/01/2009	64.8	64.8	1.1	16:00	48.4	49.5
31/01/2009	69.3	69.5	1.7	15:00	52.7	54.5
06/02/2009	84.3	84.4	1.0	16:00	74.9	75.9
07/02/2009	86.6	87.1	3.2	14:00	40.1	43.3
08/02/2009	82.9	83.0	2.8	15:00	60.9	63.7

To further examine the increase in predicted O_3 concentrations across the modelling domain, a series of plots have been prepared for each investigation day on the hour of maximum ozone increase and are shown in **Figure 10-3** through **Figure 10-8**. The plots present the maximum ozone increments for all grid cells within the model domain. The difference (Test Case – Base Case) is shown on the y axis, with the Test Case predictions shown on the x axis, for all grid cells during the hour of maximum difference noted in **Table 10-1**.

The plots show that the maximum (positive) ozone increments generally occur when ozone concentration are between 50 ppb and 70 ppb across the modelling domain. Based on the maximum predicted increments presented in **Table 10-1** being between 1.7 ppb and 5.7 ppb, the total ozone concentration is predicted to be below the NSW impact assessment criterion of 100 ppb for 1-hour average ozone concentrations on all occasions.

Also provided in **Figure 10-3** through **Figure 10-8** are the ranked changes in O_3 concentration by grid cell for the same hours. These plots show that the number of grids cells predicted to experience an increase of 1 ppb or more (under worst-case ozone formation conditions) is relatively low compared with the total number of grid cells included in the modelling domain.

A representation of the predicted extent and magnitude of the ozone increments (both positive and negative) are presented within the contour plots provided in **Figure 10-9** and **Figure** 10-14. These show the difference in ozone concentration (Test Case – Base Case) across the modelling domain for the three worst hours of O_3 impact (i.e. paired in both space and time).

Appendix E provides a series of contour plots showing the spatial distribution of the maximum predicted ozone concentrations for each investigation day.

Ozone increments in excess of 1 ppb tend to occur within the south and southwest of Sydney. This is to be expected, based on observed ozone formation within the Sydney basin. Review of the observed maximum 1-hour and 4-hour concentrations (see **Section 7.2**) in combinations with the corresponding hourly predictions (**Appendix E**) indicates that this region is subject to higher ozone concentrations with respect to the rest of the Sydney airshed.

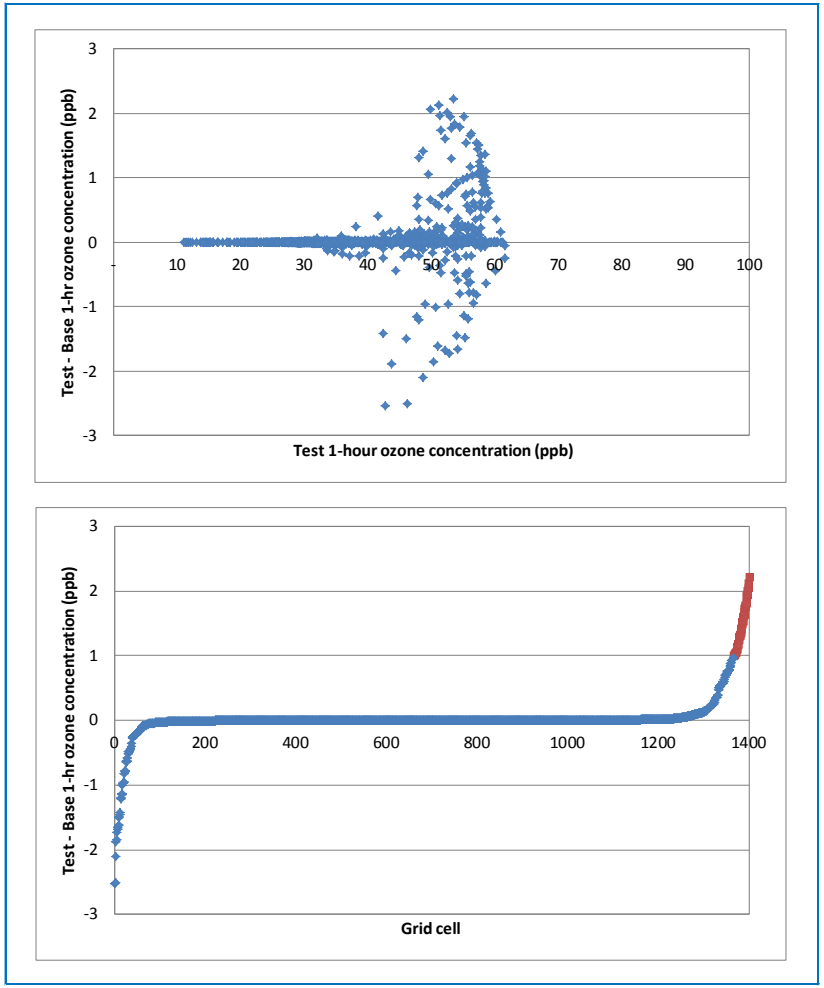


Figure 10-3: Ozone impact for 28 January 2009 at 16:00

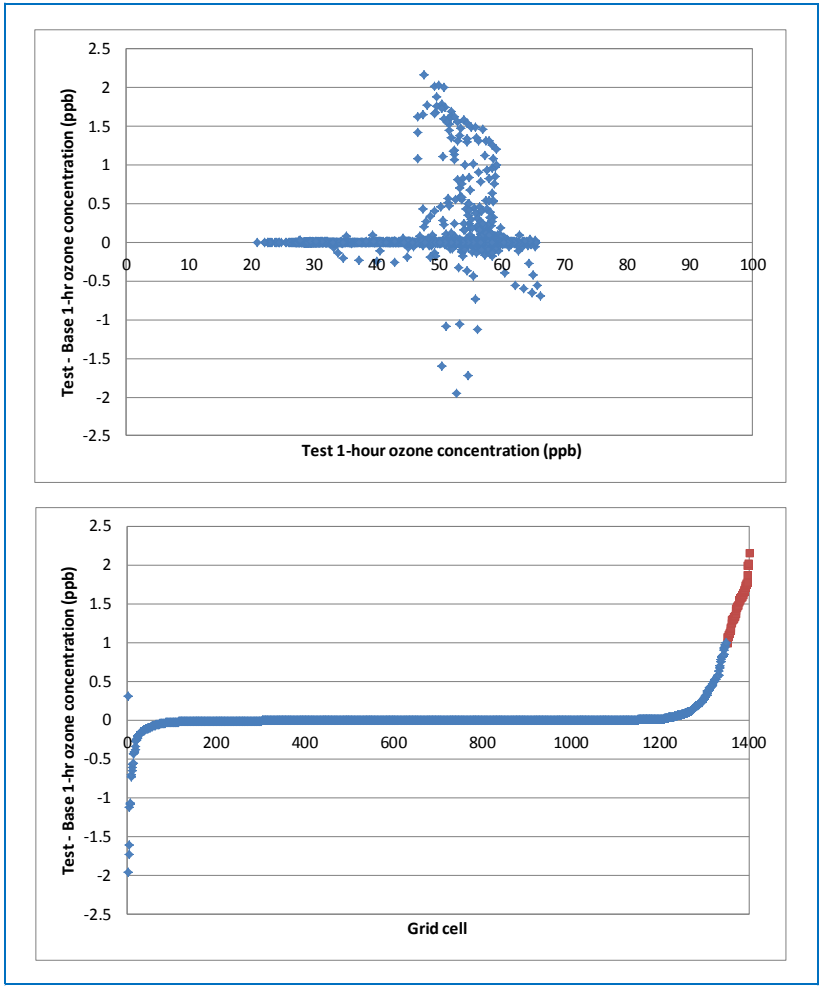


Figure 10-4: Ozone impact for 30 January 2009 at 14:00

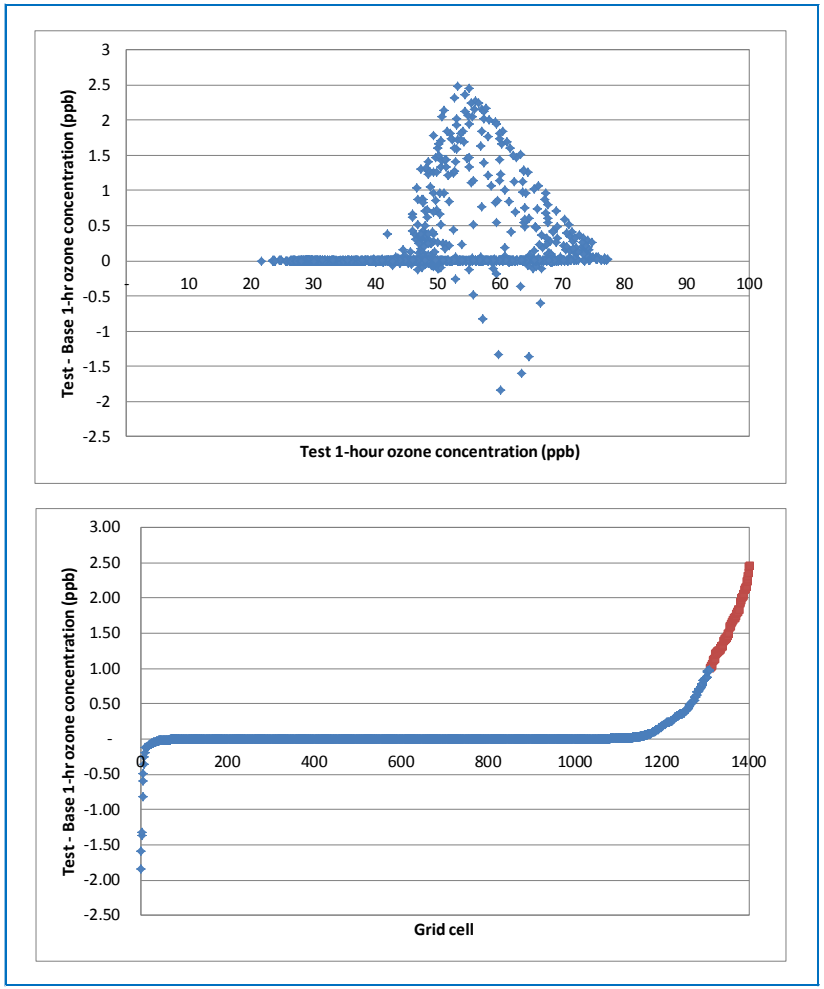


Figure 10-5: Ozone impact for 31 January 2009 at 15:00

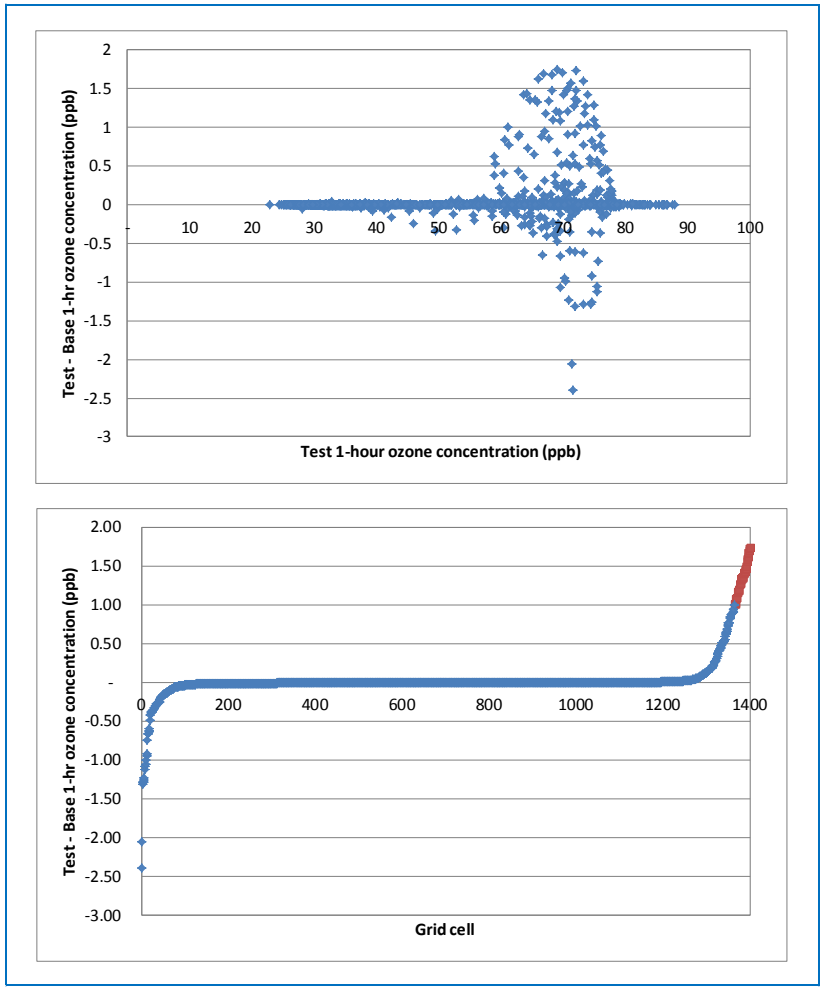


Figure 10-6: Ozone impact for 6 February2009 at 14:00

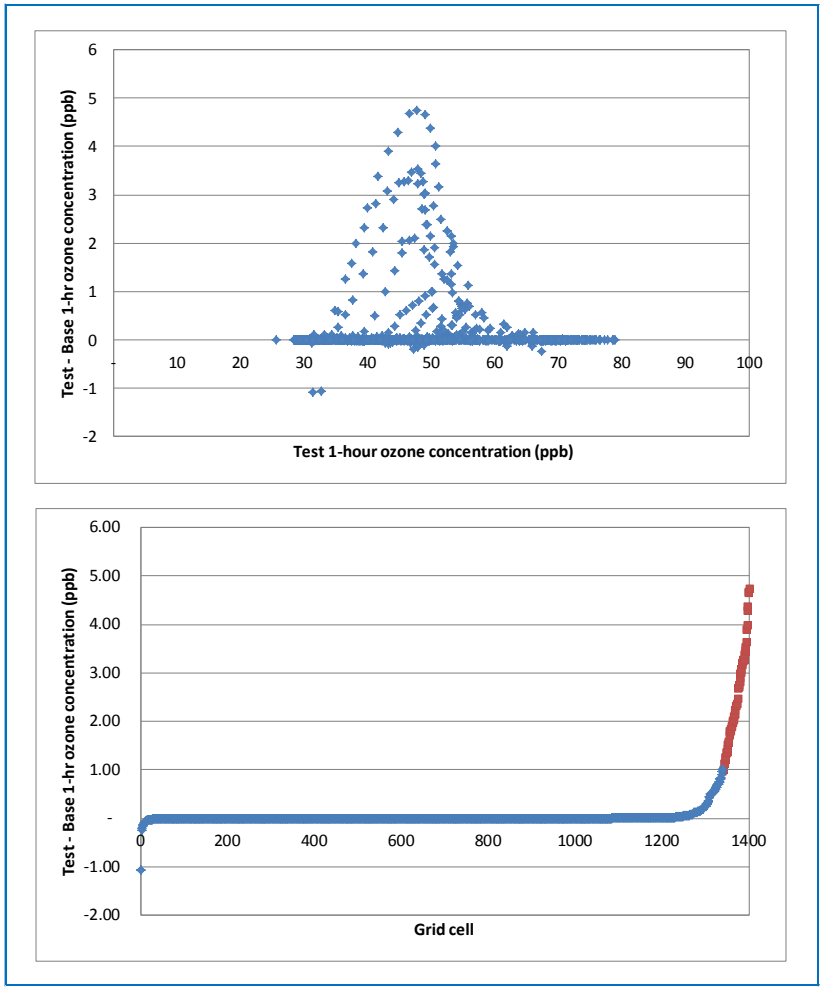


Figure 10-7: Ozone impact for 7 February2009 at 12:00

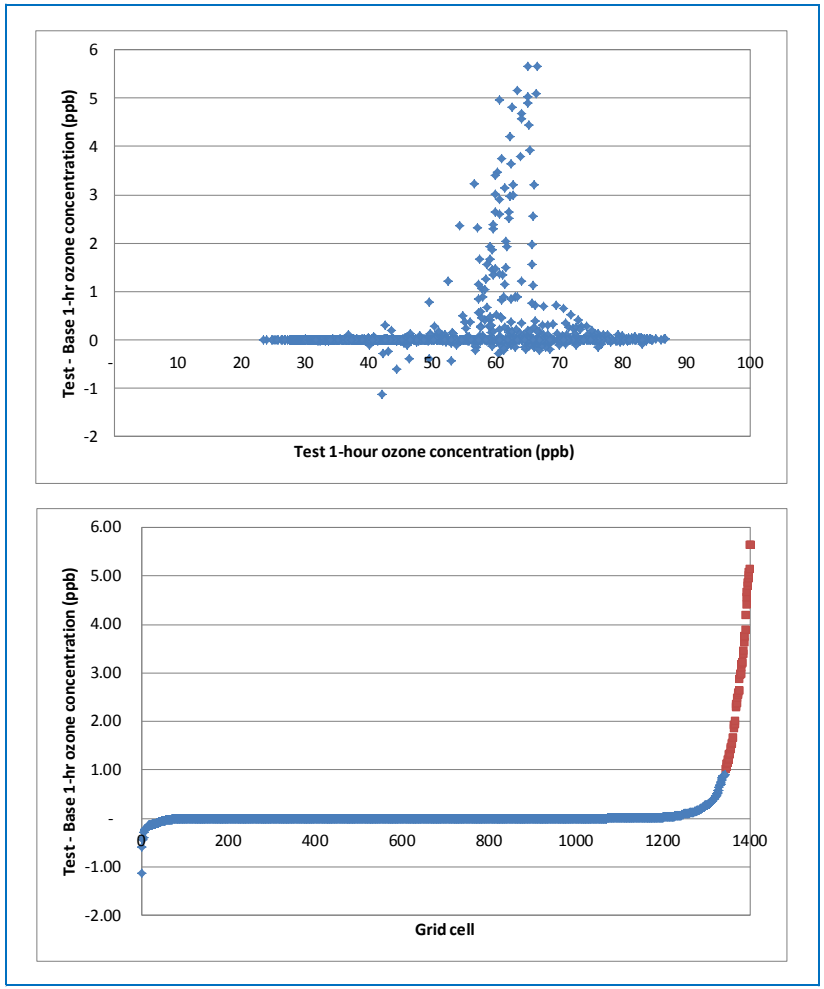


Figure 10-8: Ozone impact for 8 February2009 at 13:00

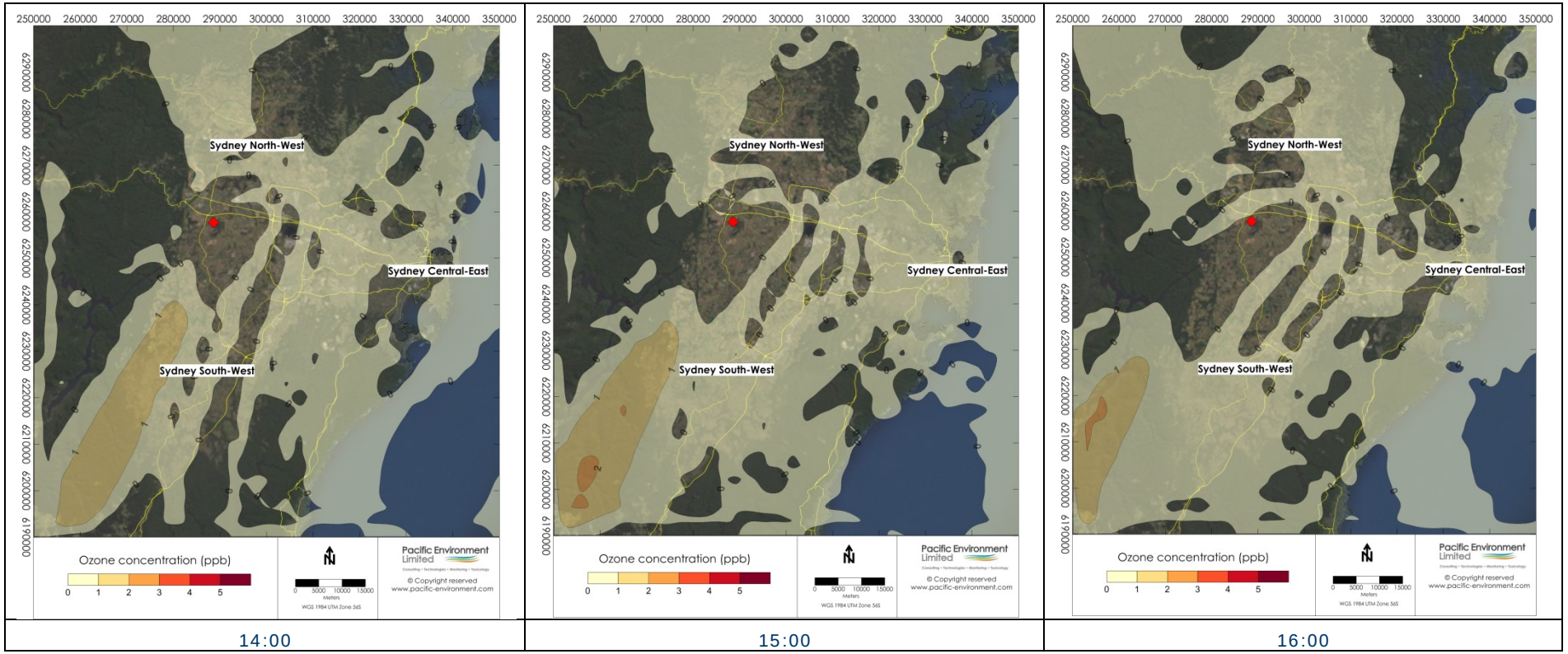


Figure 10-9: Difference in 1-hour O_3 concentration for hours of highest measured and predicted impact on 28/01/2009

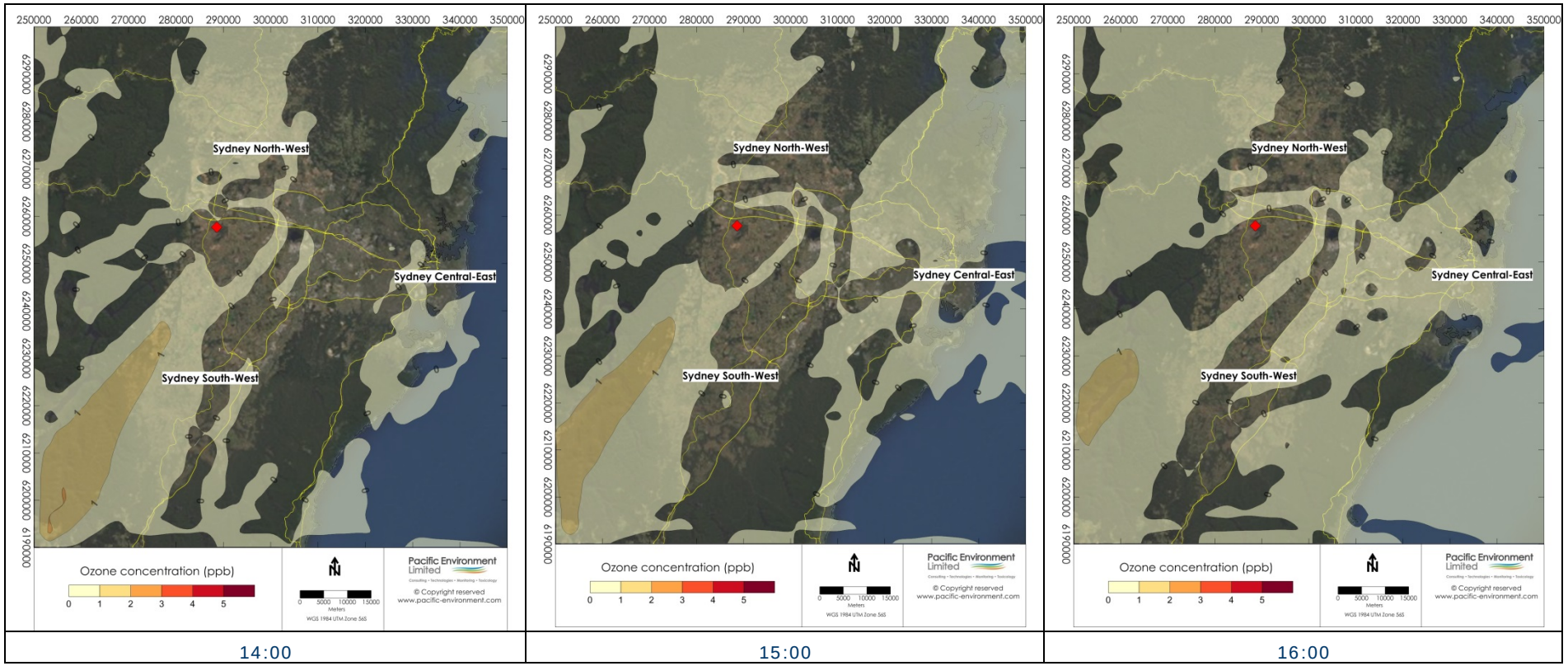


Figure 10-10: Difference in 1-hour O_3 concentration for hours of highest measured and predicted impact on 30/01/2009

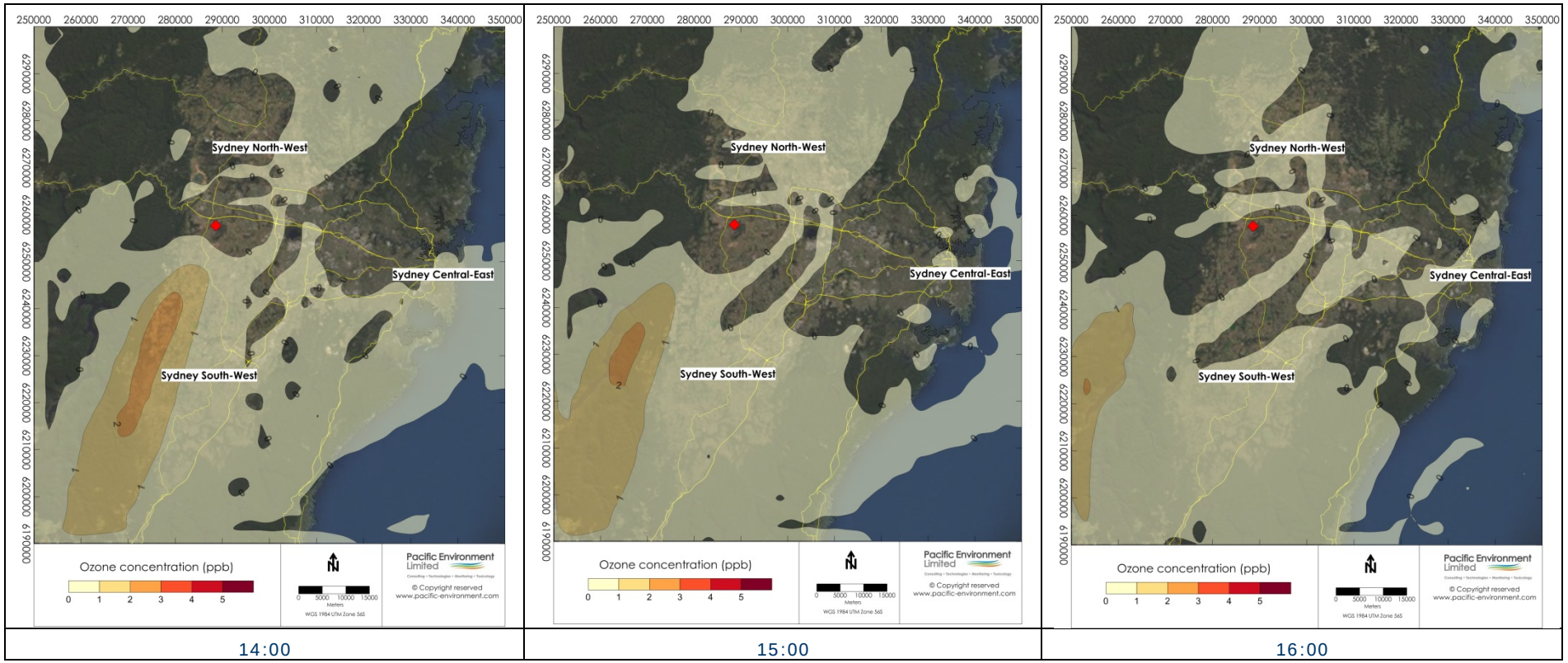


Figure 10-11: Difference in 1-hour O_3 concentration for hours of highest measured and predicted impact on 31/01/2009

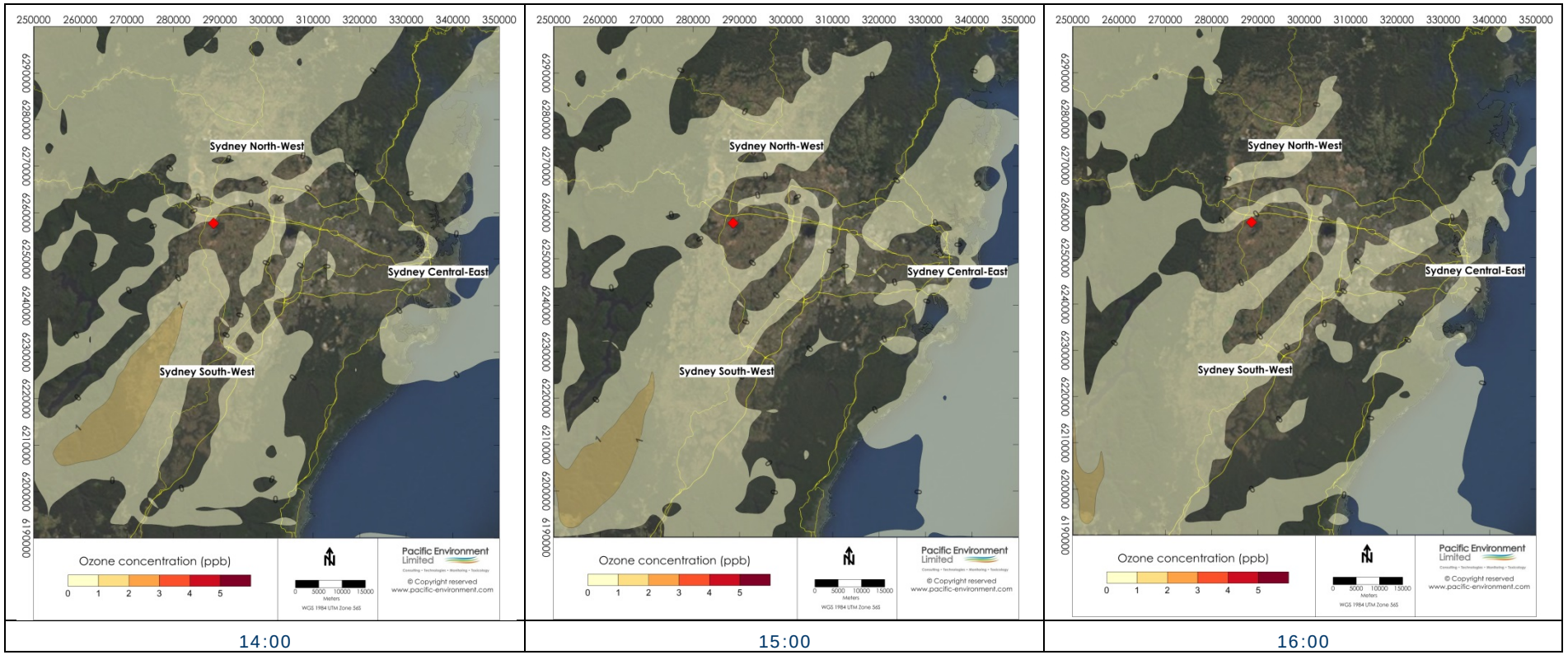


Figure 10-12: Difference in 1-hour O_3 concentration for hours of highest measured and predicted impact on 06/02/2009

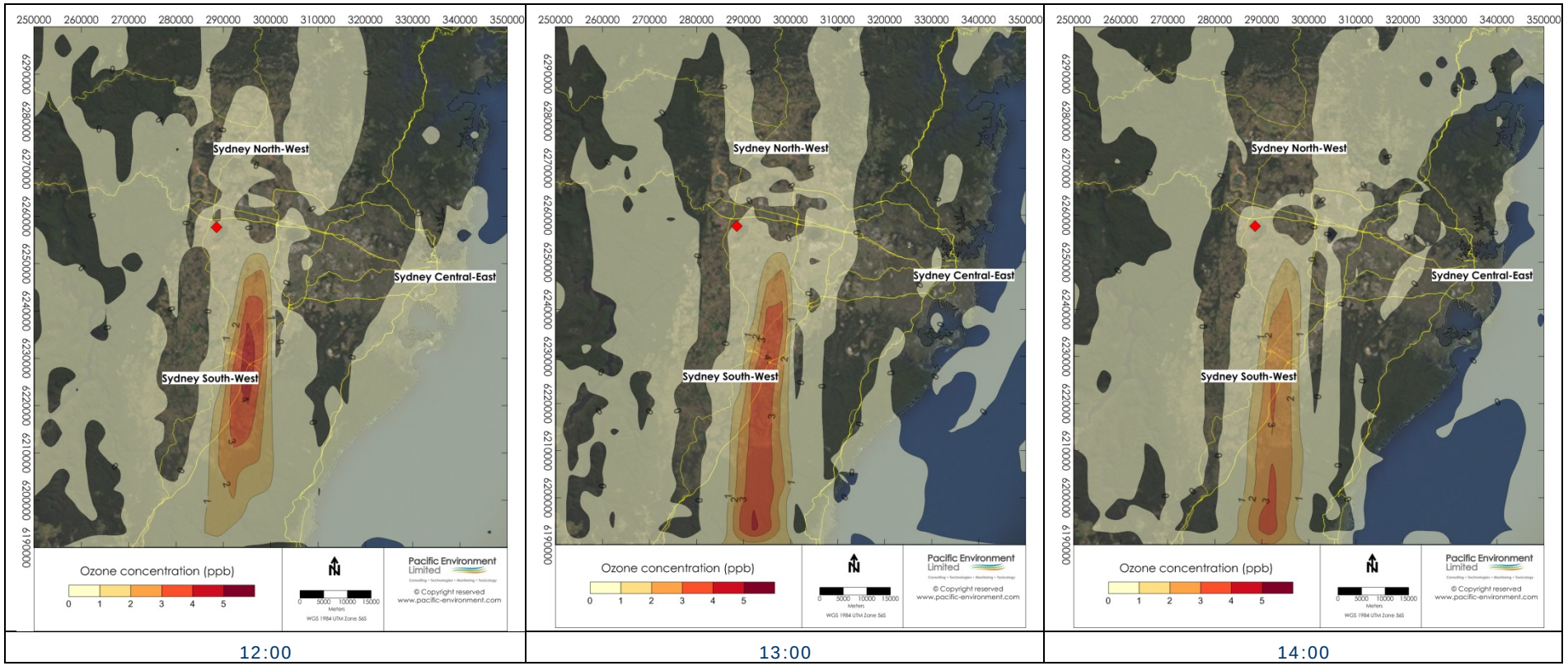


Figure 10-13: Difference in 1-hour O_3 concentration for hours of highest measured and predicted impact on 07/02/2009

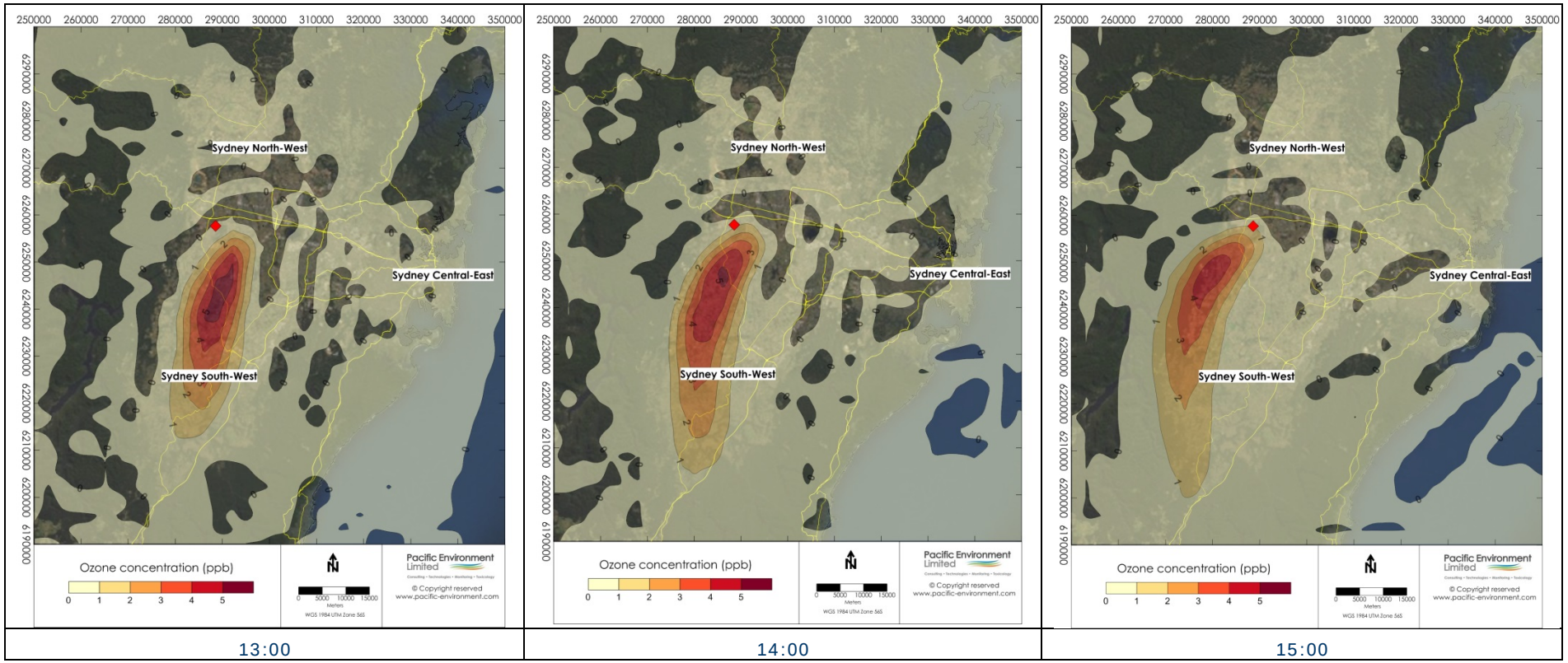


Figure 10-14: Difference in 1-hour O_3 concentration for hours of highest measured and predicted impact on 08/02/2009

10.3 Evaluation of impact

The EPA's proposed ozone assessment framework states that if the maximum ozone increment is below the SIL (0.5 ppb), the project must demonstrate that best management practice (BMP) is implemented for the emission source and all Reasonably Available Technology (RAT) should be considered. Further, it states that if the maximum ozone increment is above the SIL but below the maximum allowable increment (1 ppb), the project must demonstrate best management practice (BMP) for the emission source and consider Best Available Technology (BAT) and/or emissions offsets.

If the maximum ozone increment is above the maximum allowable increment, the EPA may consider the impact of the source on local and regional air quality having regard to the following:

vii. The outcomes of the BMP determination
viii. The frequency and duration of ground-level ozone impacts
ix. Any pollution reduction programs established or agreed to
x. Any control equipment installed or agreed to
xi. Any load reduction agreement entered into
xii. The principles of ecologically sustainable development.

As demonstrated in **Section 10.2** the difference between the maximum 1-hour and 4-hour O_3 for the Base Case and Test Case, across the entire region is, on particular hours, and at specific locations, predicted to be above the maximum allowable increase of 1 ppb.

As outlined in **Section 2.2.1** the project has been demonstrated to employ Best Available Technology (BAT) for NO_x control (described in more detail in the local air quality assessment (**Pacific Environment, 2015**)).

Further, while incremental O_3 concentrations are predicted to be greater than 1 ppb on particular hours at particular locations, these do not relate to periods of time or locations where the maximum concentrations are occurring, nor at concentrations that are predicted to exceed the NEPM ambient O_3 criteria. In other words, while the value of 1 ppb is predicted to occur on occasion under the Test Case scenario, this ozone formation is predicted to occur during periods when ambient ozone is low (and thus of lesser concern).

As described in **Section 6.2**, a worst case Test Case scenario assumes that both stacks are continuously operating at the daily average emission limit (i.e. the maximum allowable emission concentration). During normal operation of the plant, the emission levels are generally expected to be well within this limit value.

11 CONCLUSION

An ozone impact assessment, based on the EPA's proposed ozone assessment framework for NSW, has been completed using a Level 2 refined assessment methodology (modelling using TAPM-CTM).

The significance of impact on ground-level ozone in the GMR is assessed based on the screening impact level (SIL) of 0.5 ppb and maximum allowable increment of 1 ppb.

Two scenarios were examined, a Base Case and Test Case emissions scenario. The Base Case assesses model performance without the facility while the Test Case is used to assess the change in O_3 concentration with the addition of emissions from the facility.

Model performance for the Base Case was evaluated against the measured 1-hour ambient concentrations and found to perform with an acceptable degree of accuracy. A general observation is that the model tends to over predict when ambient concentrations are low and under predict peak O_3 concentrations.

An important consideration in any photochemical modelling exercise is the degree of accuracy that can be expected of the model outputs in comparison with observations. Photochemical modelling is an evolving field. Such wide degrees of uncertainty in photochemical modelling are typically a function of the uncertainty of the inputs, for example the complexity and variability in the nature of biogenic emissions.

Uncertainties in the model were identified to include the 2008 GMR inventory, the influence of bushfire events, boundary layer height predictions and the role of biogenic emissions.

As noted within the peer review provided as **Appendix F**, the resultant under prediction of the peak ozone concentrations adds to the uncertainty of the calculated TNG EfW influence on peak ozone (and hence the magnitude of the ozone change). However, such uncertainty is unlikely to change the sign of the ozone response. This is because the influence of the plant's NO_X emissions will generally robustly lead to titration and ozone reduction in the near field, and through the geographical location of the facility in the west of Sydney, to some increase in ozone concentration for situations when the NO_X emissions interact with an aged photochemical smog plume transported inland from coastal urban regions.

Six days were selected for detailed analysis of impact based on high ozone concentrations when the model performs well. The analysis shows that the difference between the maximum 1-hour and 4-hour O_3 for the Base Case and Test Case, across the region, may be above the maximum allowable increase of 1 ppb on specific occasions and at locations.

Further, while incremental O_3 concentrations are predicted to be greater than 1 ppb on particular hours at particular locations, these do not relate to periods of time or locations where the maximum concentrations are occurring, nor at concentrations that are predicted to exceed the NEPM ambient O_3 criteria. In other words, while the value of 1 ppb is predicted to occur on occasion under the Test Case scenario, this ozone formation is predicted to occur during periods when ambient ozone is low (and thus of lesser concern).

It is noted that a reasonable worst case Test Scenario assumes that both stacks are continuously operating at the EU IED daily emission limit. Typically during normal operations of the plant, the emission levels are anticipated to be lower. The facility will employ Best Available Technology (BAT) in the form of Selective Non-Catalytic Reduction (SNCR) for reducing emissions of NO_x, the dominant ozone precursor released from the facility. VOCs will be minimised through combustion control with additional controls afforded from activated carbon injection as part of the flue gas treatment.

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Appendix A: BOUNDARY CONDITIONS

Vertical initial conditions

Emission	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)
CO	65	65	65	65	65	65
SO2	1	1	1	1	1	0.1
NO2	1	1	1	1	1	0.1
NO	0.1	0.1	0.1	0.1	0.1	0.01
O3	20	20	20	20	20	20
HCHO	0	0	0	0	0	0
ALD	0	0	0	0	0	0
PAR	1	1	1	1	1	0.5
ETH	0.03	0.03	0.03	0.03	0.03	0.01
OLE	0.03	0.03	0.03	0.03	0.03	0.01
TOL	0.02	0.02	0.02	0.02	0.02	0.002
XYL	0.02	0.01	0.01	0.01	0.01	0.001
MEK	0.001	0.001	0.001	0.001	0.001	0.001
PAN	0.03	0.03	0.03	0.03	0.03	0.035
CH4	1700	1700	1700	1700	1700	1700

Boundary conditions aloft

Emission	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)	Conc (ppb)
CO	NORT	65	65	65	65	65	65
CO	EAST	65	65	65	65	65	65
CO	SOUT	65	65	65	65	65	65
CO	WEST	65	65	65	65	65	65
SO2	NORT	1	1	1	1	1	0.1
SO2	EAST	1	1	1	1	1	0.1
SO2	SOUT	1	1	1	1	1	0.1
SO2	WEST	1	1	1	1	1	0.1
NO2	NORT	1	1	1	1	1	0.1
NO2	EAST	1	1	1	1	1	0.1
NO2	SOUT	1	1	1	1	1	0.1
NO2	WEST	1	1	1	1	1	0.1
NO	NORT	0.1	0.1	0.1	0.1	0.1	0.01
NO	EAST	0.1	0.1	0.1	0.1	0.1	0.01
NO	SOUT	0.1	0.1	0.1	0.1	0.1	0.01
NO	WEST	0.1	0.1	0.1	0.1	0.1	0.01
O3	NORT	20	20	20	20	20	20
O3	EAST	20	20	20	20	20	20
O3	SOUT	20	20	20	20	20	20
O3	WEST	20	20	20	20	20	20
HCHO	NORT	2	2	2	2	2	0.2

HCHO	EAST	2	2	2	2	2	0.2
HCHO	SOUT	0	0	0	0	0	0
HCHO	WEST	2	2	2	2	2	0.2
ALD	NORT	1	1	1	1	1	0.2
ALD	EAST	1	1	1	1	1	0.2
ALD	SOUT	0.1	0.1	0.1	0.1	0.1	0.02
ALD	WEST	1	1	1	1	1	0.2
PAR	NORT	10	10	10	10	10	5
PAR	EAST	10	10	10	10	10	5
PAR	SOUT	1	1	1	1	1	0.5
PAR	WEST	10	10	10	10	10	5
ETH	NORT	0.3	0.3	0.3	0.3	0.3	0.1
ETH	EAST	0.3	0.3	0.3	0.3	0.3	0.1
ETH	SOUT	0.03	0.03	0.03	0.03	0.03	0.01
ETH	WEST	0.3	0.3	0.3	0.3	0.3	0.1
OLE	NORT	0.3	0.3	0.3	0.3	0.3	0.1
OLE	EAST	0.3	0.3	0.3	0.3	0.3	0.1
OLE	SOUT	0.03	0.03	0.03	0.03	0.03	0.01
OLE	WEST	0.3	0.3	0.3	0.3	0.3	0.1
TOL	NORT	0.2	0.2	0.2	0.2	0.2	0.02
TOL	EAST	0.2	0.2	0.2	0.2	0.2	0.02
TOL	SOUT	0.02	0.02	0.02	0.02	0.02	0.002
TOL	WEST	0.2	0.2	0.2	0.2	0.2	0.02
XYL	NORT	0.2	0.2	0.2	0.2	0.2	0.01
XYL	EAST	0.2	0.1	0.1	0.1	0.1	0.01
XYL	SOUT	0.02	0.01	0.01	0.01	0.01	0.001
XYL	WEST	0.2	0.1	0.1	0.1	0.1	0.01
MEK	NORT	0.01	0.01	0.01	0.01	0.01	0.01
MEK	EAST	0.01	0.01	0.01	0.01	0.01	0.01
MEK	SOUT	0.001	0.001	0.001	0.001	0.001	0.001
MEK	WEST	0.01	0.01	0.01	0.01	0.01	0.01
PAN	NORT	0.3	0.3	0.3	0.3	0.3	0.35
PAN	EAST	0.2	0.2	0.2	0.2	0.2	0.25
PAN	SOUT	0.03	0.03	0.03	0.03	0.03	0.035
PAN	WEST	0.3	0.3	0.3	0.3	0.3	0.35
CH4	NORT	1700	1700	1700	1700	1700	1700
CH4	EAST	1700	1700	1700	1700	1700	1700
CH4	SOUT	1700	1700	1700	1700	1700	1700
CH4	WEST	1700	1700	1700	1700	1700	1700

Appendix B: METEOROLOGICAL VALIDATION

Summary statistics for the evaluation sites and selected assimilation sites are presented in **Table A12-2**. At both of the evaluation sites (Earlwood and Oakdale) performed well based on the average wind speed, with TAPM predicting a slightly higher annual average wind speed for the modelled period. This is also the case for the St Marys assimilation site. Conversely, the Macarthur site showed a decrease of 0.4m/s in wind speed when averaged across the modelling period. Further comparison of wind statistics for all sites (evaluation and assimilation) are shown in **Table A12-3**. Review of the percentage of calm periods (when the wind speed is less than or equal to 0.5 m/s) shows that the model is over-predicting low wind speeds at the evaluation sites. For the assimilation sites the percentage of calm periods significantly improves, with the exception of Albion Park and Randwick sites.

Table A12-2 shows that observed and predicted average temperatures correlate well across all evaluation sites.

The statistical measures used to quantify the differences between model predictions and observations are taken from the BOOT Statistical Model Evaluation Software Package (**Chang and Hanna, 2005**) and assessed against the performance benchmarks set for model evaluation (**Emery et. al, 2001)**. Performance is assessed against a benchmark or ideal score. For example, Index of Agreement is a standardised measure of the degree of model prediction error and varies between 0 and 1, with 1 indicating a perfect match (ideal score) and 0 indicating no agreement at all (**Willmott, 1981**). Other measures, such as those for mean gross error (MGE), use the same units as the parameter being tested and the benchmark is met if the model prediction falls within the acceptable range. The statistical measures are summarised in **Table A12-1** along with the performance benchmarks adopted for the study.

Table A12-1: Statistical measures used to evaluate CALMET performance

Statistical measure	Description	Parameter	Benchmark / Ideal Score
Index of agreement (IOA)	$IOA = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(\lvert P_i - \bar{O}\rvert + \lvert O_i - \bar{O}\rvert)^2}$	Wind Speed	≥0.6
		Temp	≥0.8
Mean bias (MB)	$MB = \frac{1}{n}\sum_{i=1}^{N}\lvert P_i - O_i\rvert$	Wind Speed	≤± 0.5 m/s
		Temp	≤± 0.5 K
		Wind Direction	≤10°
Fractional bias	$FBIAS = \frac{2}{n}\sum_{i=1}^{n}\left(\frac{P_i - O_i}{P_i - O_i}\right) \times 100\%$	All	≤± 0.67

Notes:

N = number of observations
P = predicted value
O = observed value
$\bar{O}$ = mean of observed values
$\bar{P}$ = mean of predicted values
I = time period

The evaluation of TAPM performance against these benchmarks is presented in **Table A12-4**.

For both options, the index of agreement (IOA) compares well against the benchmark for all sites and variables, with some approaching the ideal score of 1. Fractional bias for all sites fall within the acceptable range. Model performance against mean bias (MB) falls outside the acceptable benchmark for some parameters at some sites.

Table A12-2: Summary statistics – observed and predicted

Parameter		Earlwood		Oakdale		Macarthur		St Marys	
		Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
Wind Speed (m/s)	Mean	1.9	2.0	1.8	1.9	3.0	2.6	1.8	1.9
Calms (%)		12.0	2.5	10.2	3.0	4.0	6.1	14	15
Wind Direction (deg)		140	125	146	139	147	145	69	151
Temperature (°C)		22.5	22.8	20.1	20.5	22.0	22.9	22.4	24.0

Note: [a] Wind speed less than 0.5 m/s.

Table A12-3: Summary statistics for wind speed (WS) – observed and predicted - all sites

Site	Observed		Predicted	
	Mean WS (m/s)	% Calms	Mean WS (m/s)	% Calms
Albion Park	2.6	20.1	2.3	2.5
Bargo	1.6	13.5	1.7	9.3
Bringelly	2.0	12.3	2.0	13.8
Chullora	2.6	6.2	1.9	6.5
Earlwood	**1.9**	**12.0**	**2.0**	**2.5**
Macarthur	3.0	4.0	2.6	6.1
Oakdale	**1.8**	**10.2**	**1.9**	**3.0**
Prospect	1.9	8.9	2.0	8.2
Randwick	2.8	5.2	2.6	1.6
St Marys	1.8	14.2	1.9	14.9
Vineyard	1.8	13.0	2.1	11.9

Note: sites in bold are evaluation sites

Table A12-4: Statistical evaluation of TAPM performance

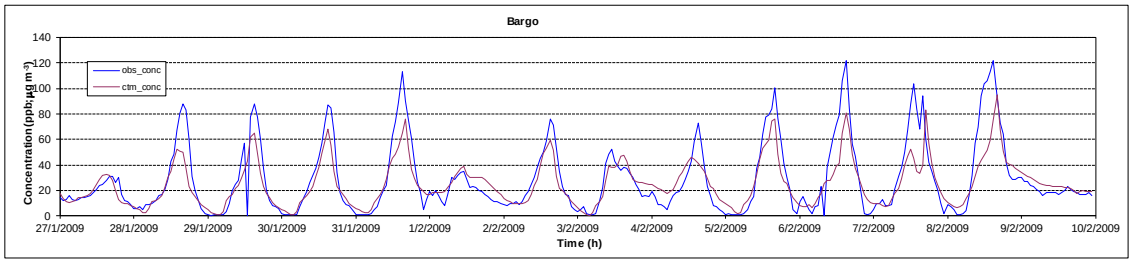
Site	Variable	IOA		Mean bias		Fractional Bias	
	Ideal Score	1		0		≤±0.67	
		Benchmark	Result	Benchmark	Result	Benchmark	Result
Earlwood	Wind speed	≥0.6	0.90	≤±0.5 m/s	0.4	≤±0.67	0.22
	Wind direction	-	-	≤10 °	29	-	-
	Temperature	≥0.8	0.95	≤± 0.5 K	-0.3	≤±0.67	-0.02
Oakdale	Wind speed	≥0.6	0.85	≤±0.5 m/s	0.4	≤±0.67	0.25
	Wind direction	-	-	≤10 °	43	-	-
	Temperature	≥0.8	0.96	≤± 0.5 K	-0.4	≤±0.67	-0.02
Macarthur	Wind speed	≥0.6	0.89	≤±0.5 m/s	1.0	≤±0.67	0.39
	Wind direction	-	-	≤10 °	19	-	-
	Temperature	≥0.8	0.95	≤± 0.5 K	-0.8	≤±0.67	-0.04
St Marys	Wind speed	≥0.6	0.95	≤±0.5 m/s	0.3	≤±0.67	0.19
	Wind direction	-	-	≤10 °	21	-	-
	Temperature	≥0.8	0.93	≤± 0.5 K	-1.6	≤±0.67	0.07

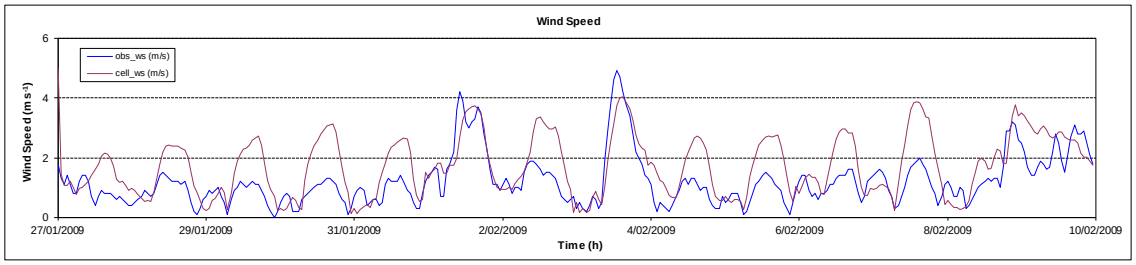
Note: shaded cells denote where results falls outside benchmark

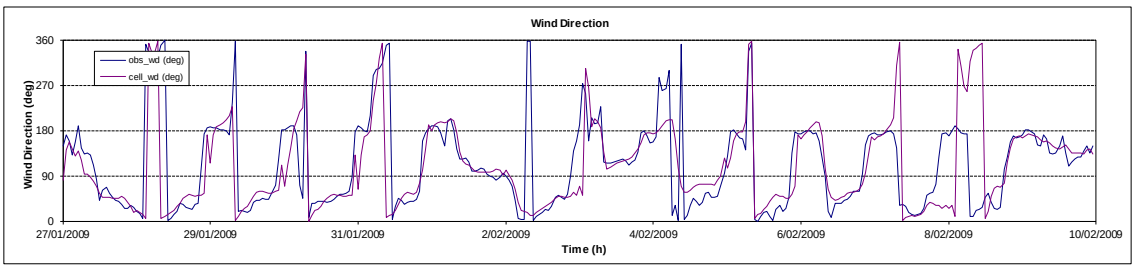
Appendix C BASE MODEL VALIDATION PLOTS

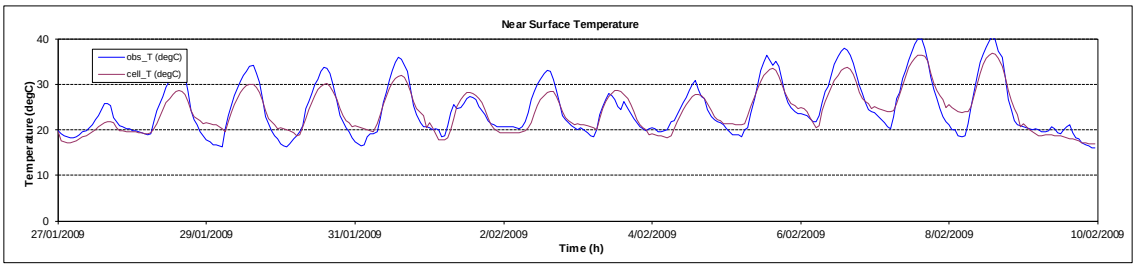
C.1 TIME SERIES OF OBSERVED AND PREDICTED

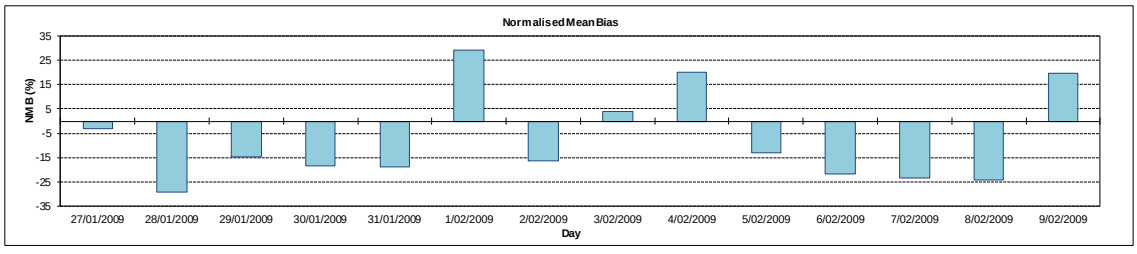
C.1.1 Bargo – 1-hour

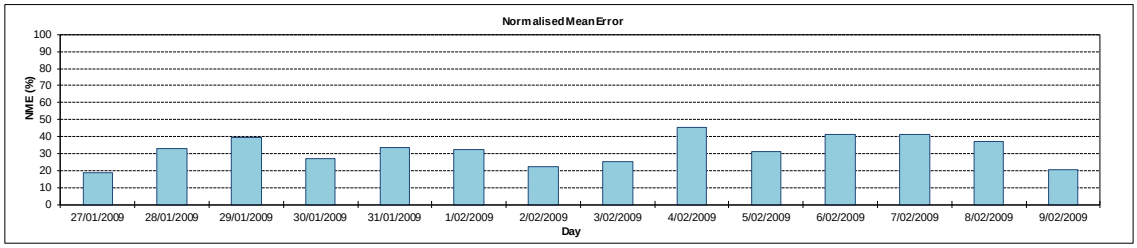












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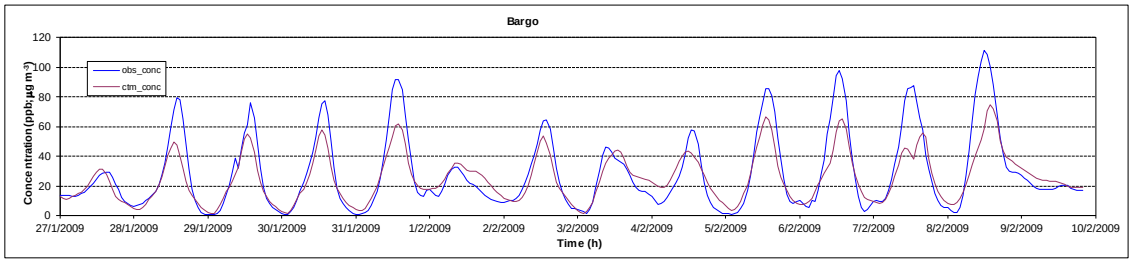
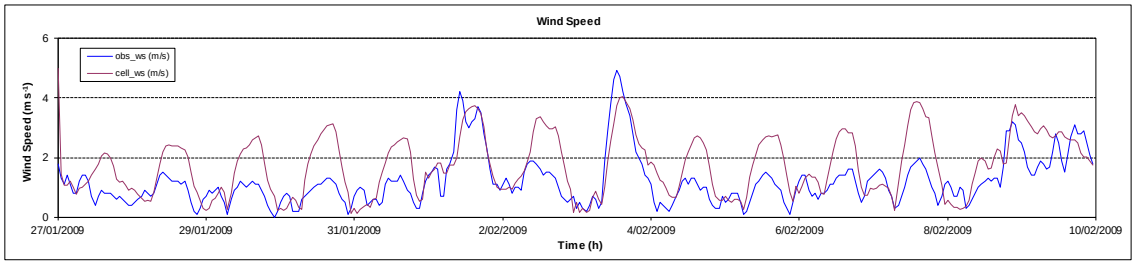
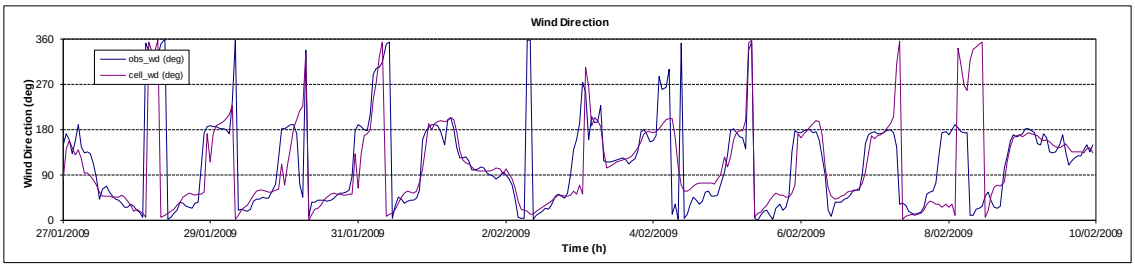
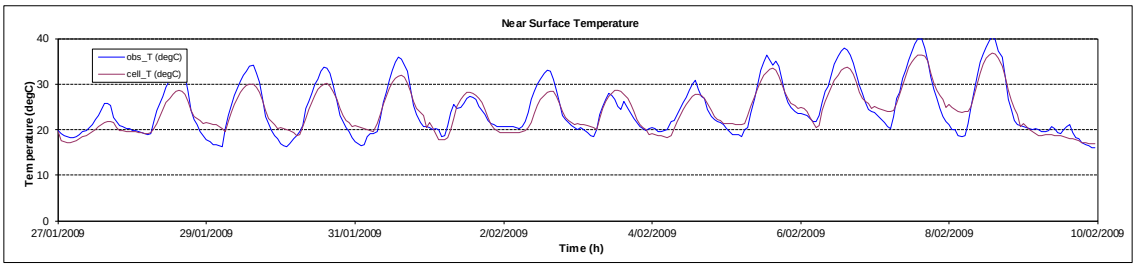
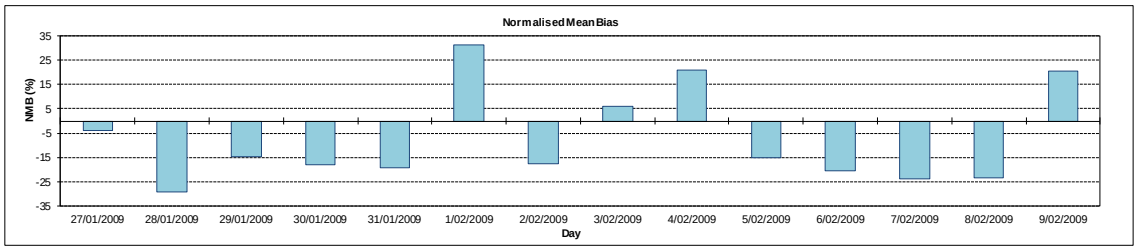
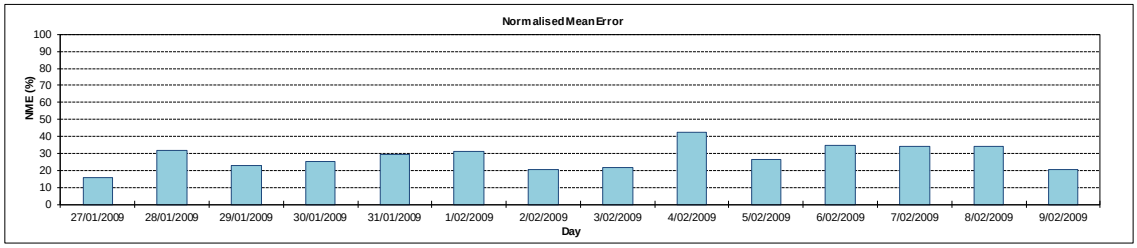




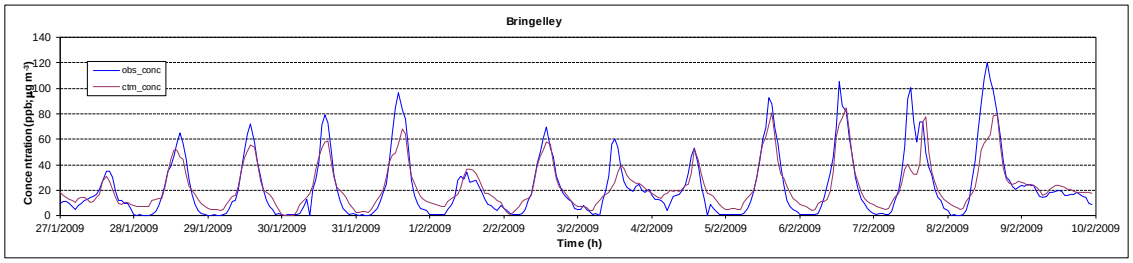


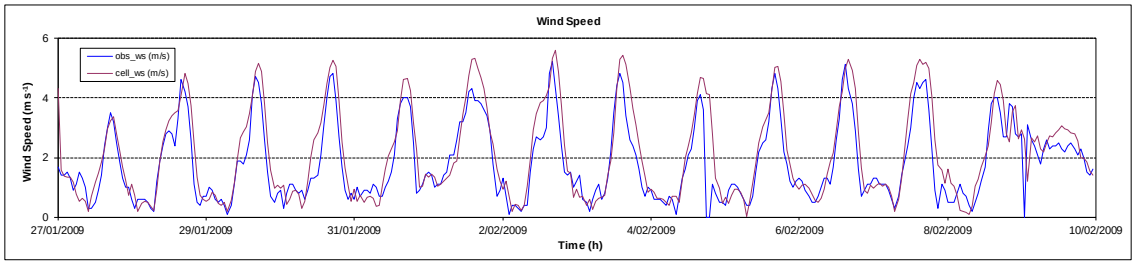


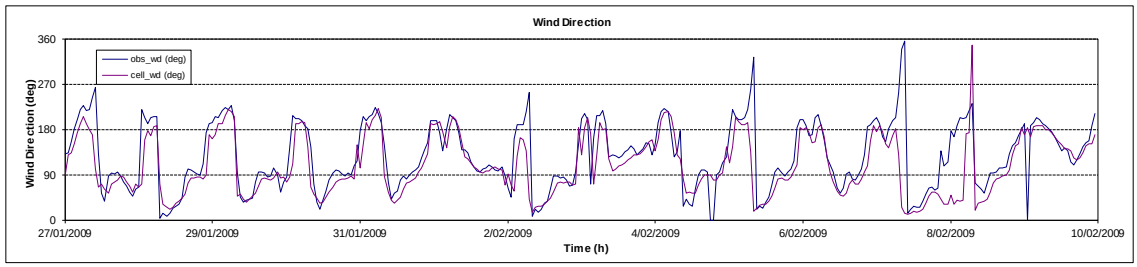


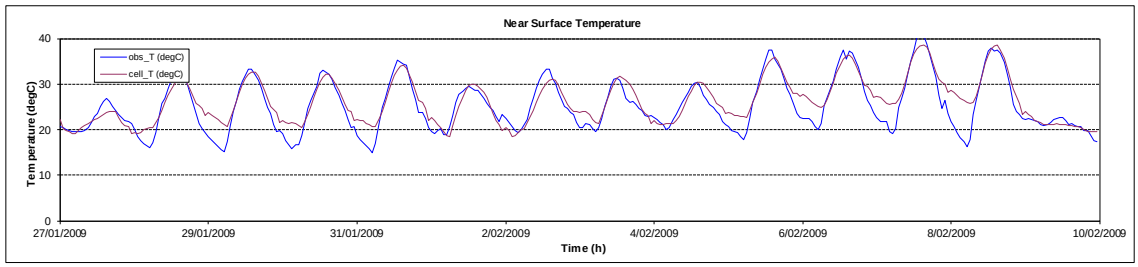


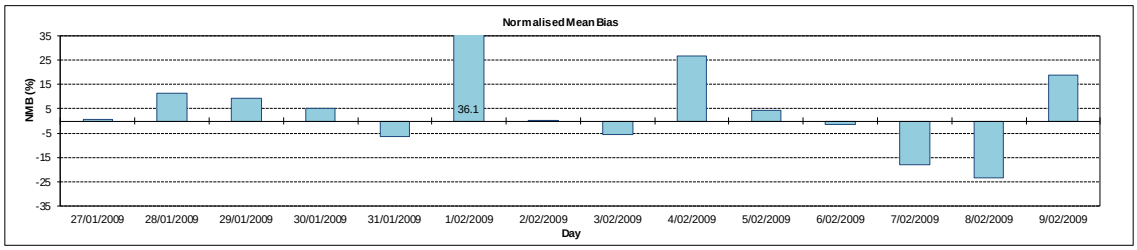
C.1.3 Bringelly – 1-hour

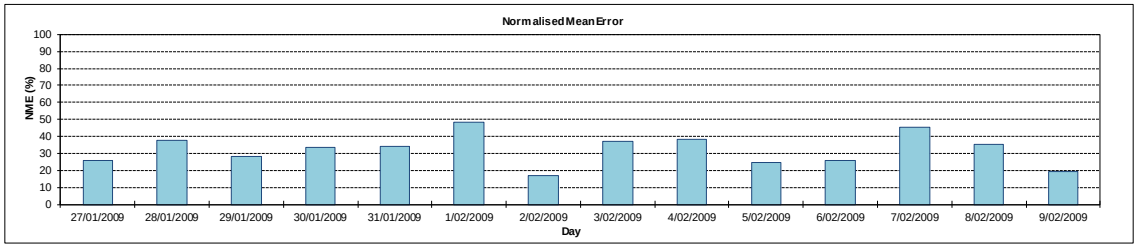












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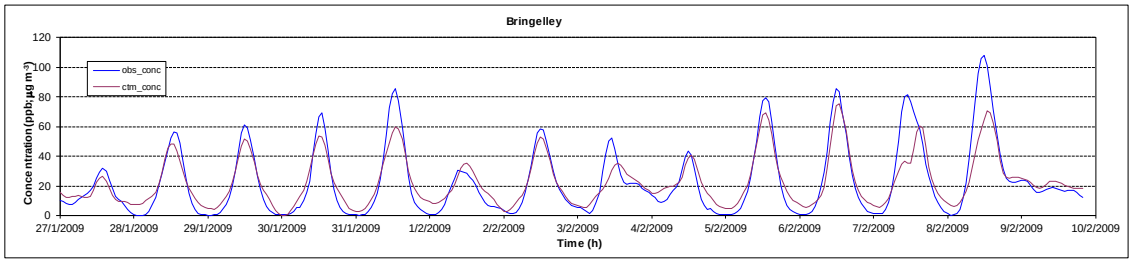
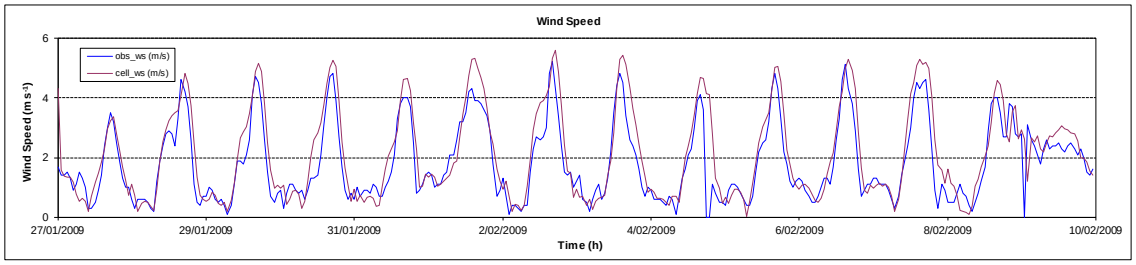
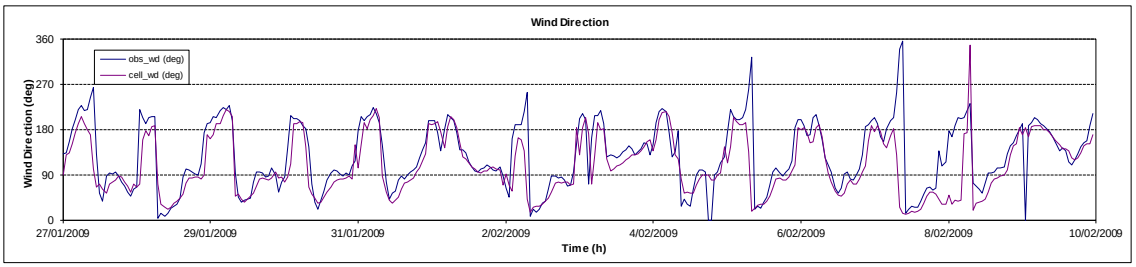
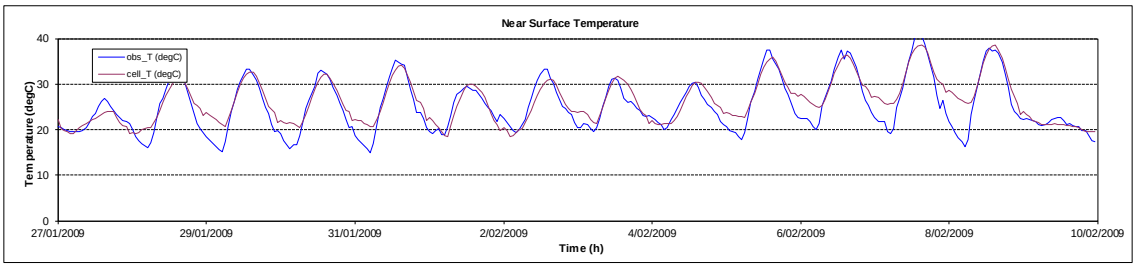
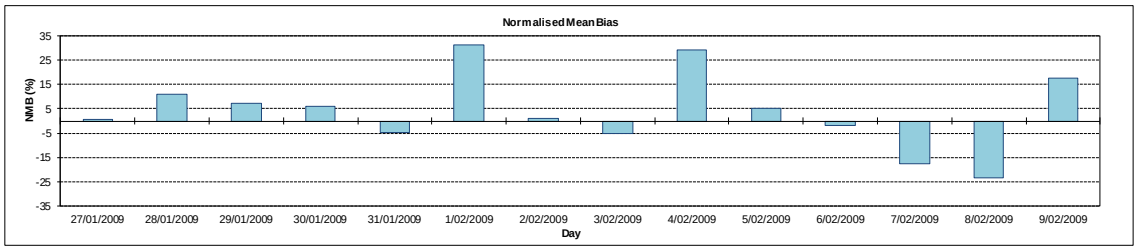
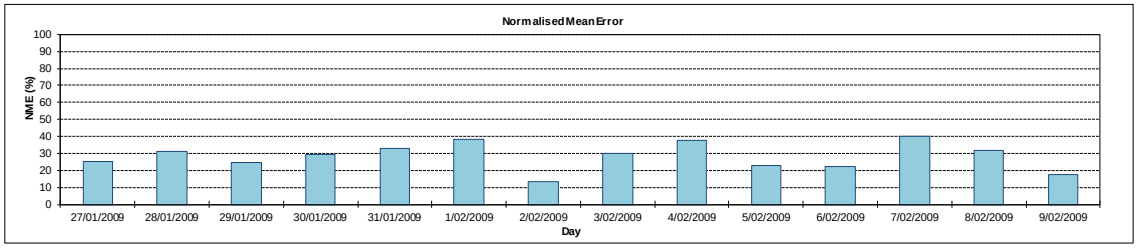




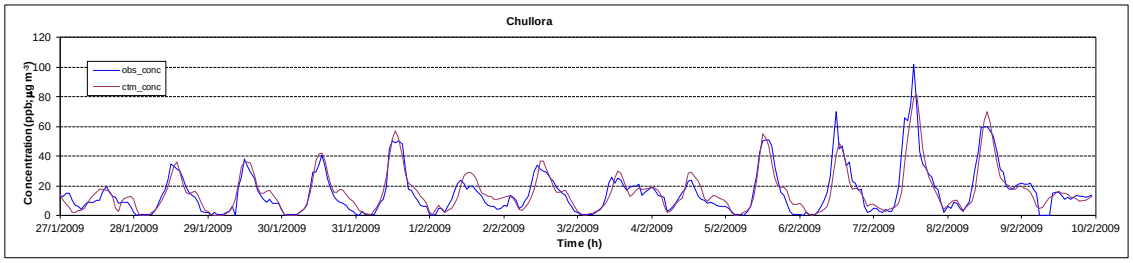


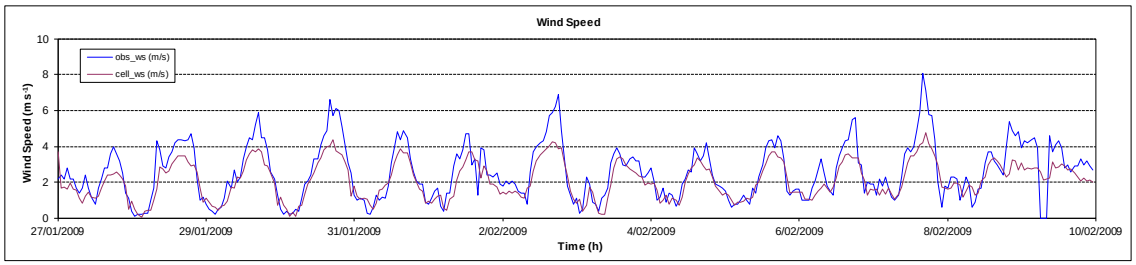


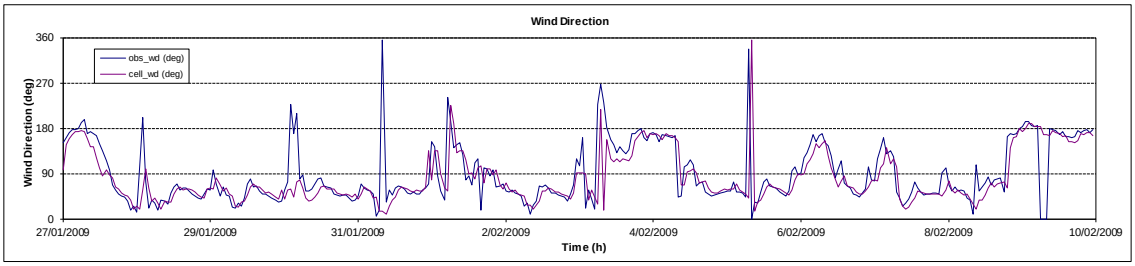


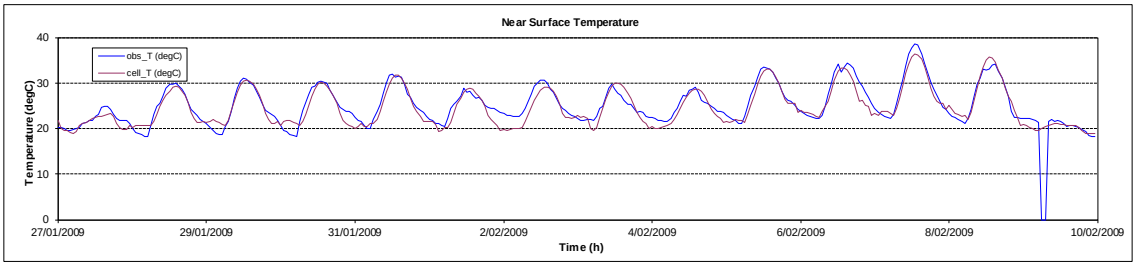


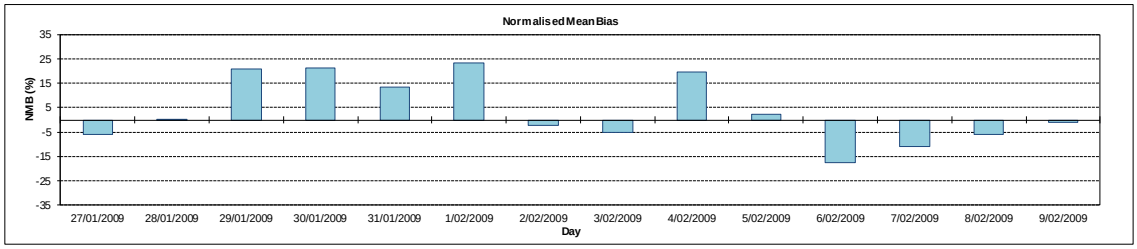
C.1.5 Chullora – 1-hour

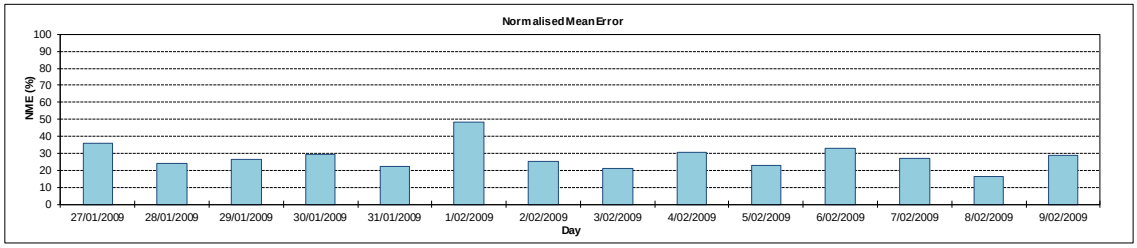












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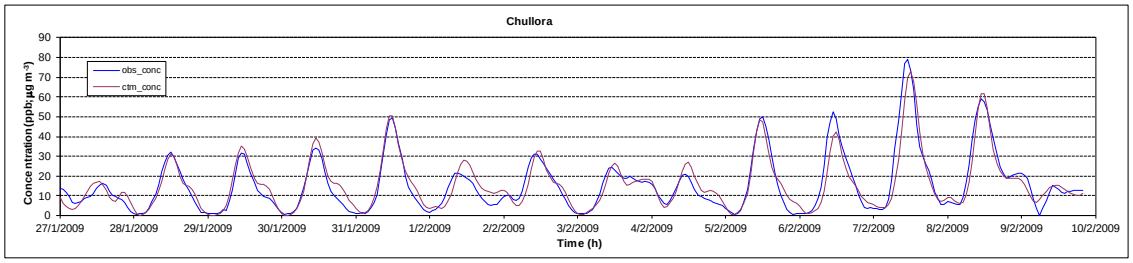
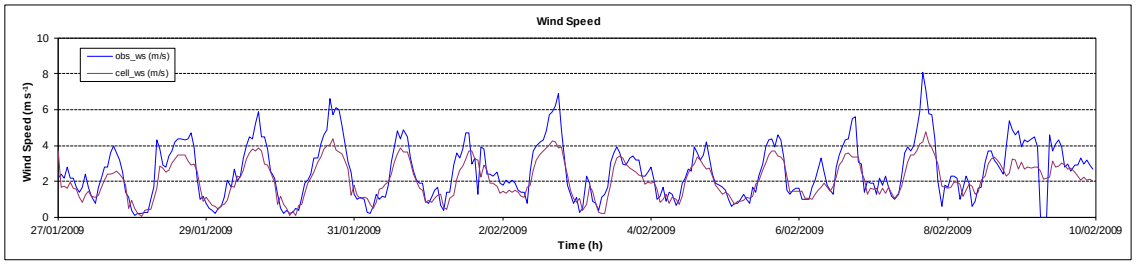
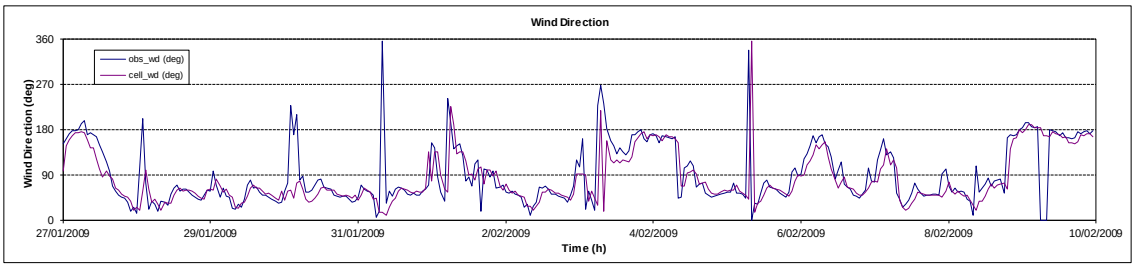
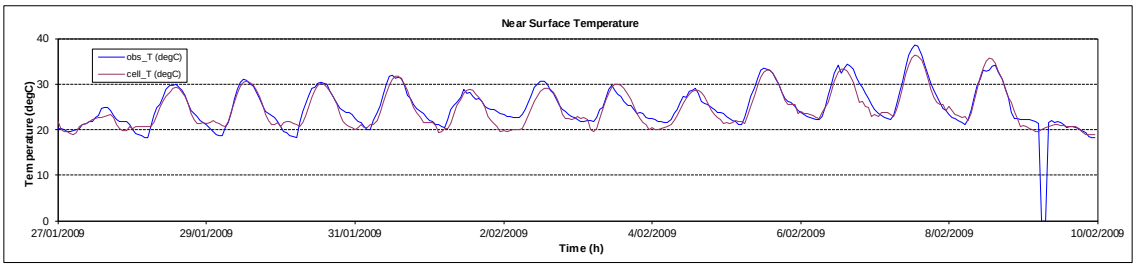
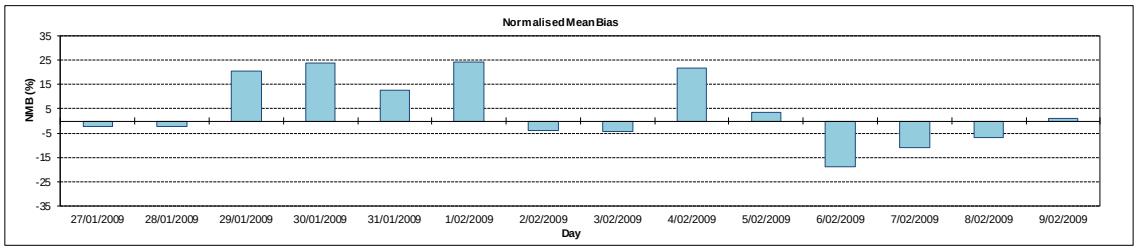
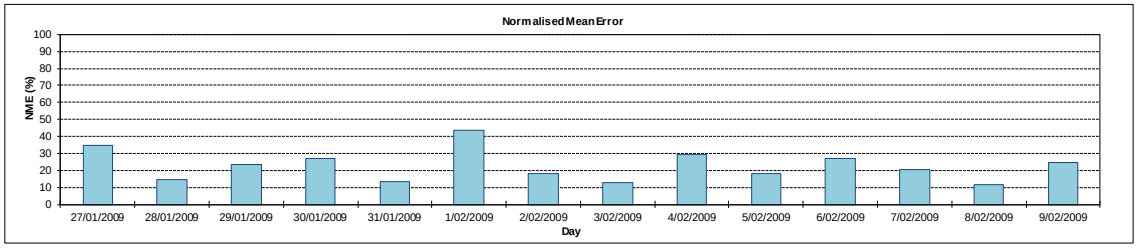




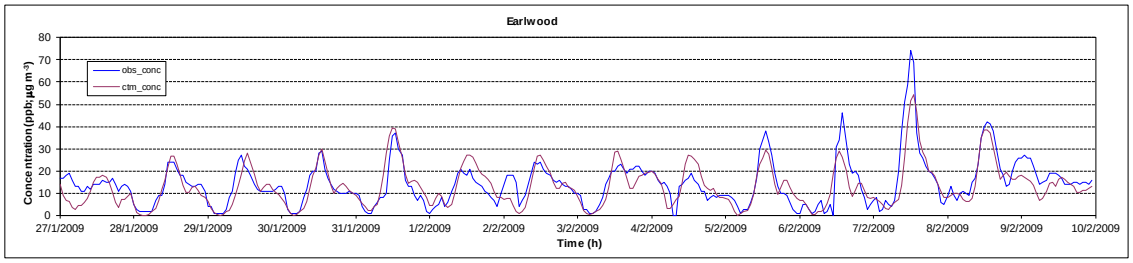


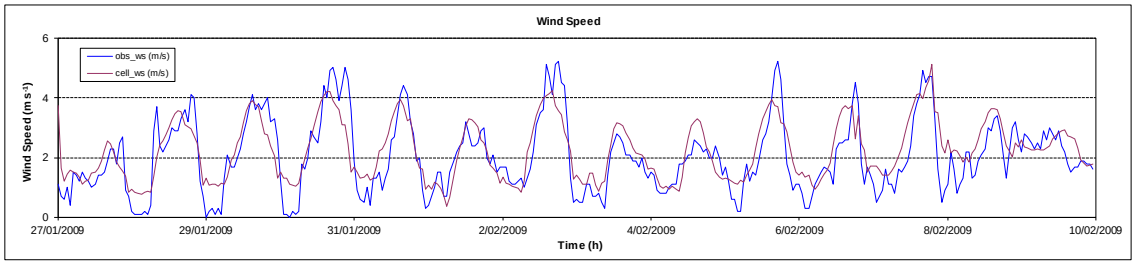


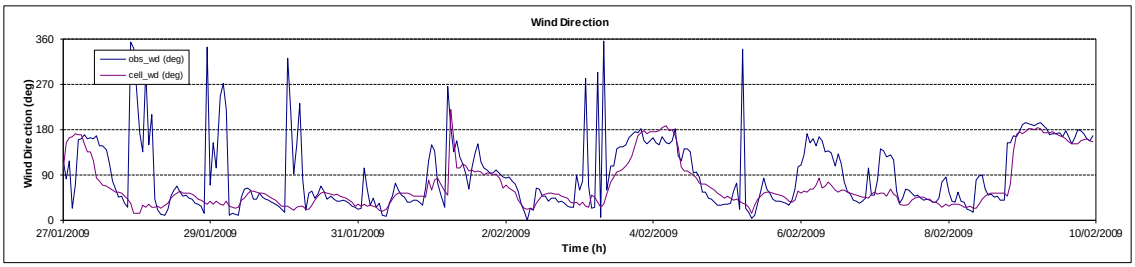


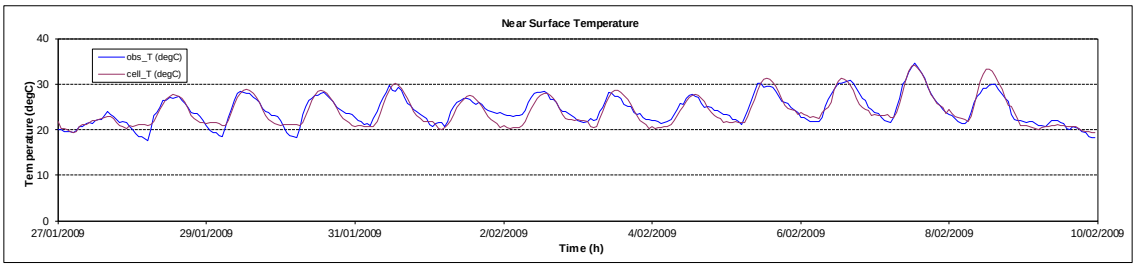


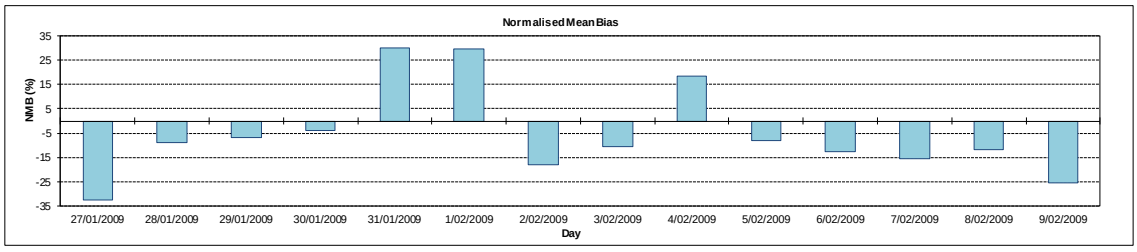
C.1.7 Earlwood – 1-hour

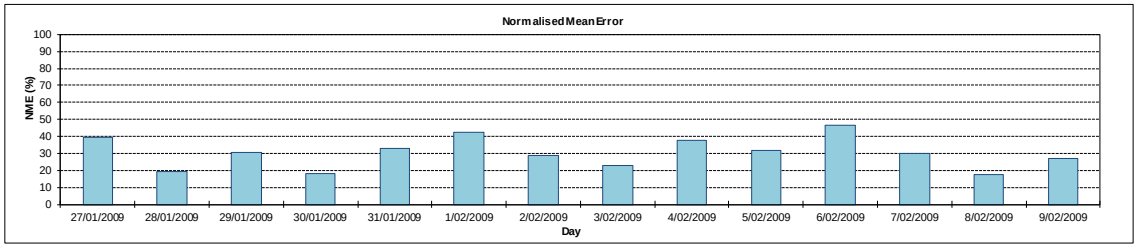




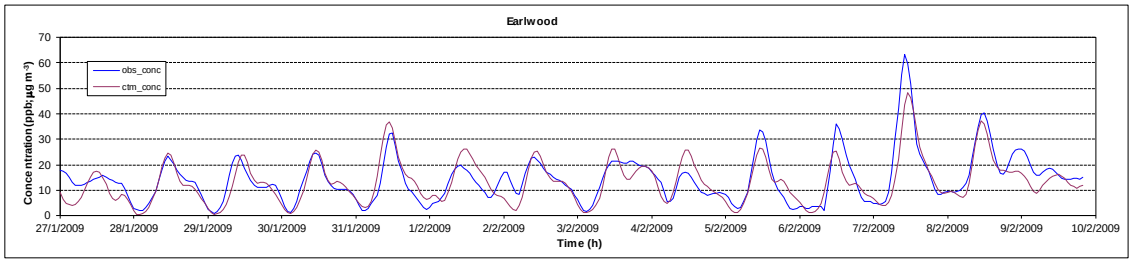


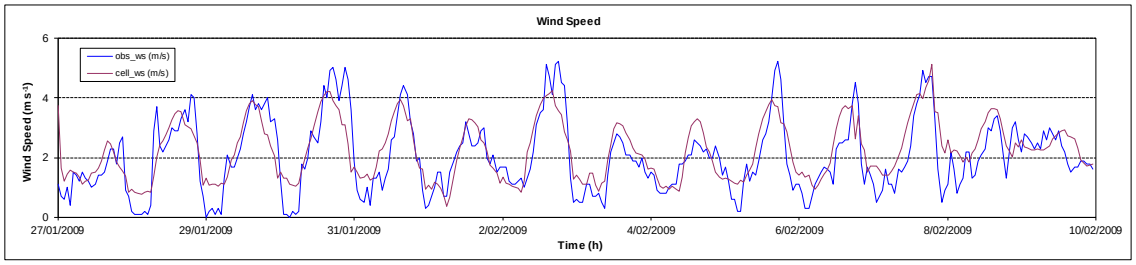


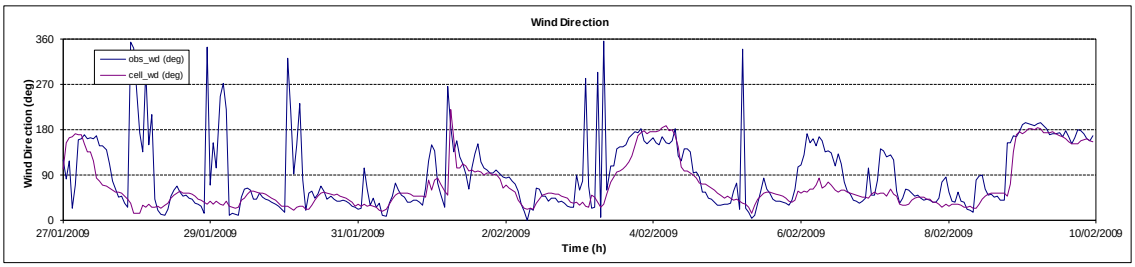


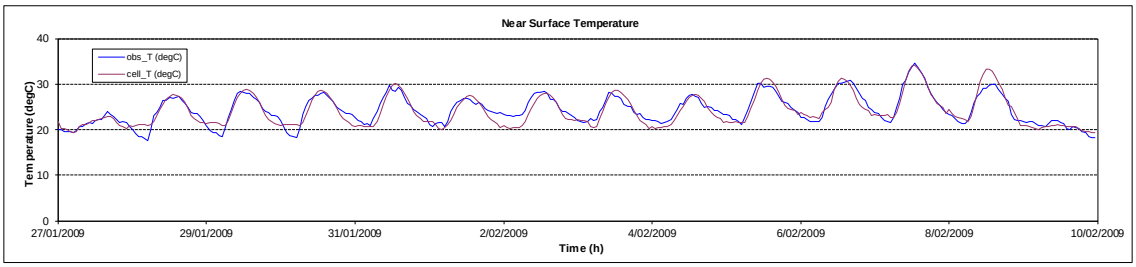


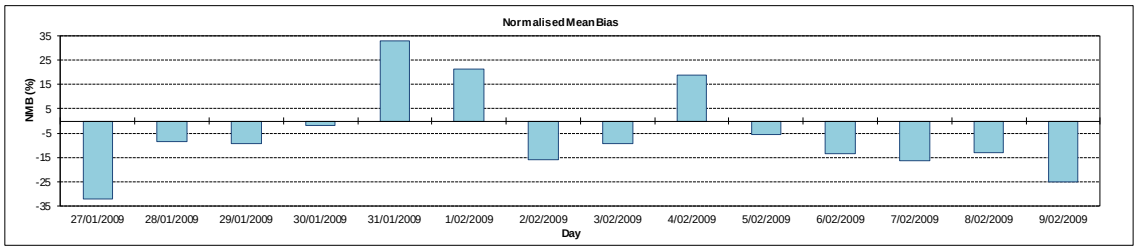
C.1.8 Earlwood – 4-hour

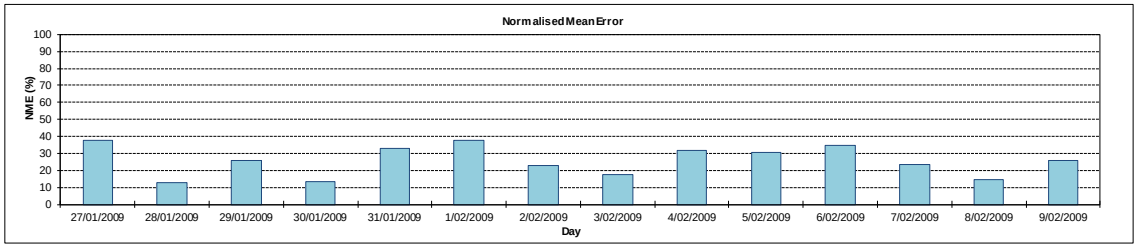




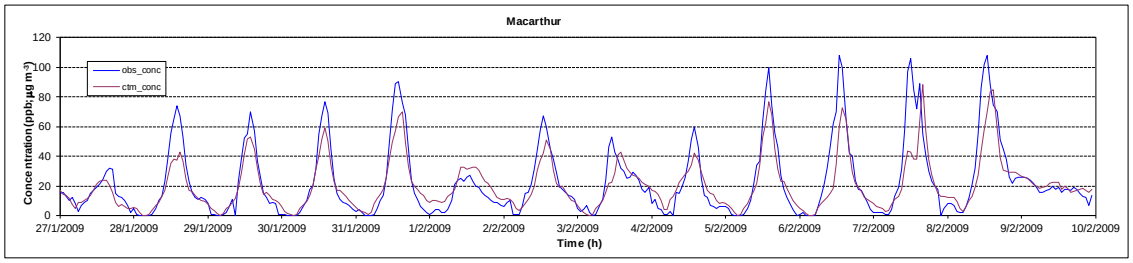


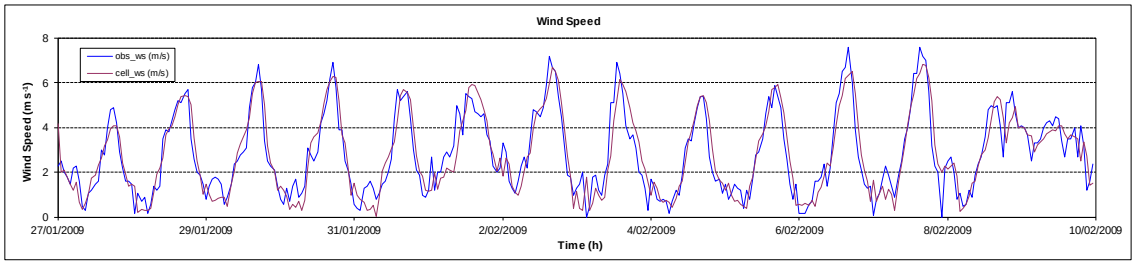


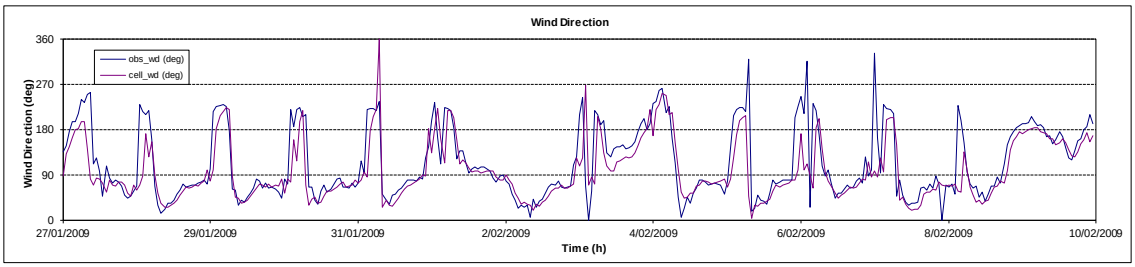


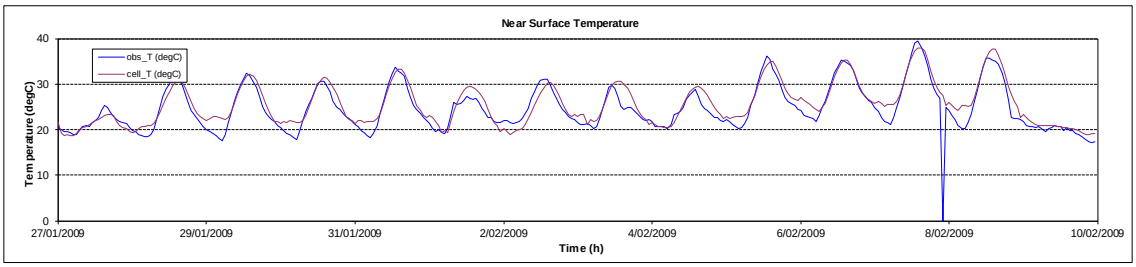


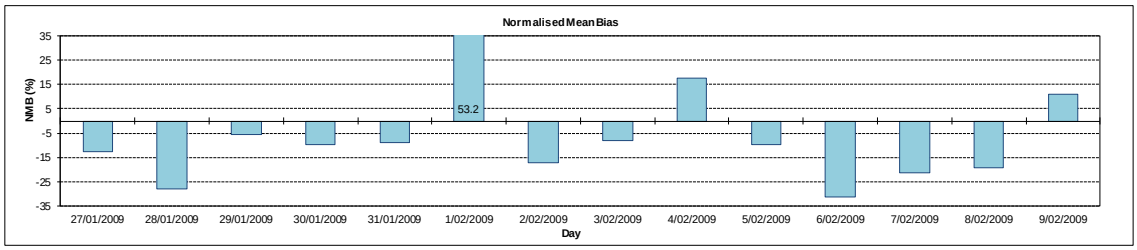
C.1.9 Macarthur – 1-hour

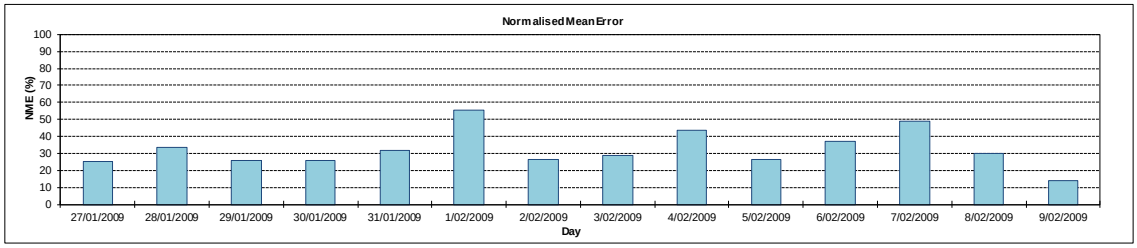




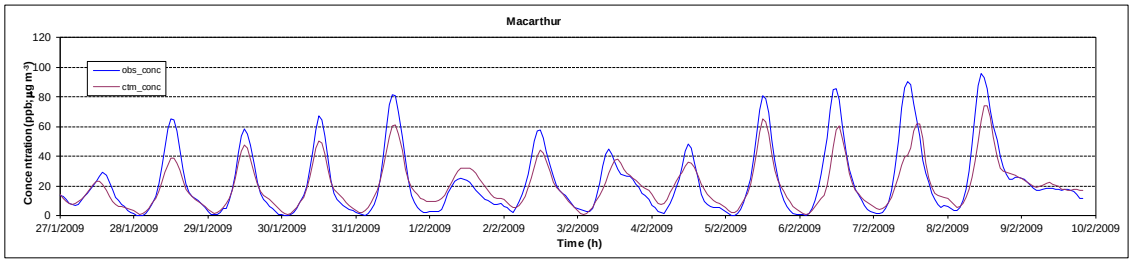


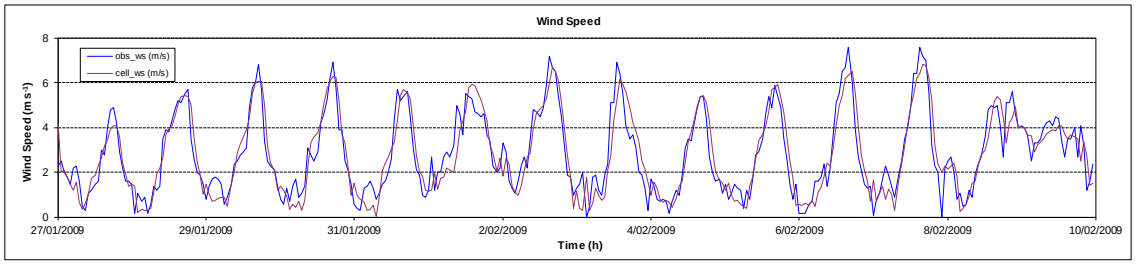


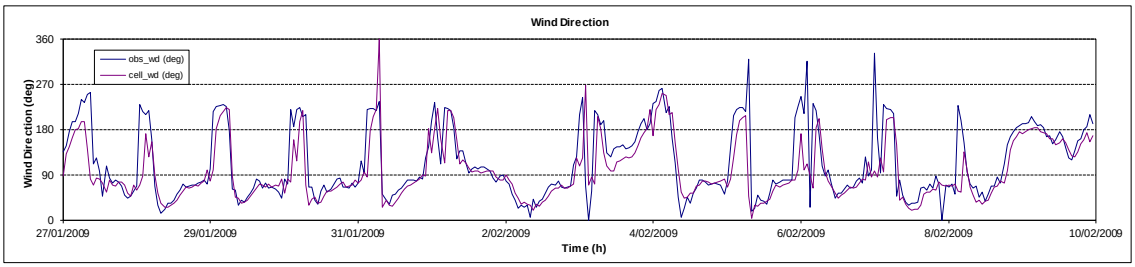


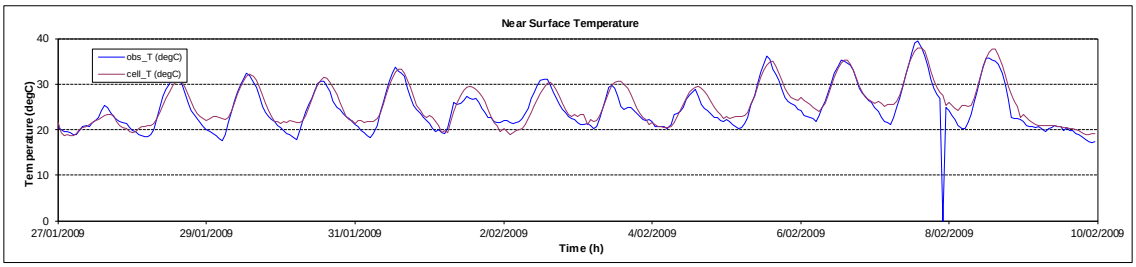


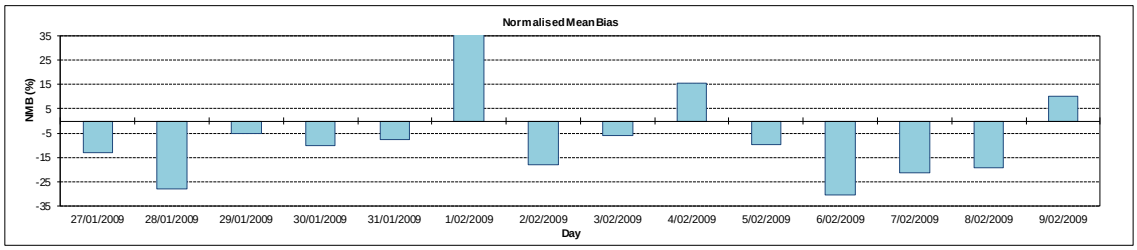
C.1.10 Macarthur – 4-hour

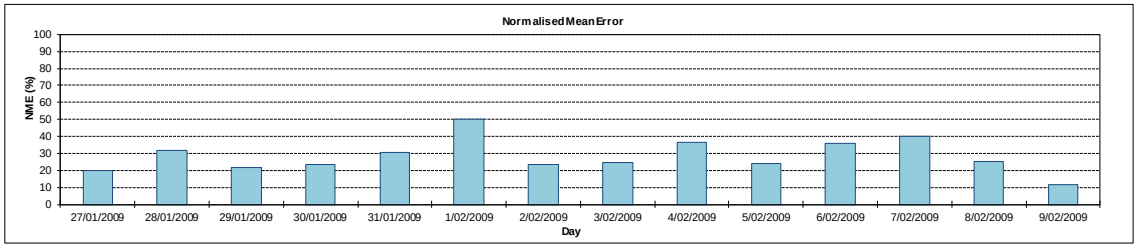




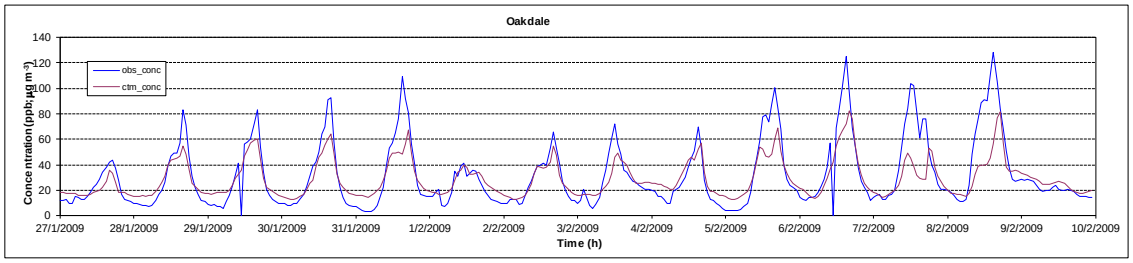


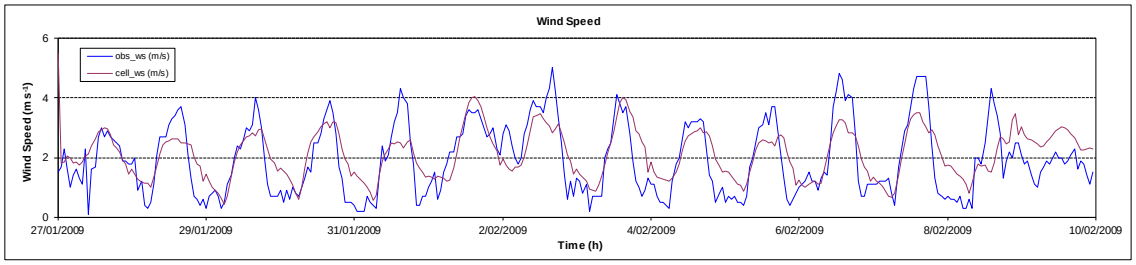


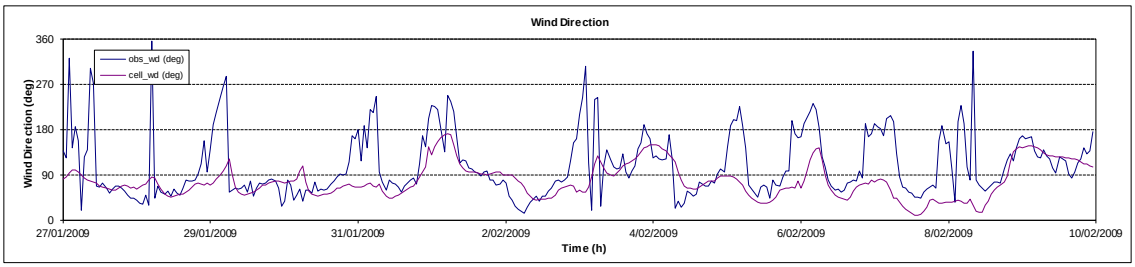


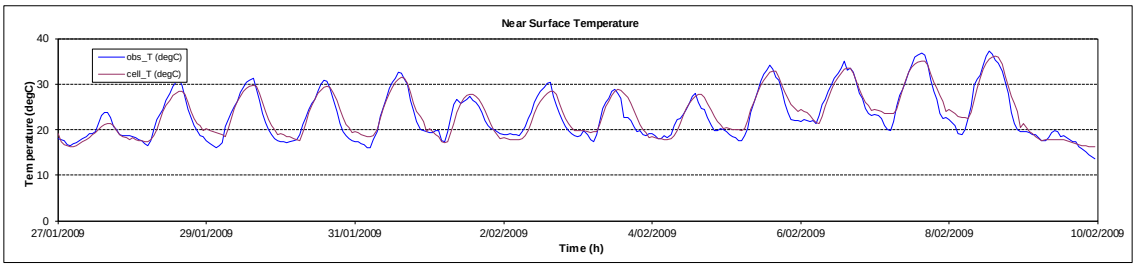


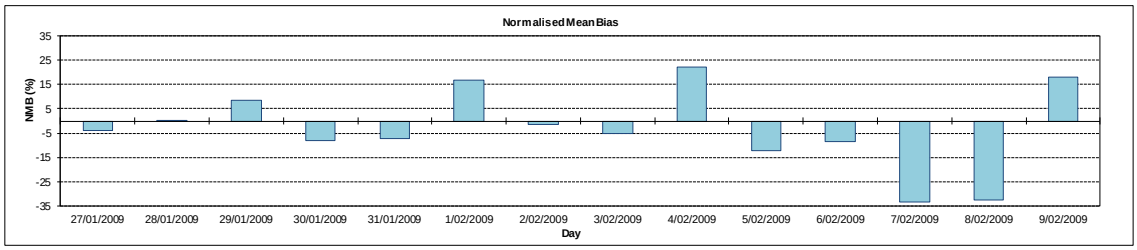
C.1.11 Oakdale – 1-hour

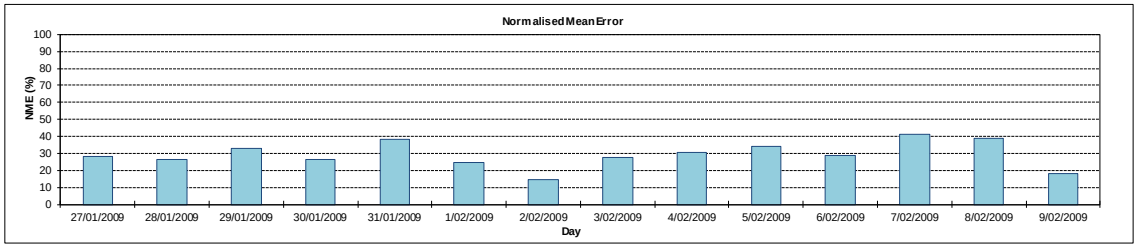




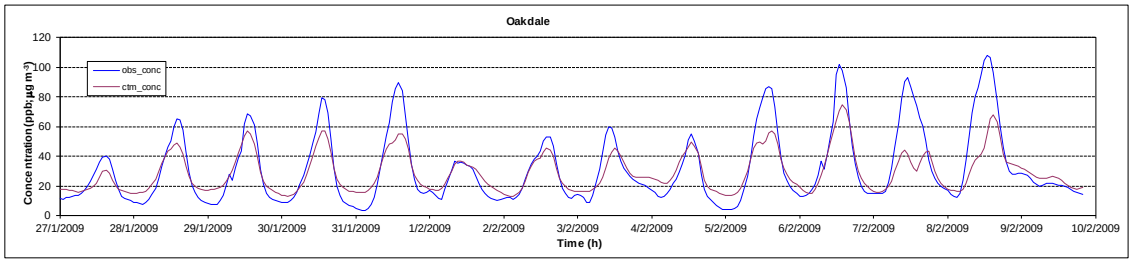


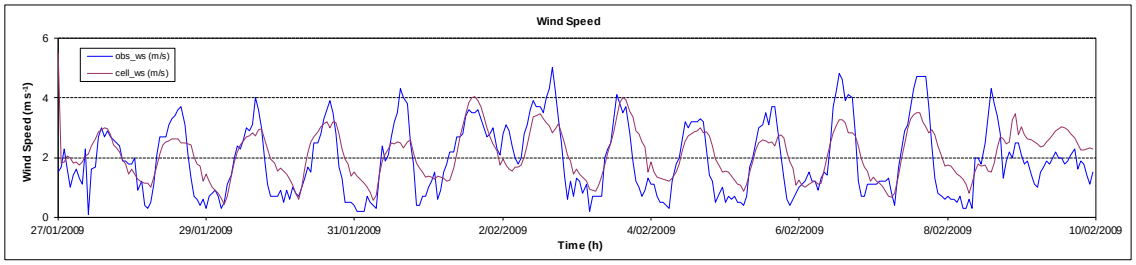


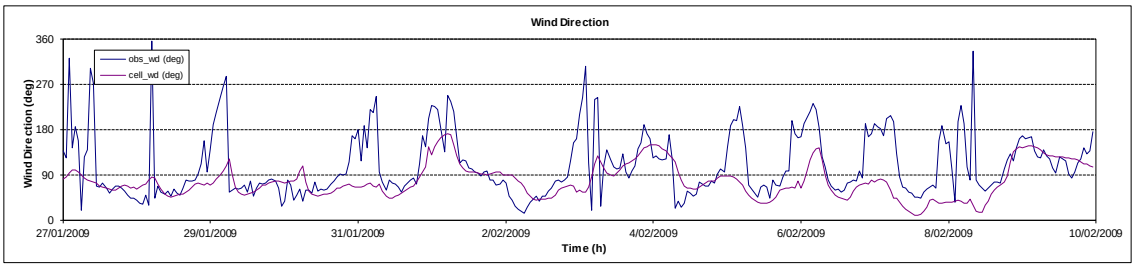


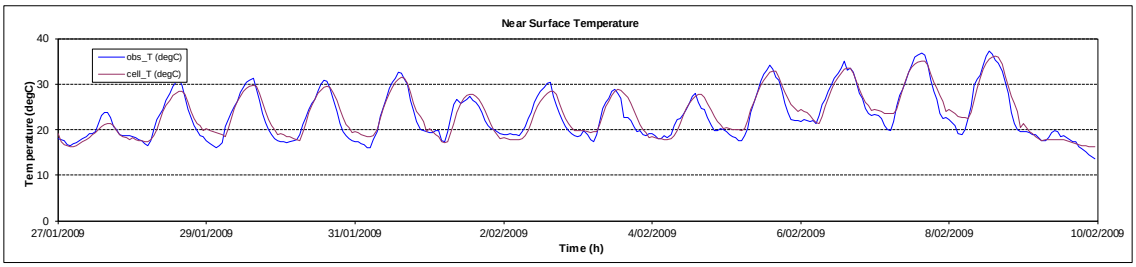


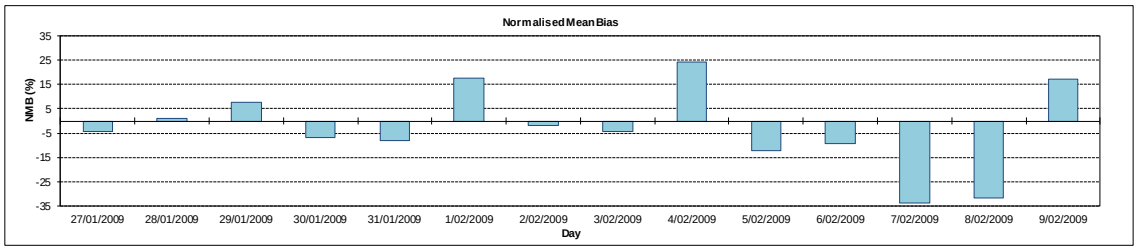
C.1.12 Oakdale – 4-hour

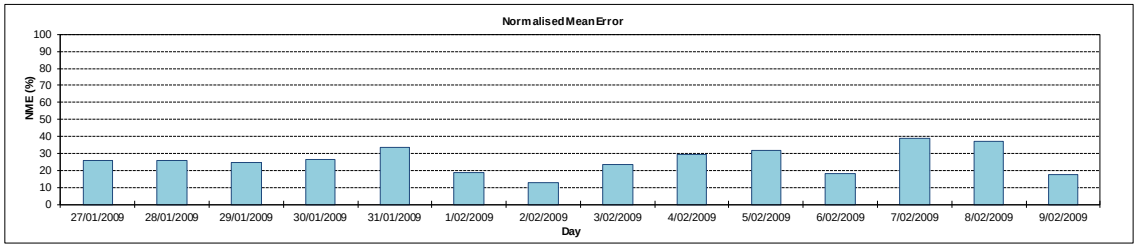




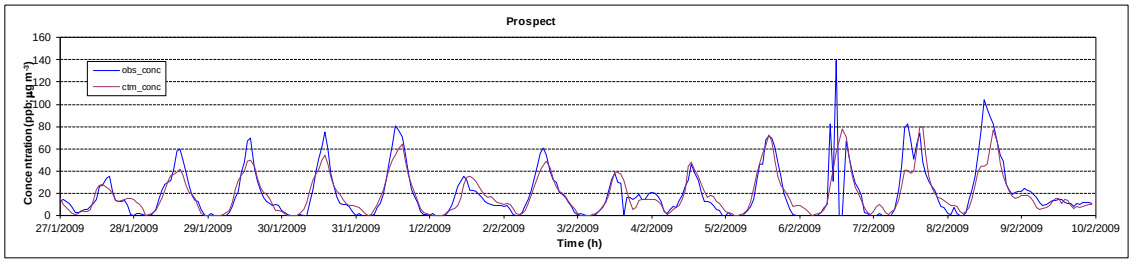


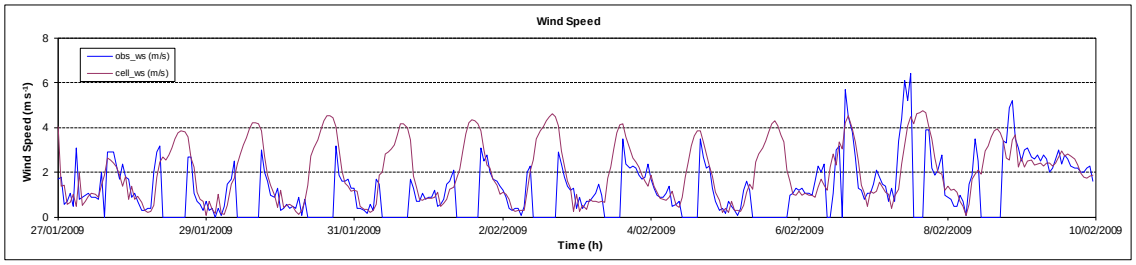


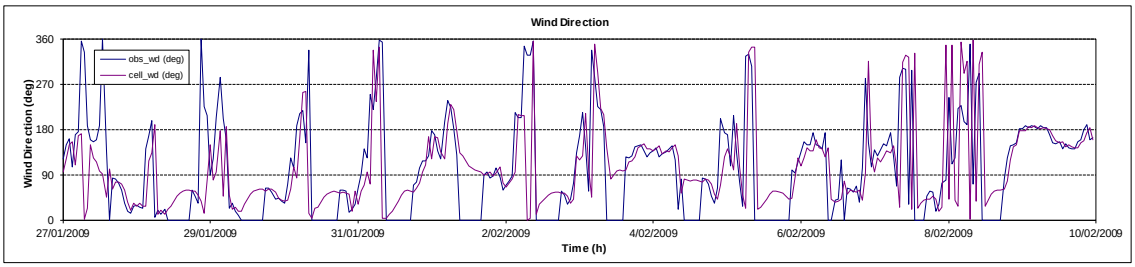


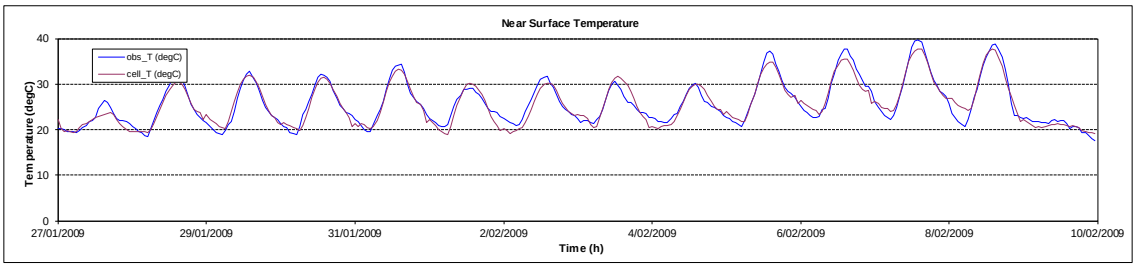


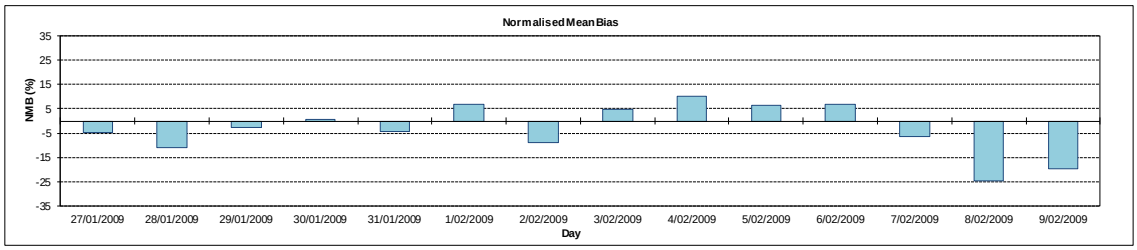
C.1.13 Prospect – 1-hour

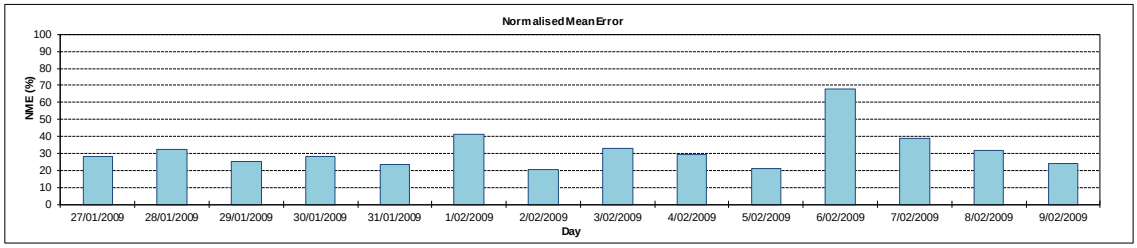




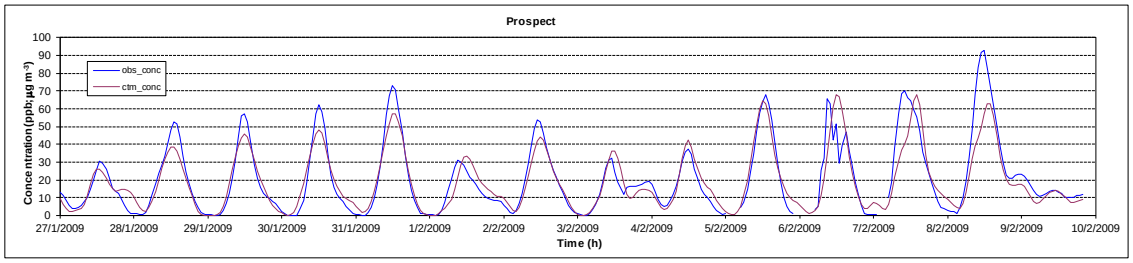


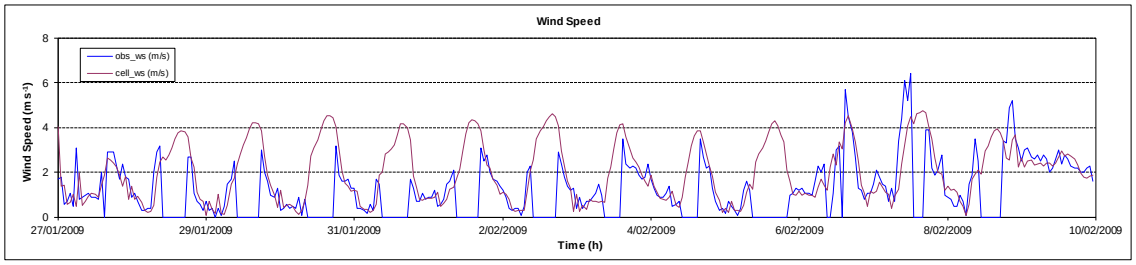


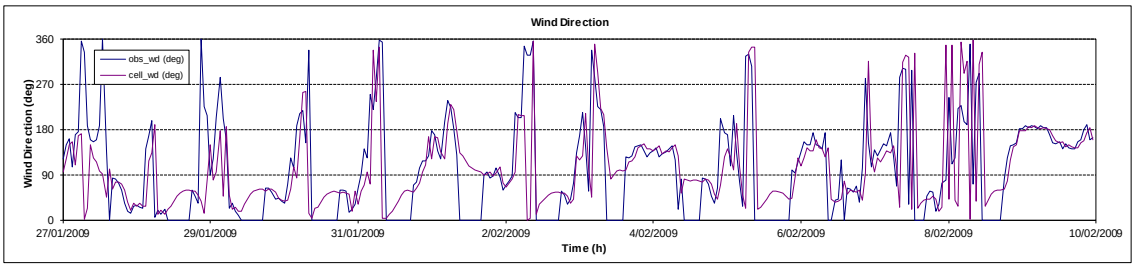


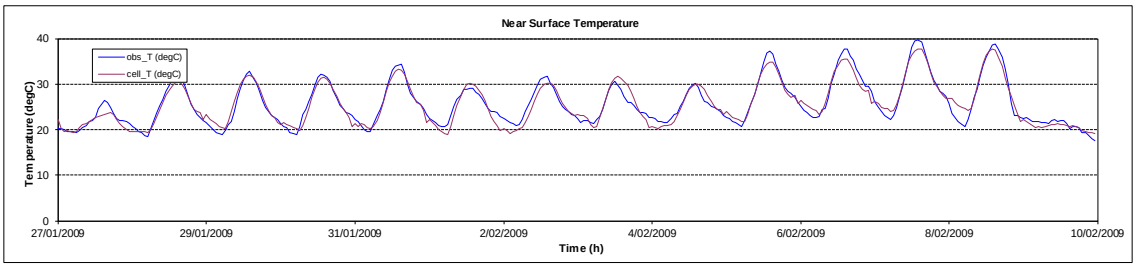


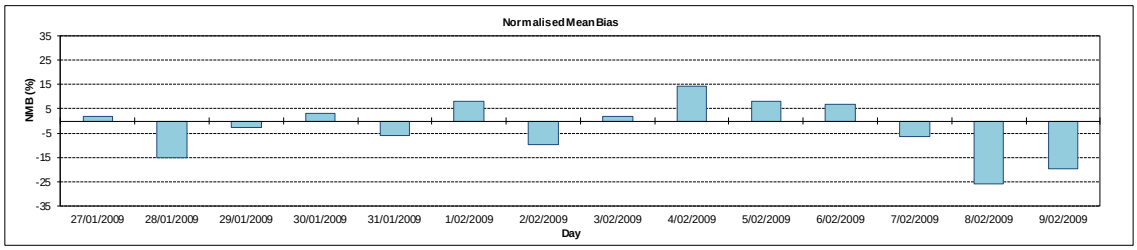
C.1.14 Prospect – 4-hour

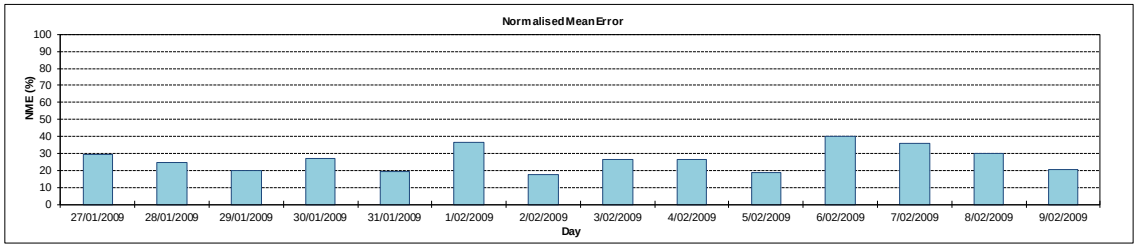




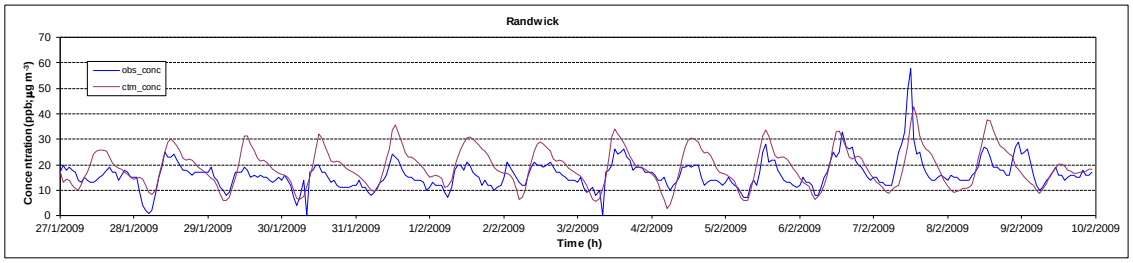


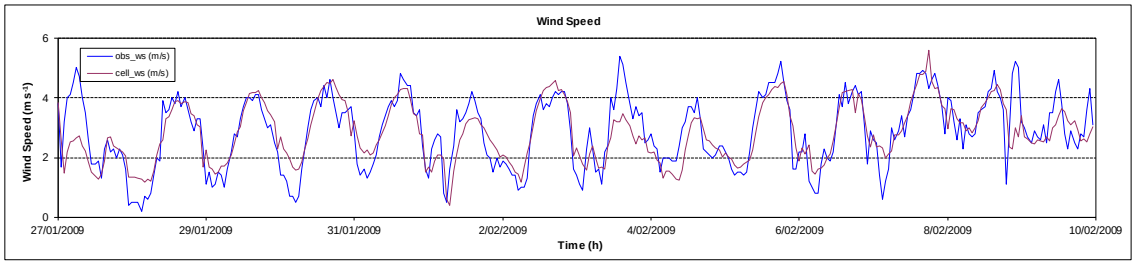


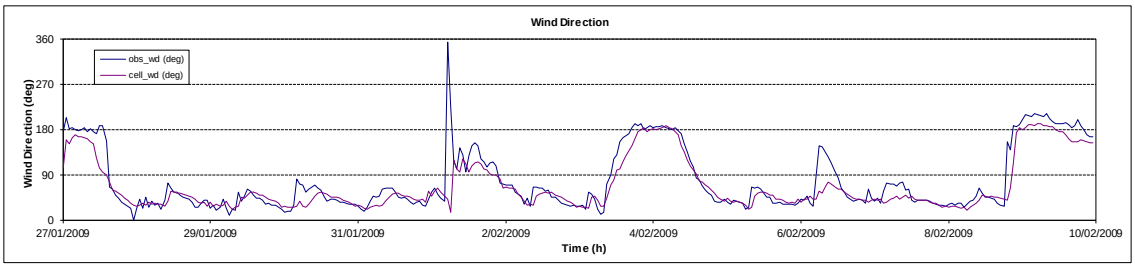


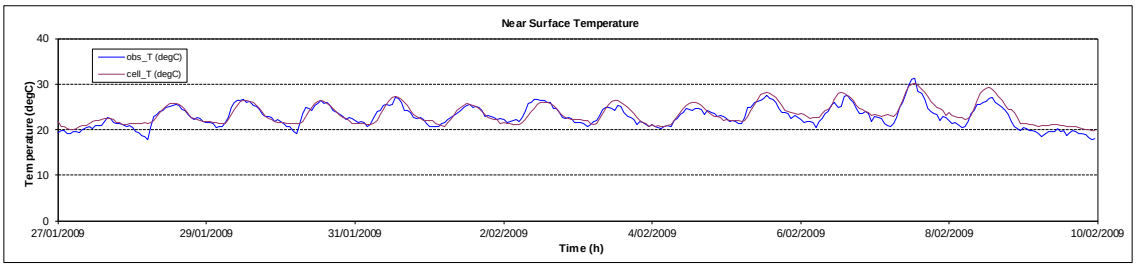


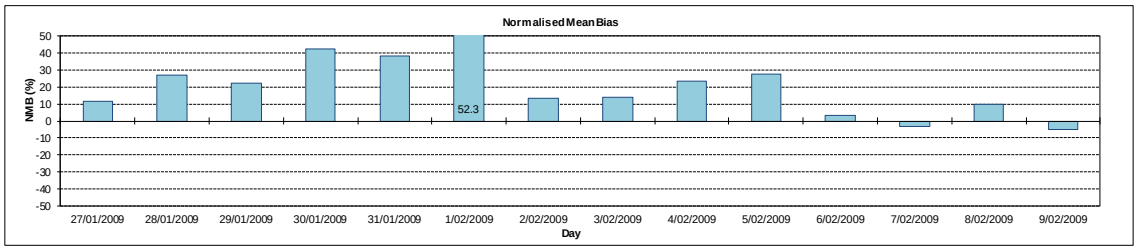
C.1.15 Randwick – 1-hour

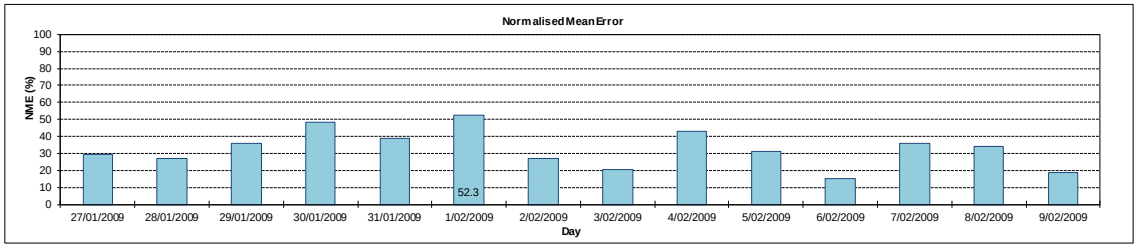




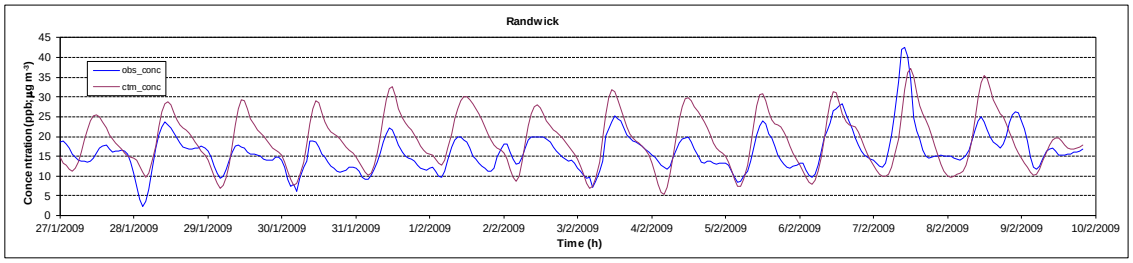


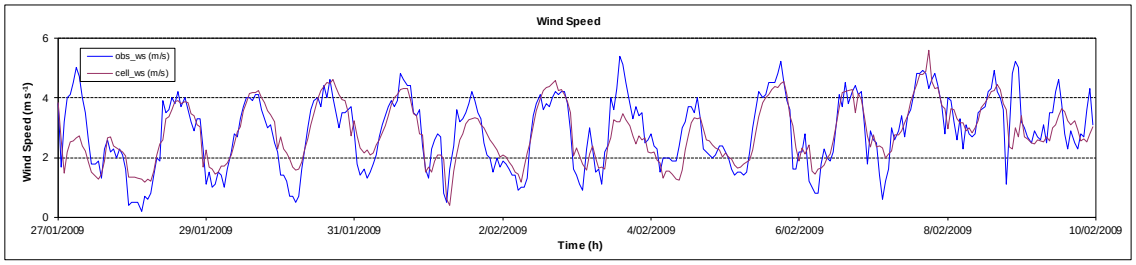


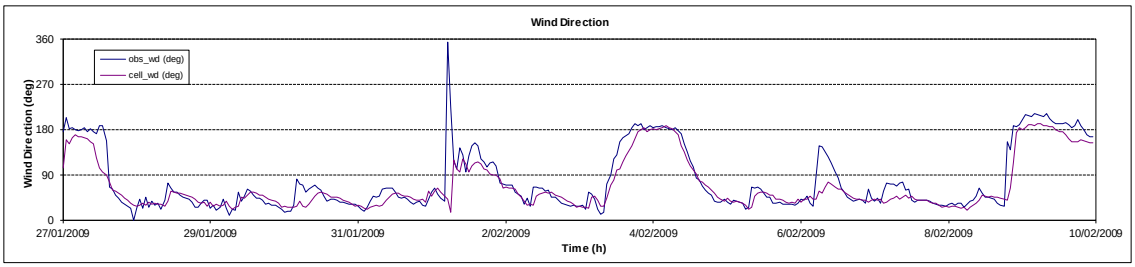


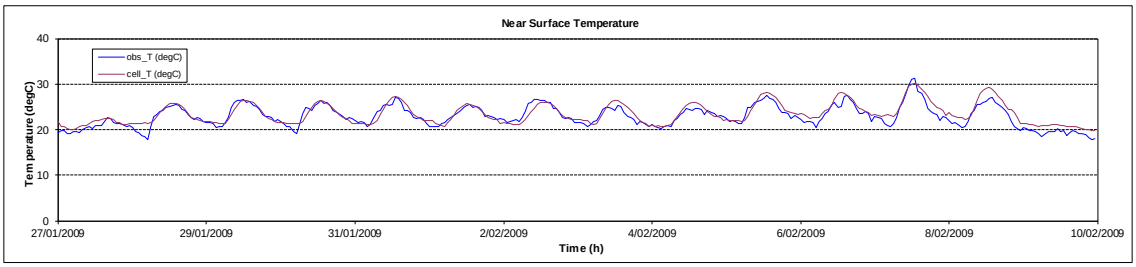


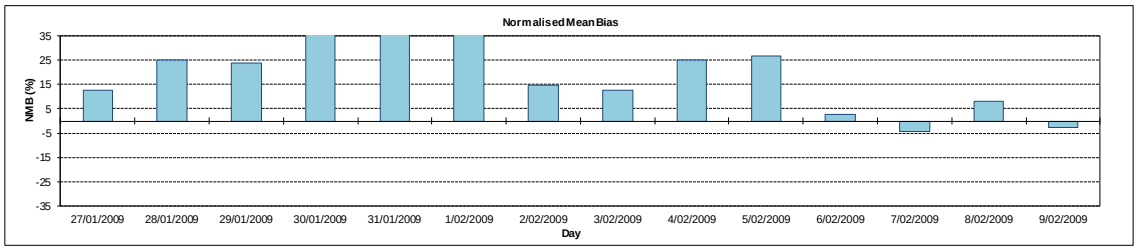
C.1.16 Randwick – 4-hour

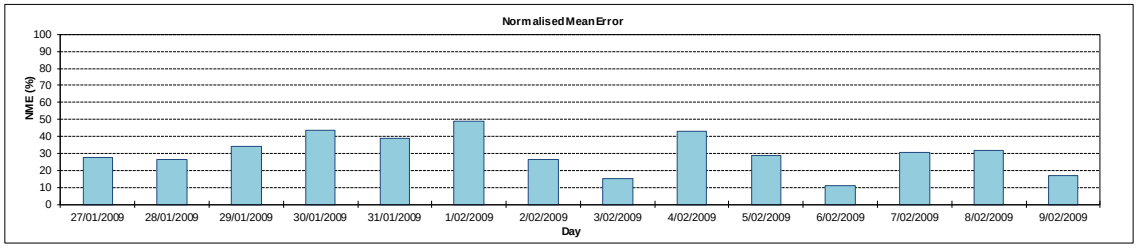




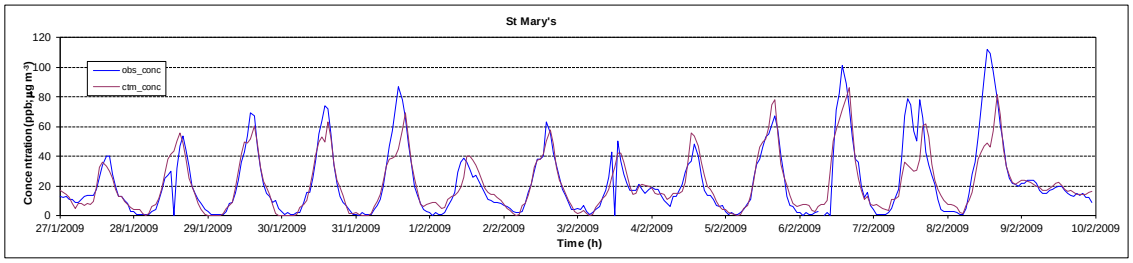


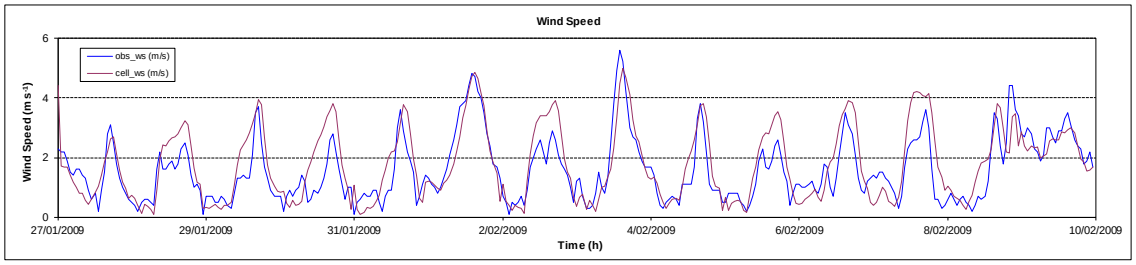


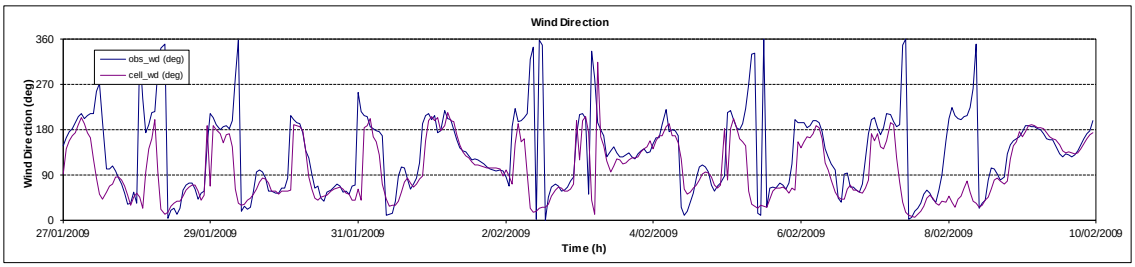


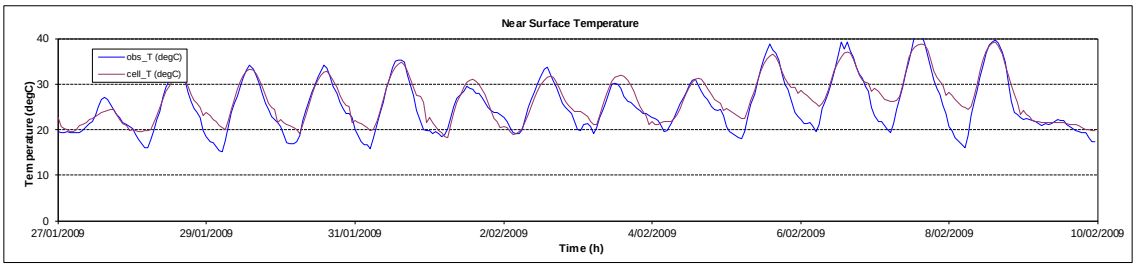


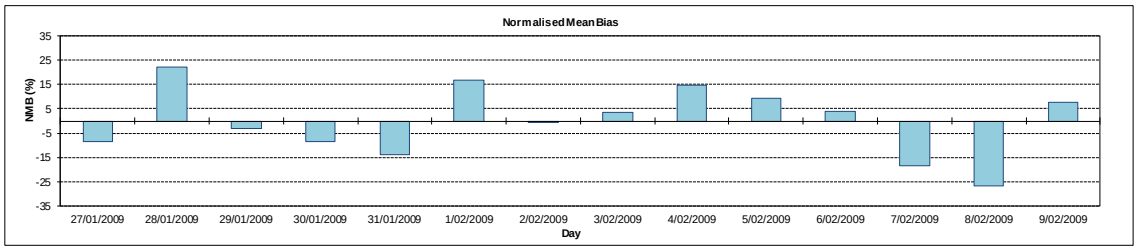
C.1.17 St Marys – 1-hour

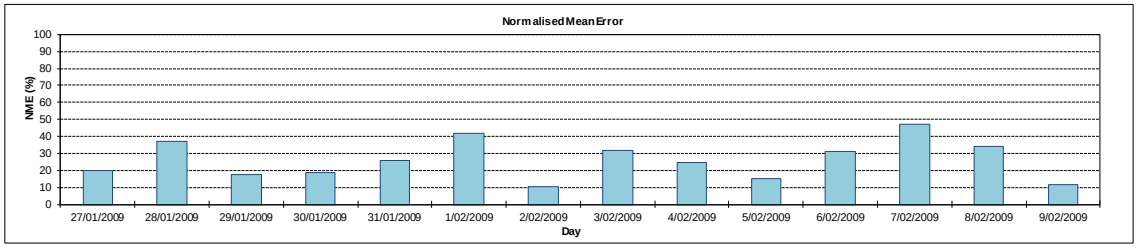




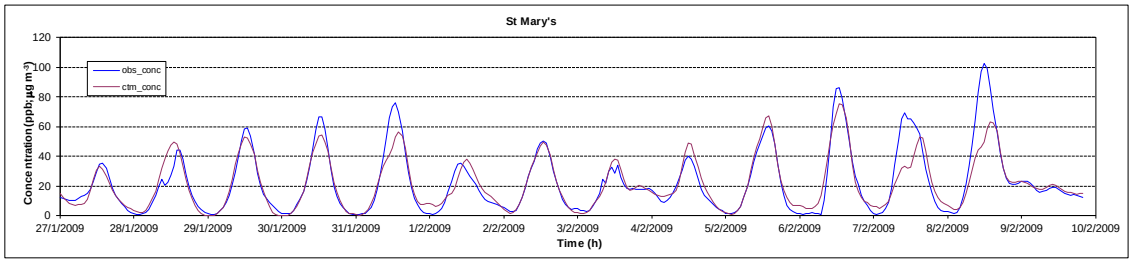


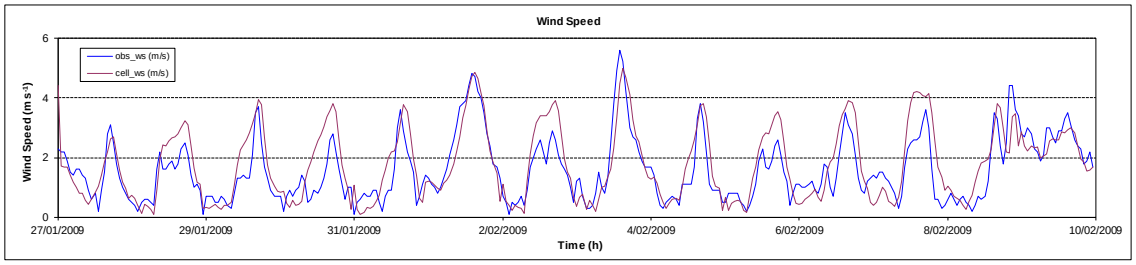


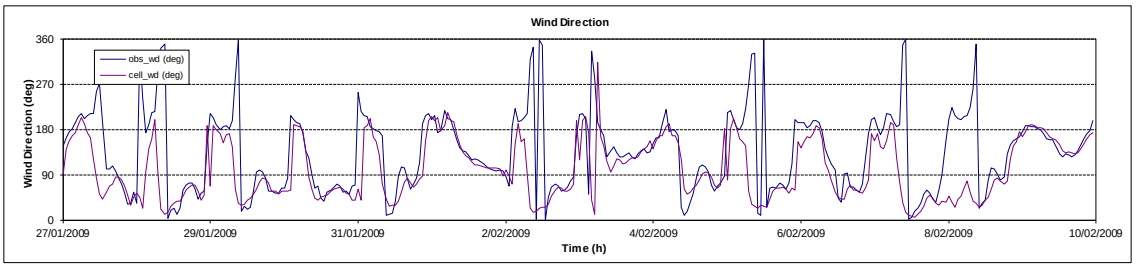


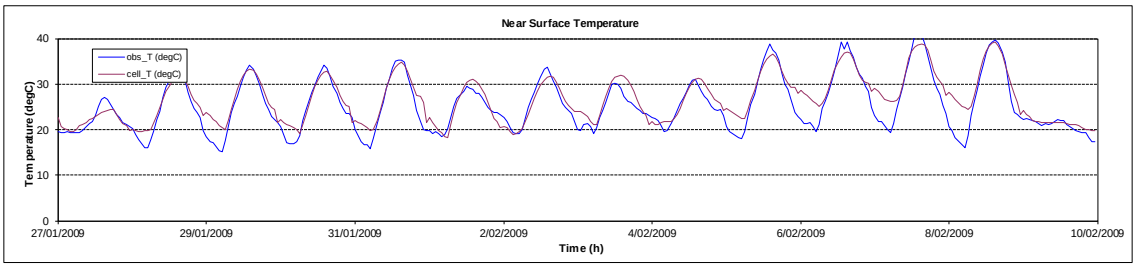


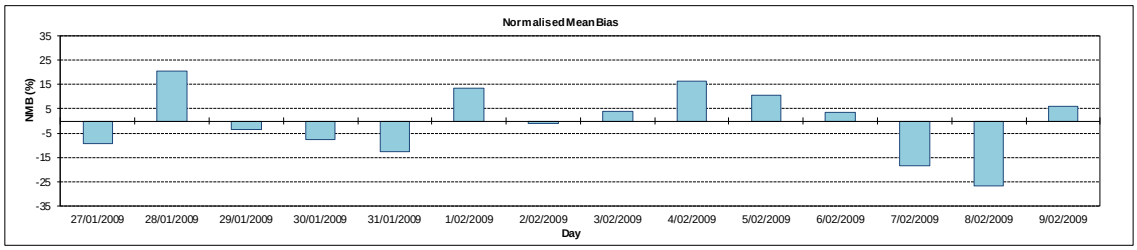
C.1.18 St Marys – 4-hour

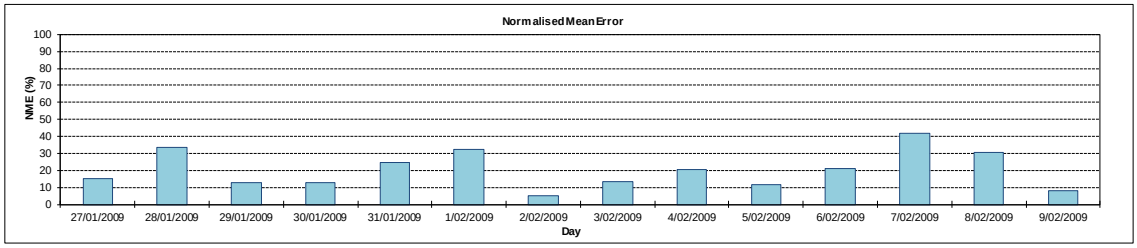




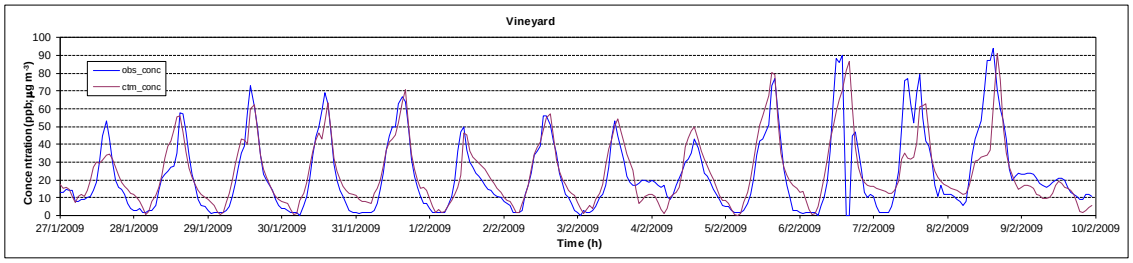


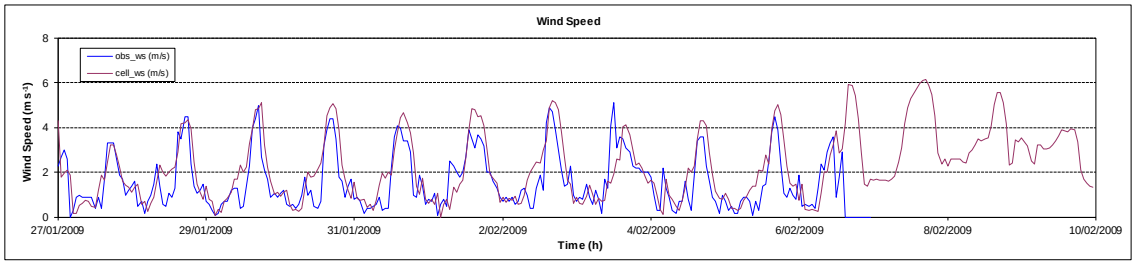


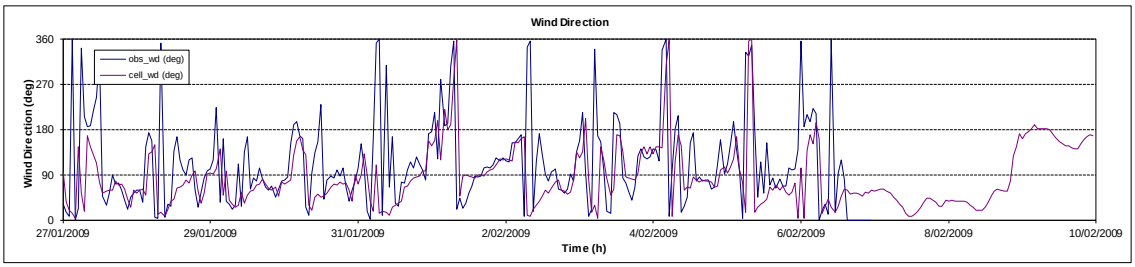


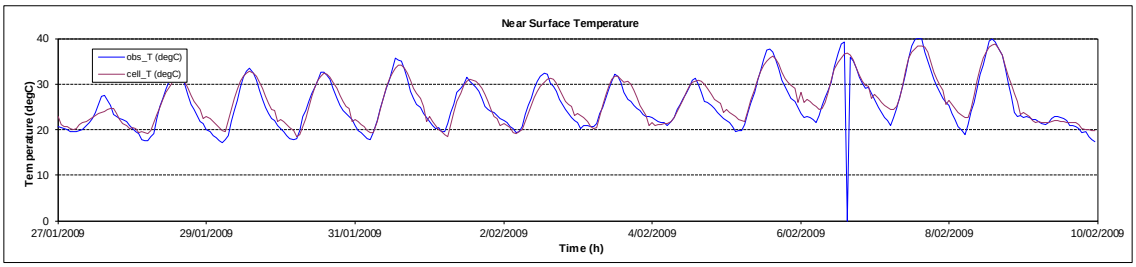


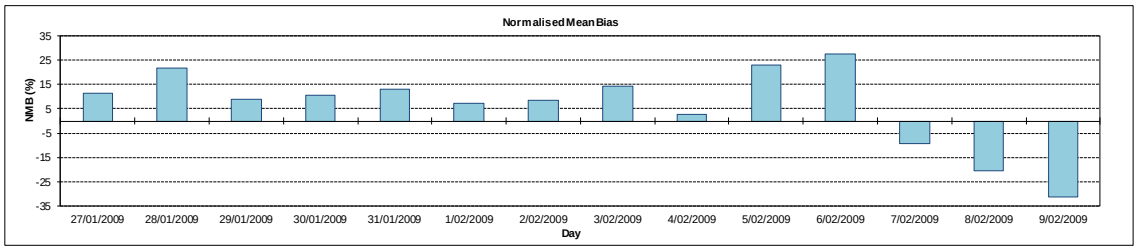
C.1.19 Vineyard – 1-hour

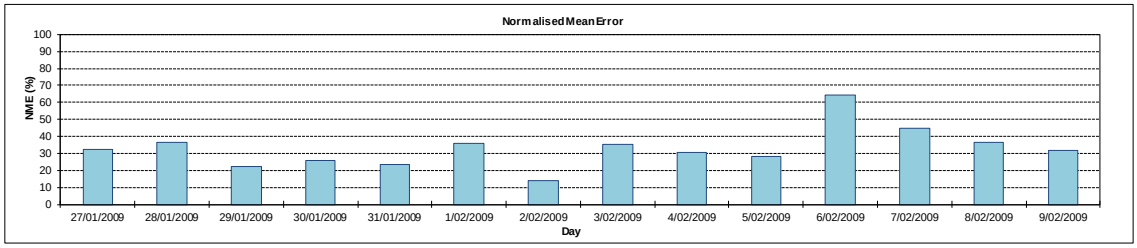




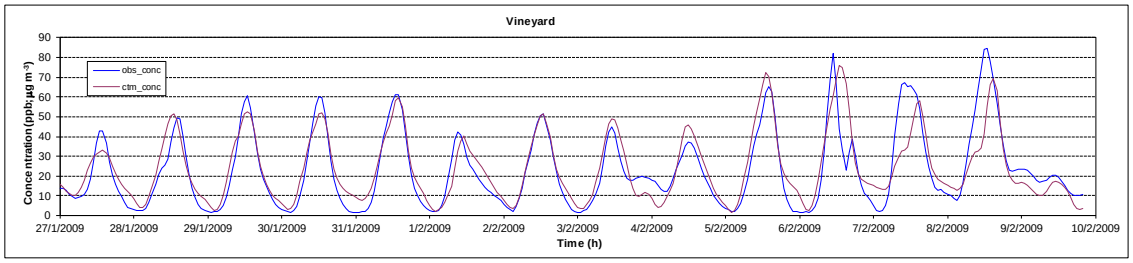


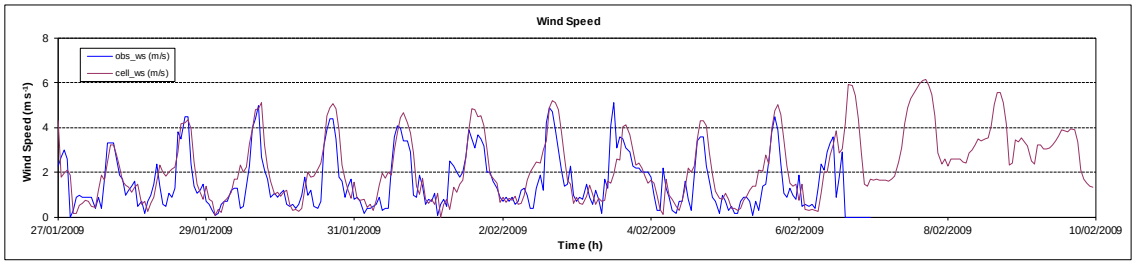


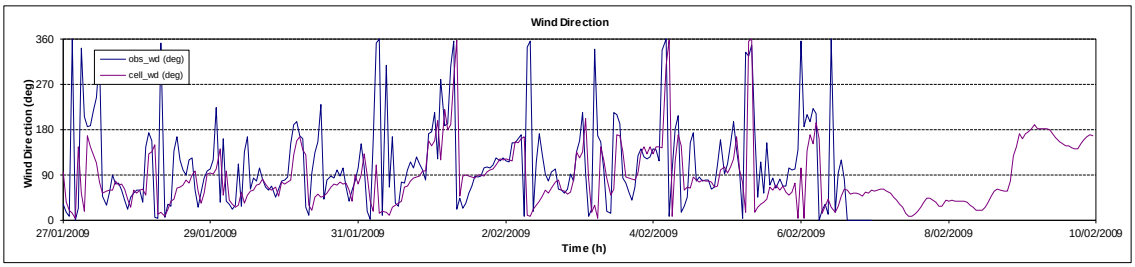


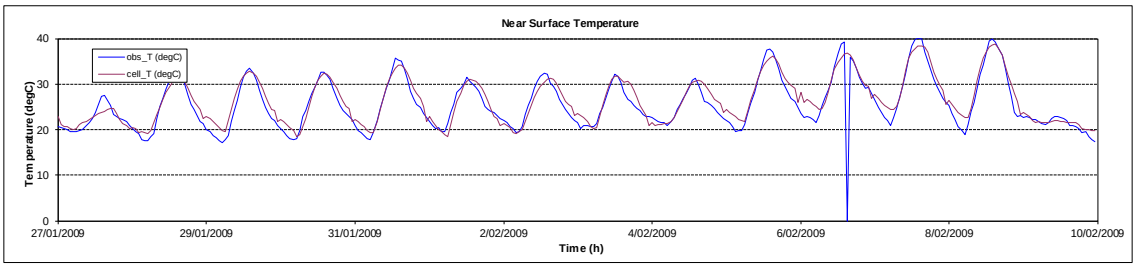


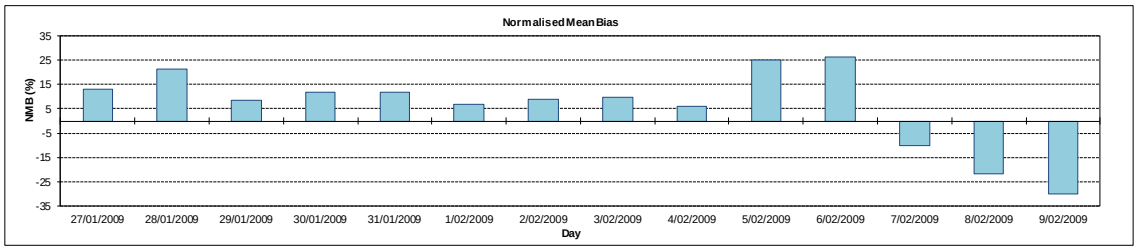
C.1.20 Vineyard – 4-hour

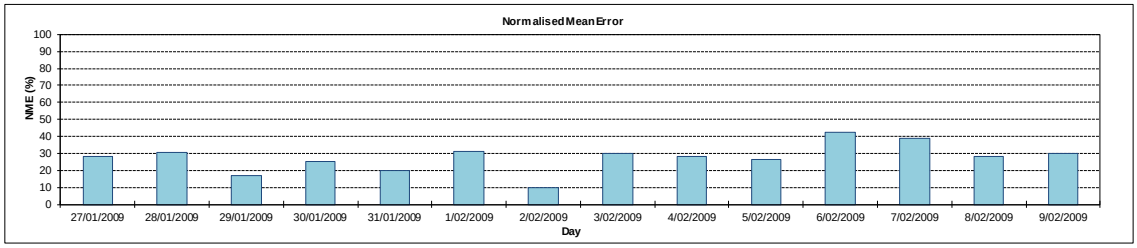






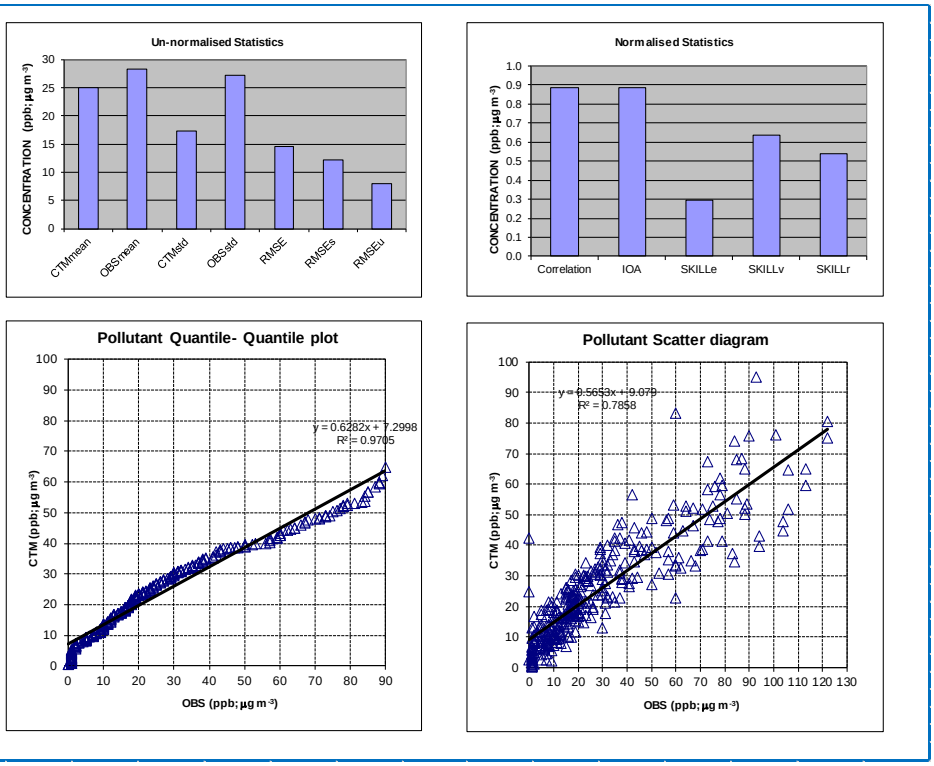




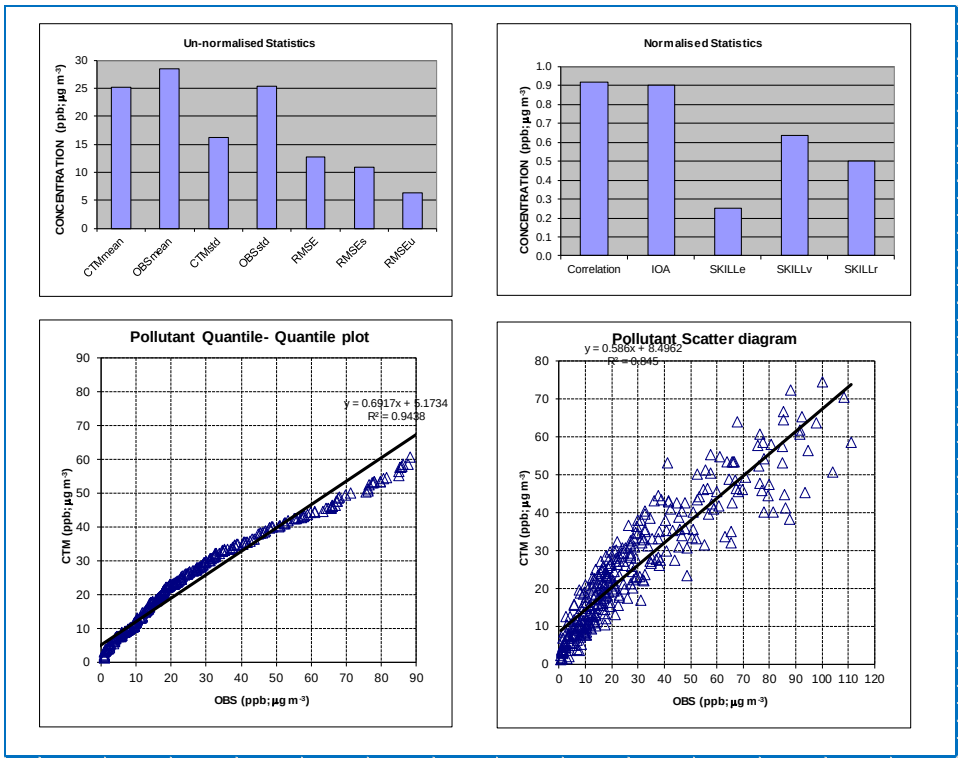


C.2 STATISTICAL EVALUATION OF OBSERVED AND PREDICTED

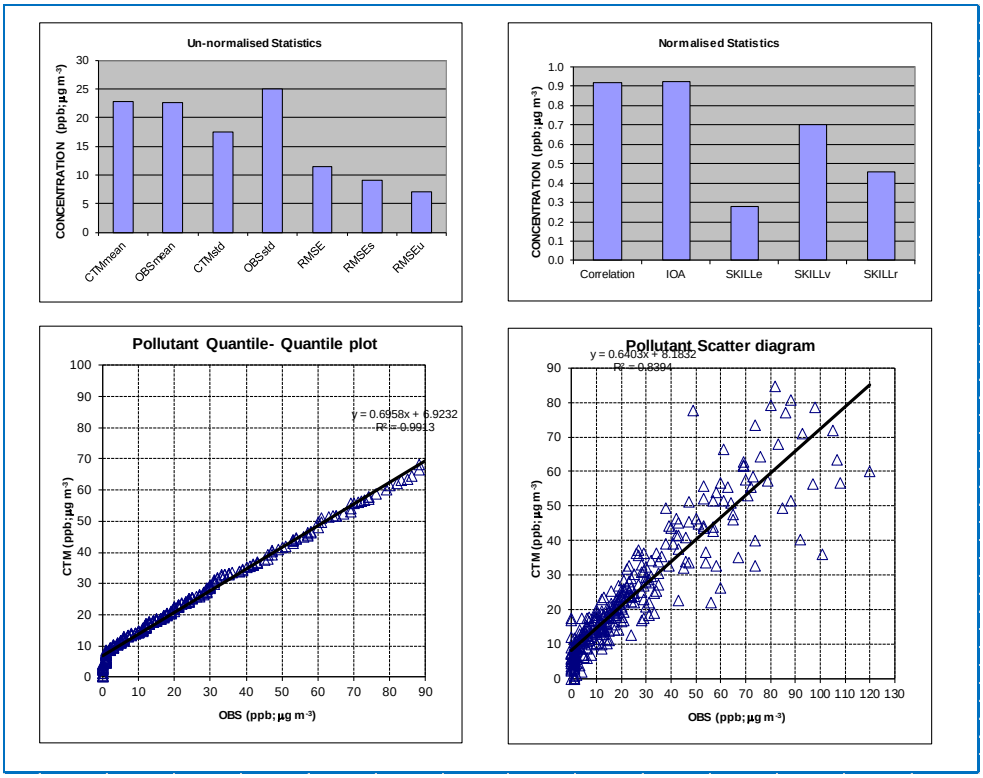
C.2.1 Bargo – 1-hour



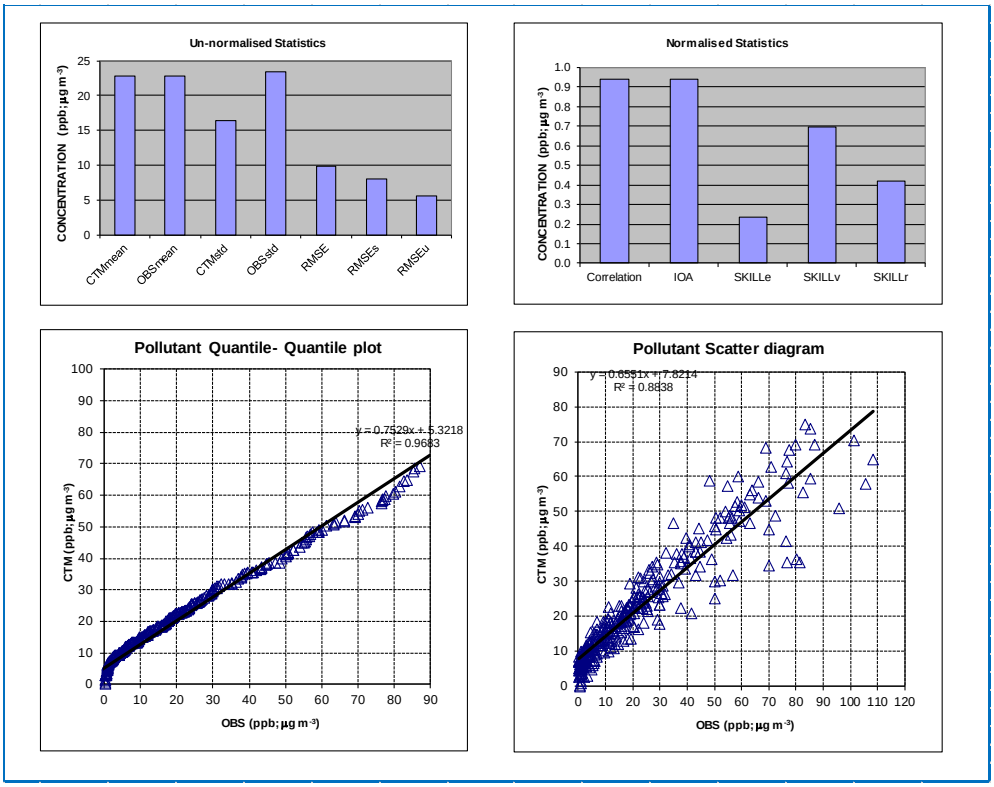
C.2.2 Bargo – 4-hour



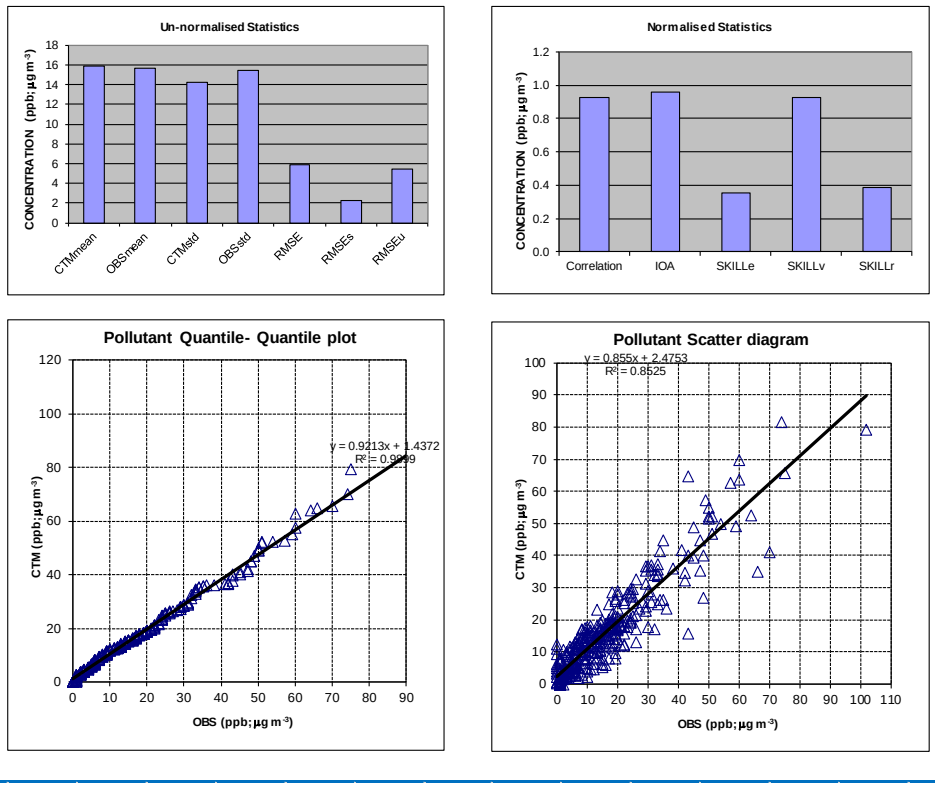
C.2.3 Bringelley – 1-hour



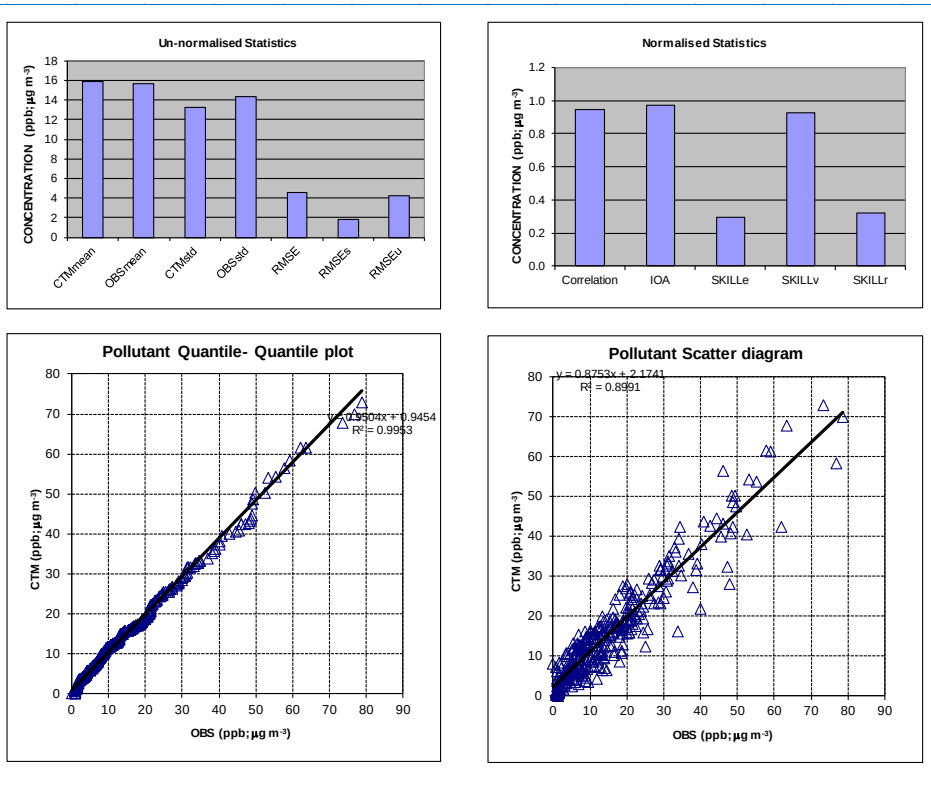
C.2.4 Bringelley – 4-hour



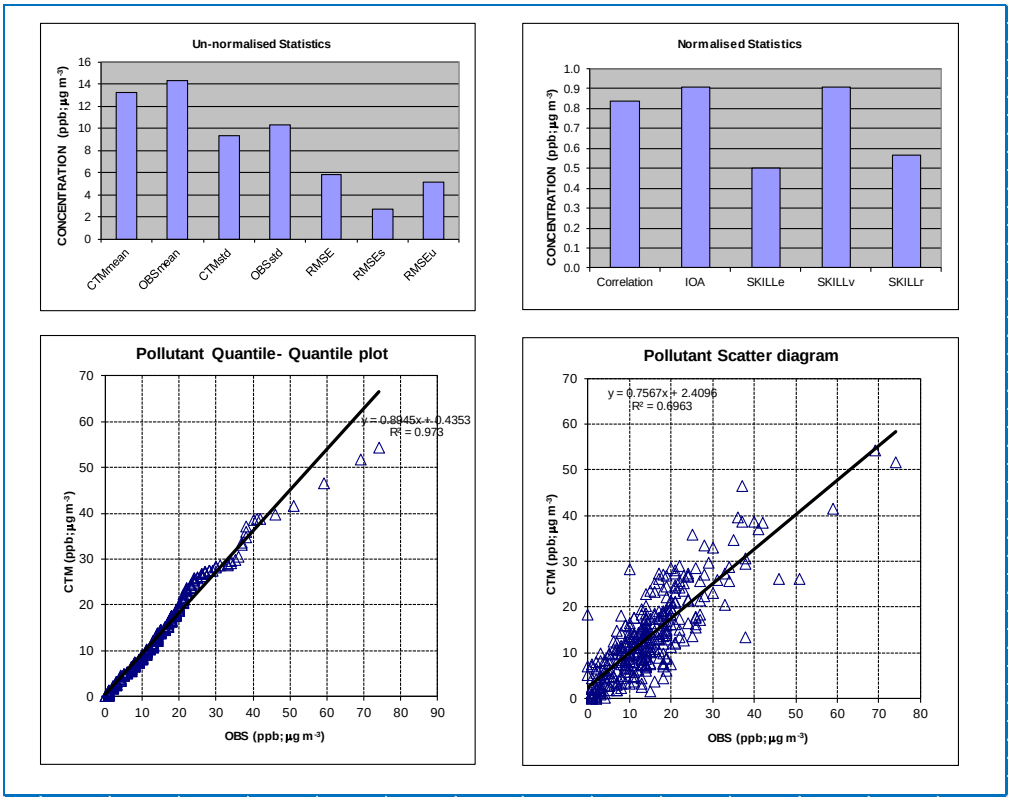
C.2.5 Chullora – 1-hour



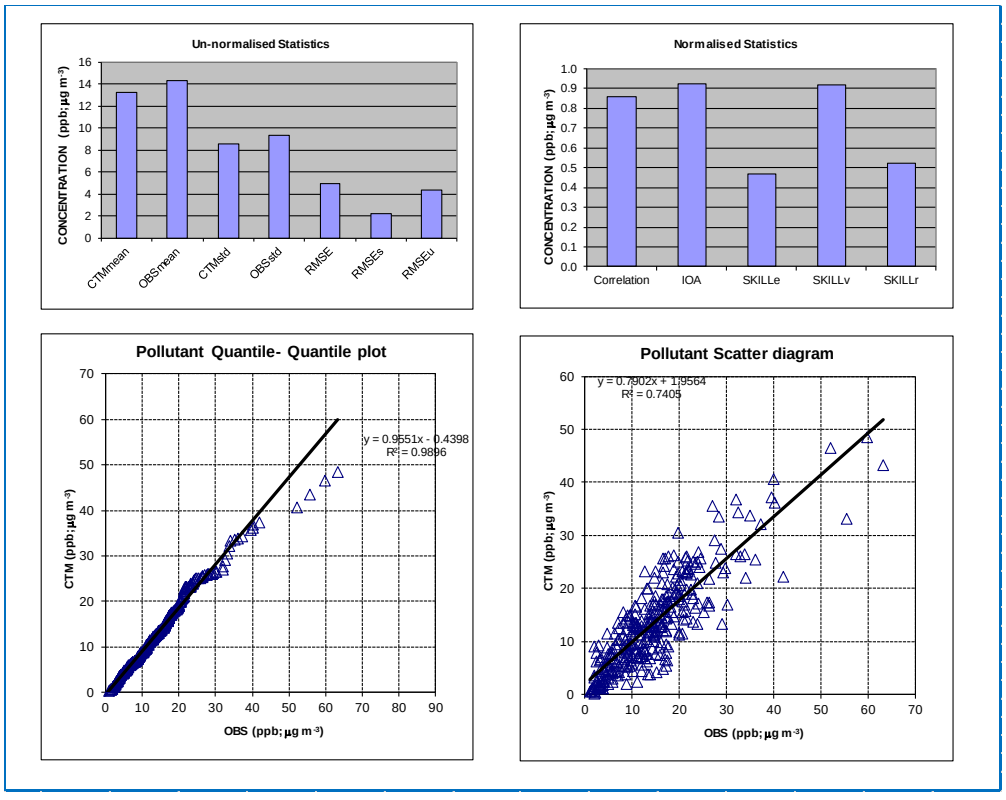
C.2.6 Chullora – 4-hour



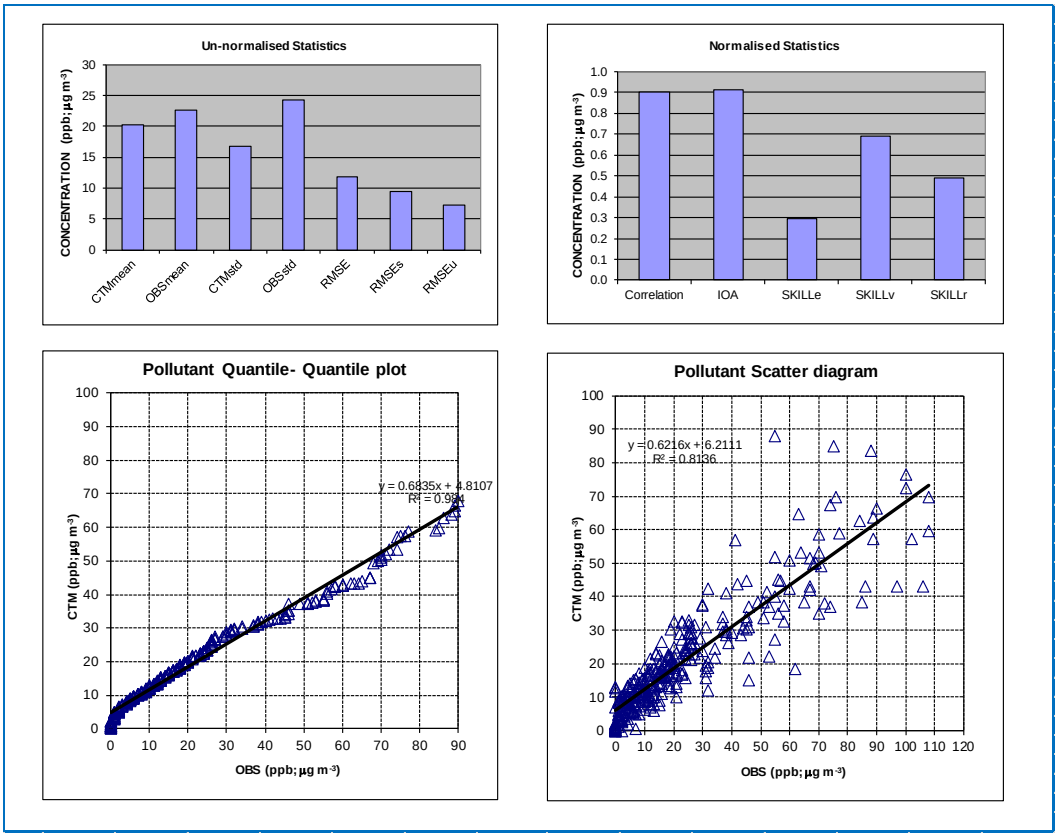
C.2.7 Earlwood – 1-hour



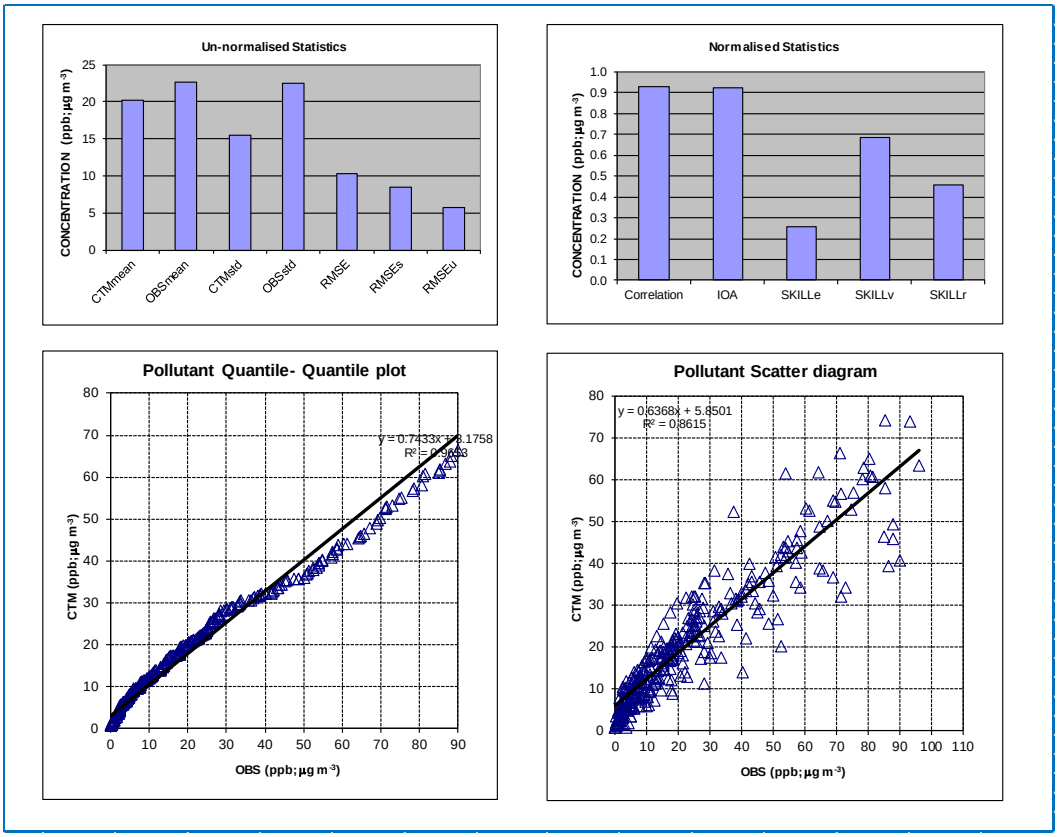
C.2.8 Earlwood – 4-hour



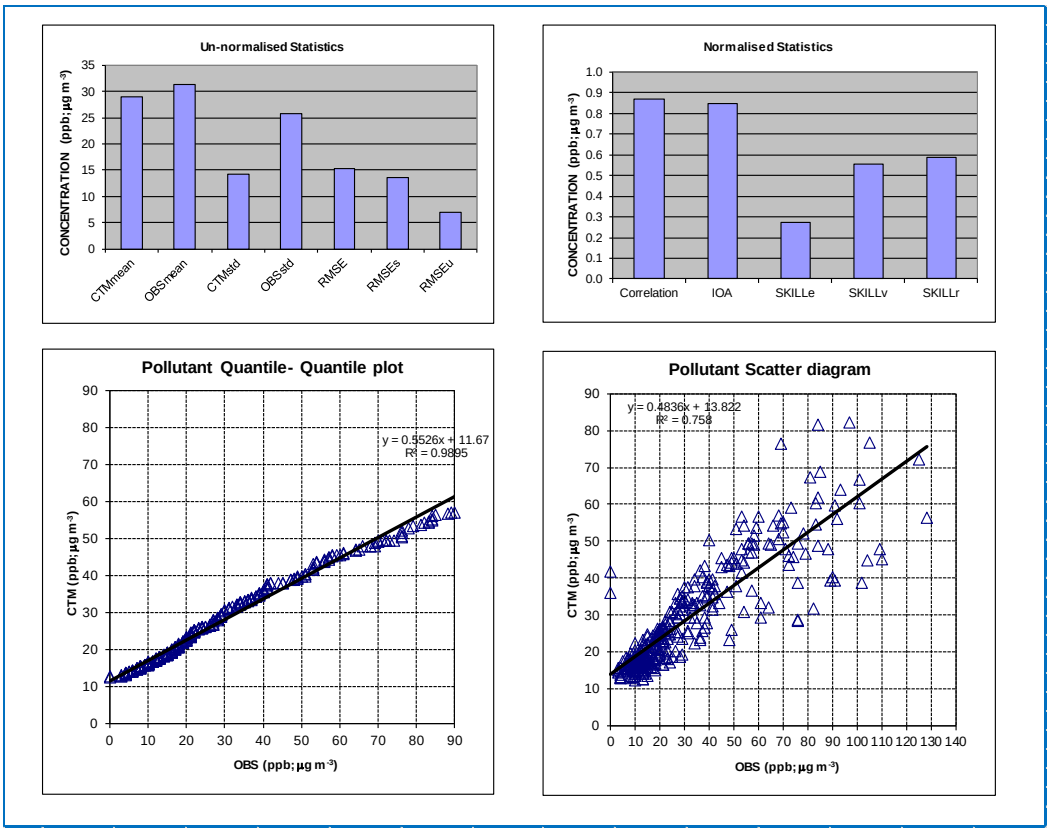
C.2.9 Macarthur – 1-hour



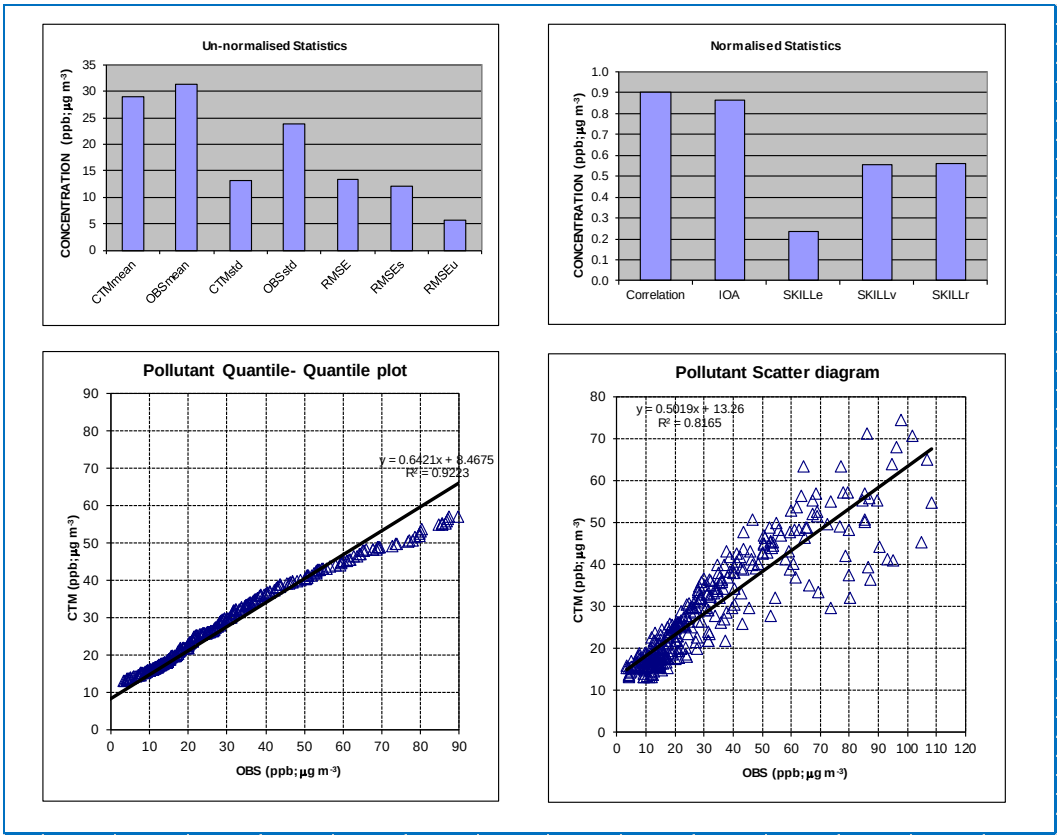
C.2.10 Macarthur – 4-hour



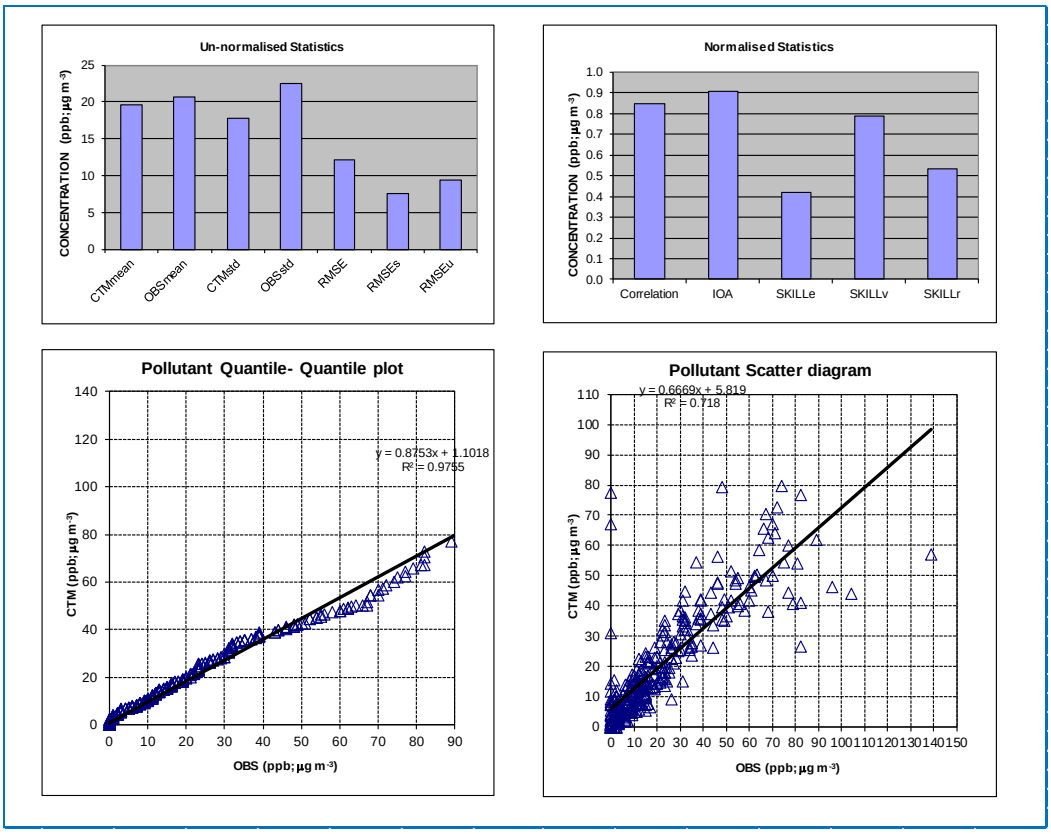
C.2.11 Oakdale – 1-hour



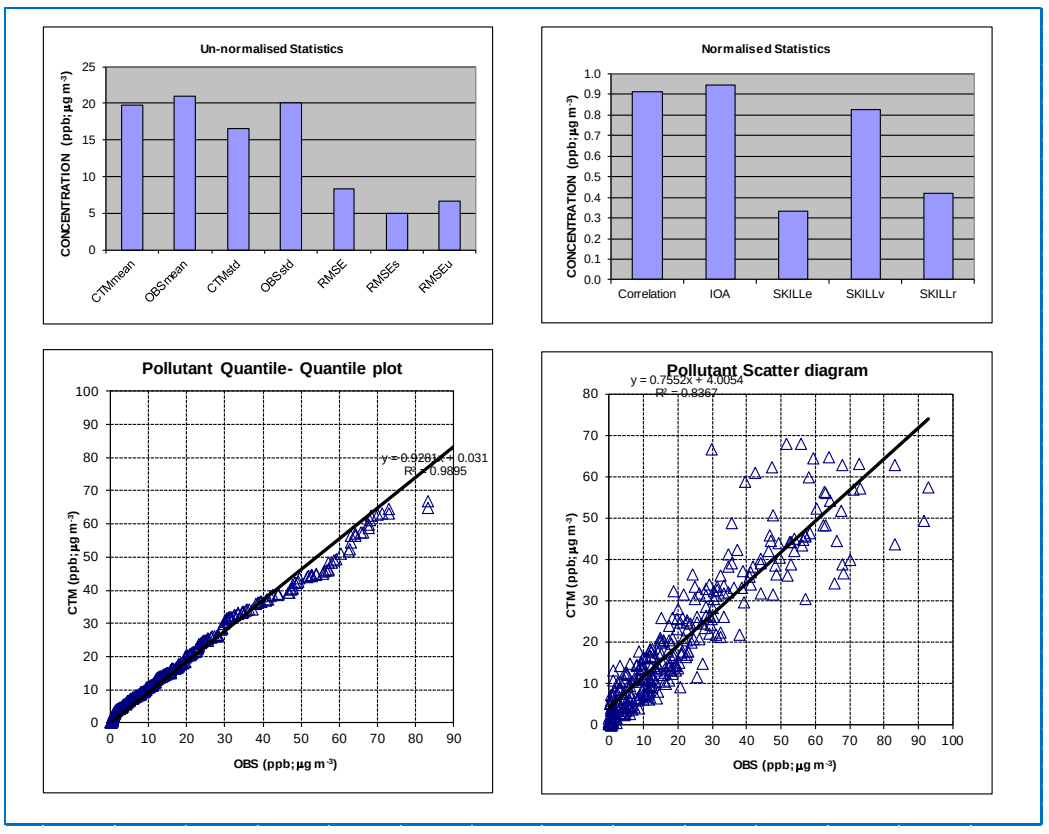
C.2.12 Oakdale – 4-hour



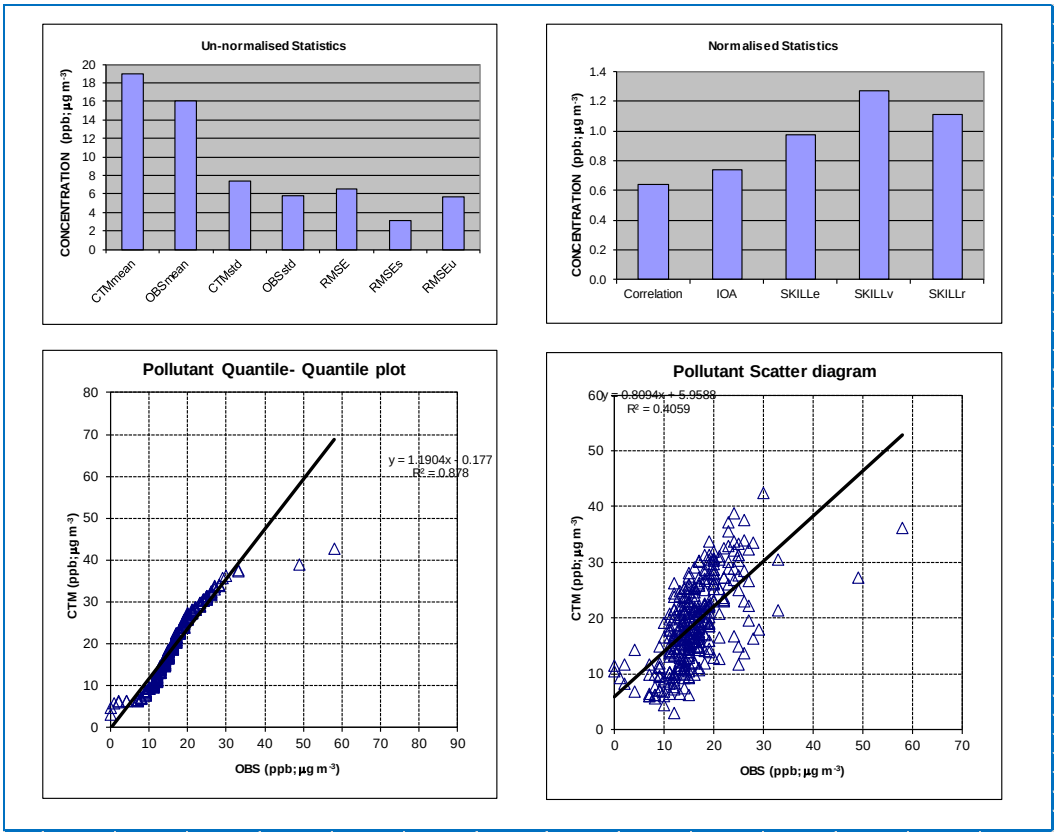
C.2.13 Prospect – 1-hour



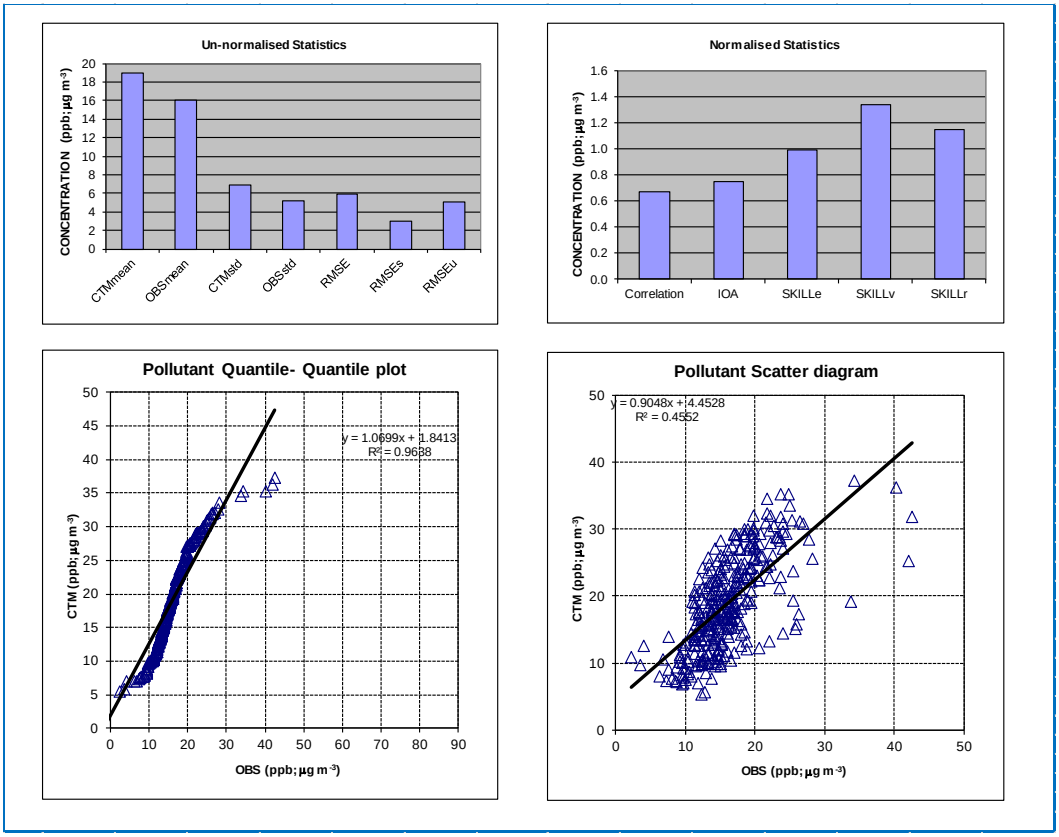
C.2.14 Prospect – 4-hour



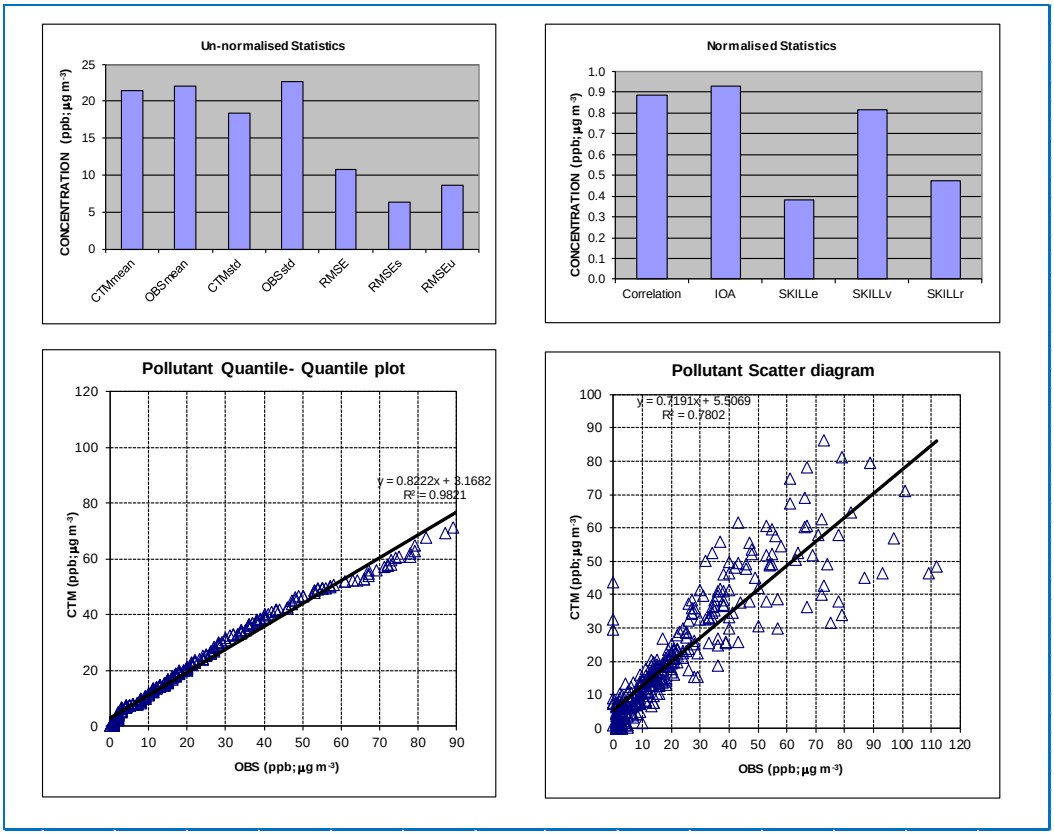
C.2.15 Randwick – 1-hour



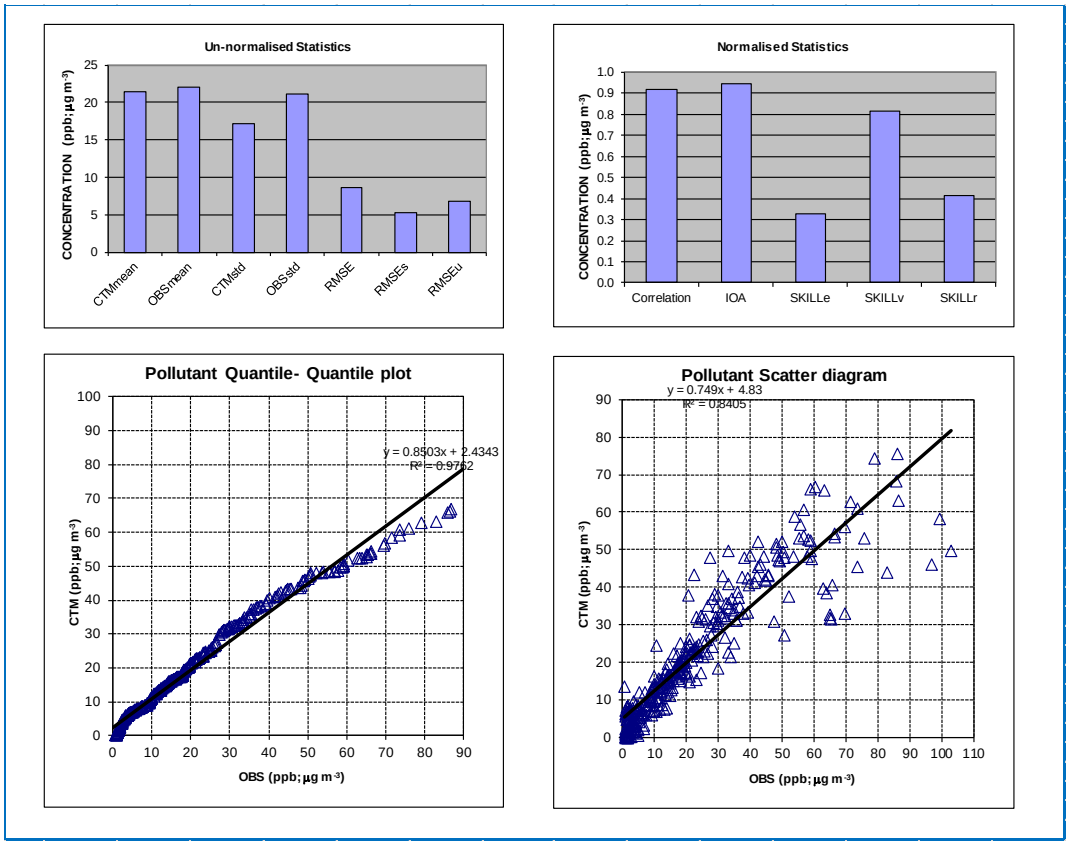
C.2.16 Randwick – 4-hour



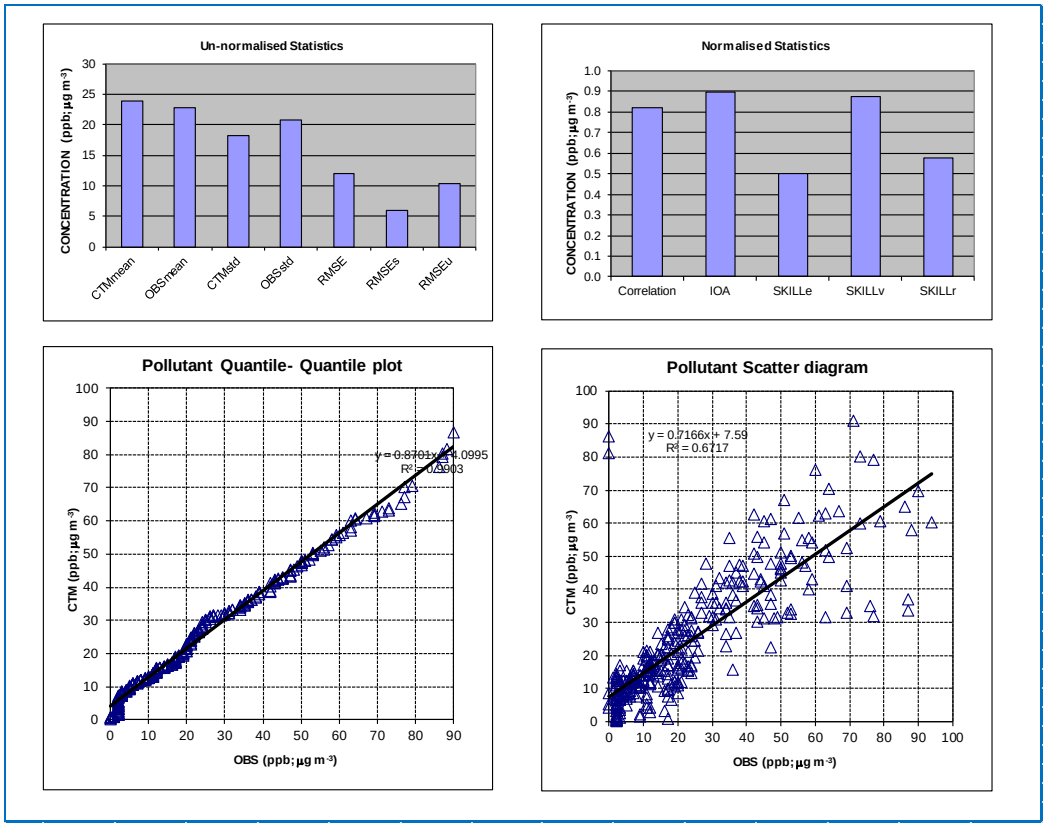
C.2.17 St Marys – 1-hour



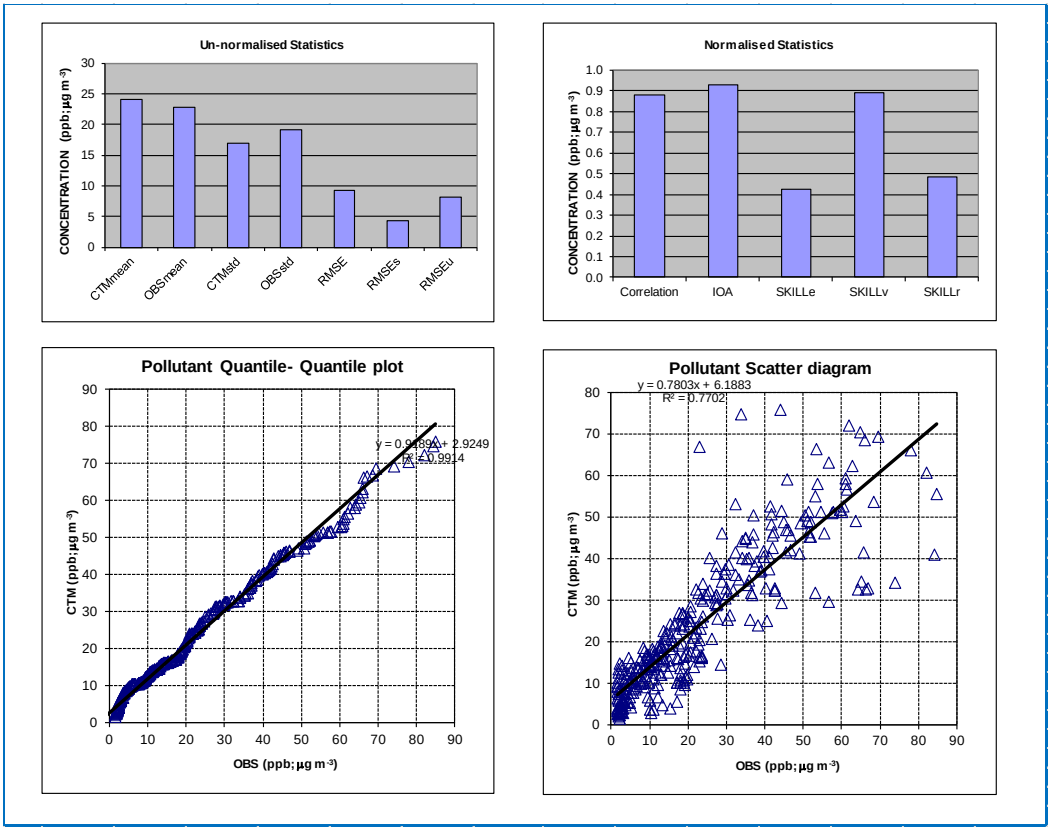
C.2.18 St Marys – 4-hour



C.2.19 Vineyard – 1-hour

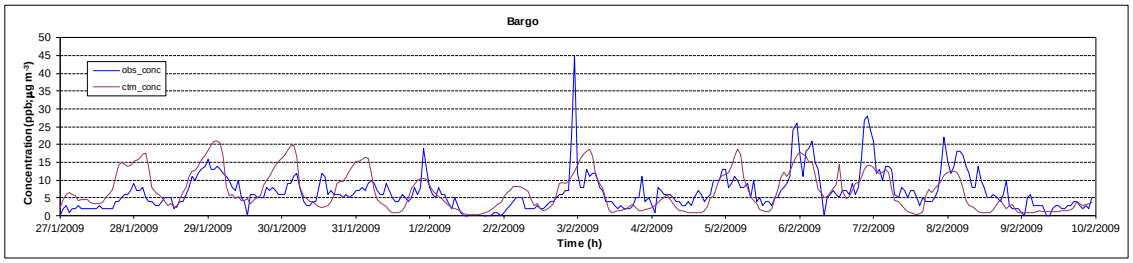


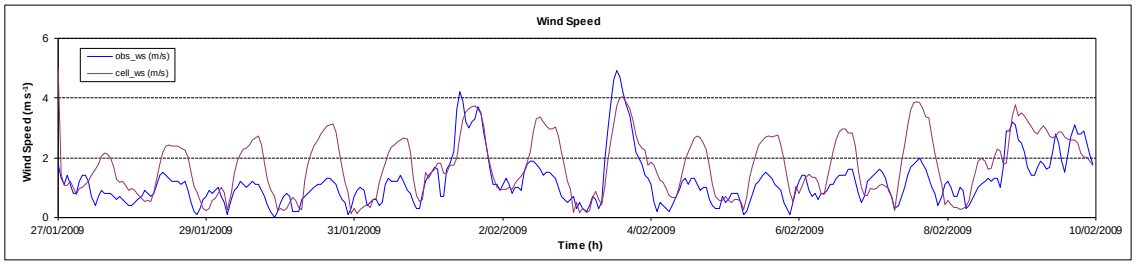
C.2.20 Vineyard – 4-hour

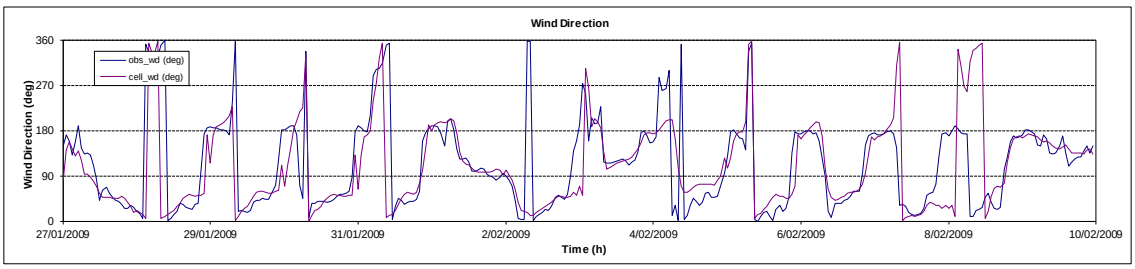


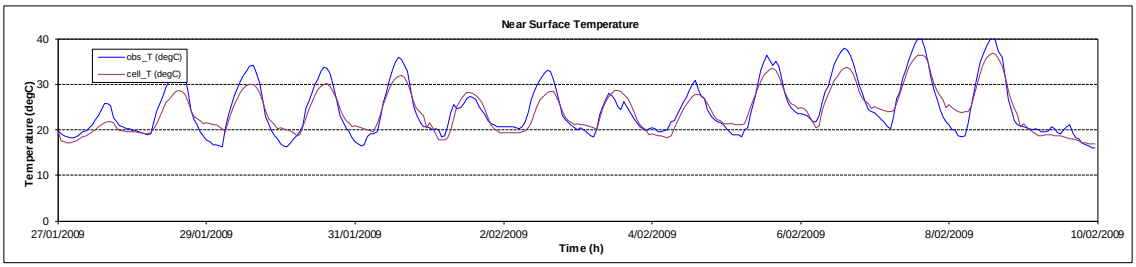
C.3 TIME SERIES OF OBSERVED AND PREDICTED

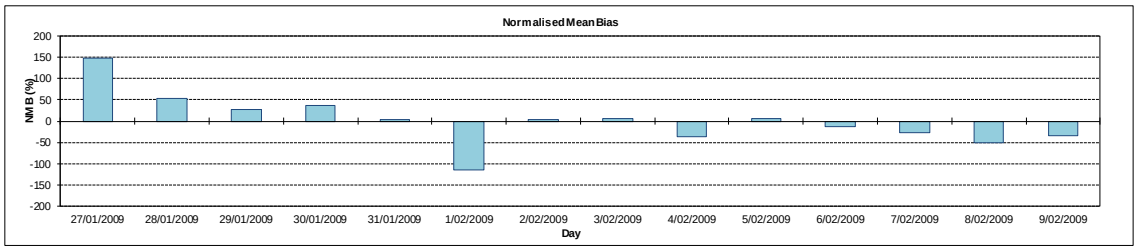
C.3.1 Bargo – NO_2

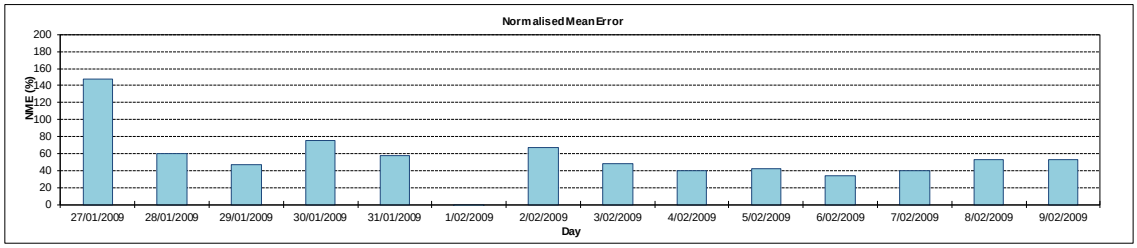




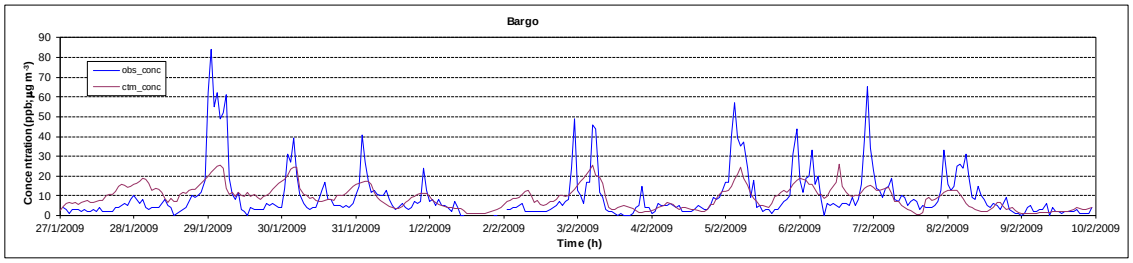


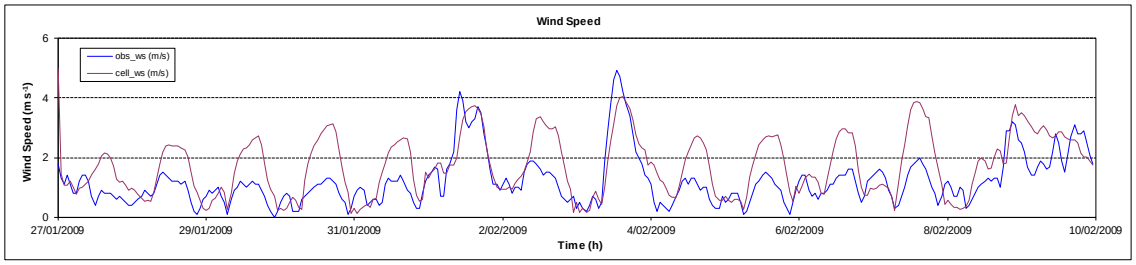


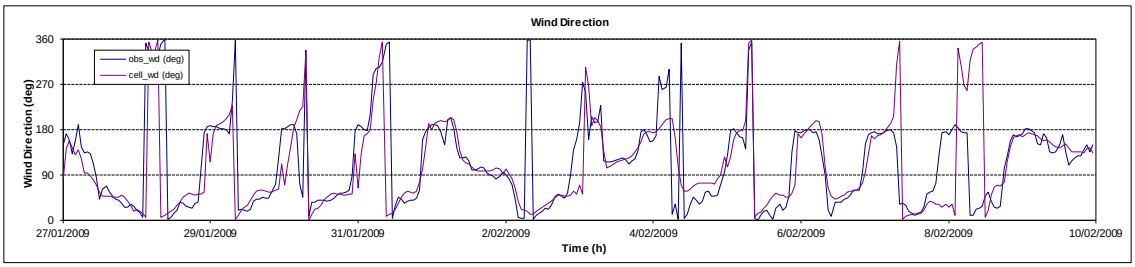


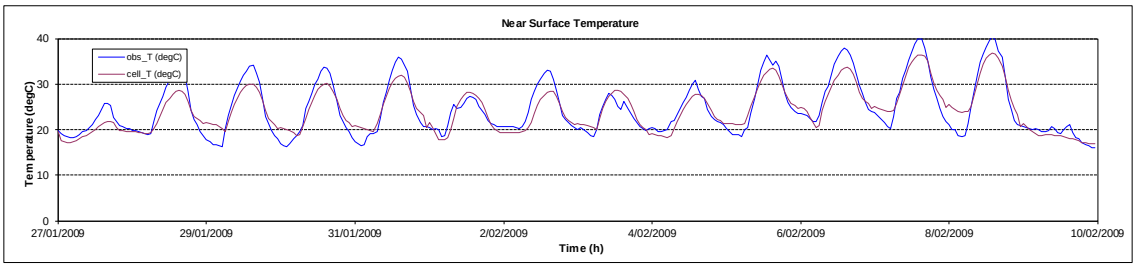


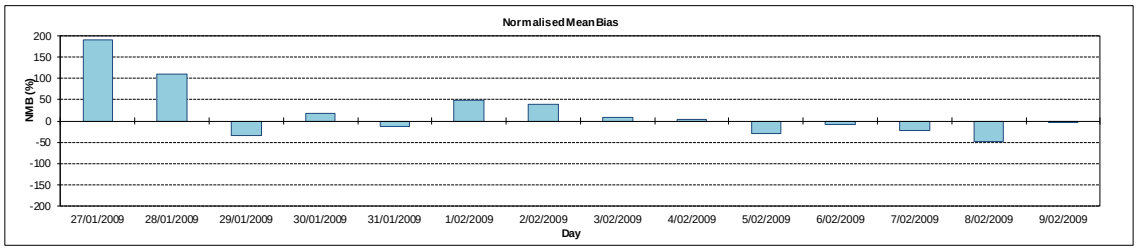
C.3.2 Bargo – NO_x

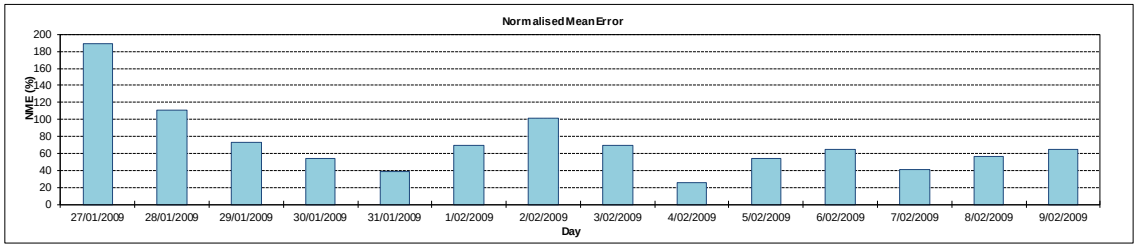




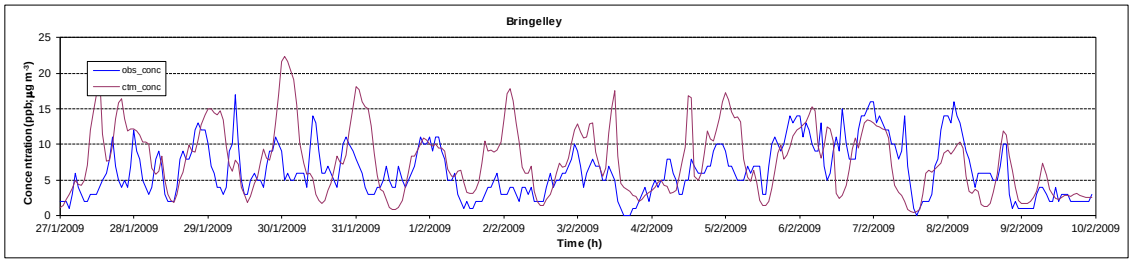


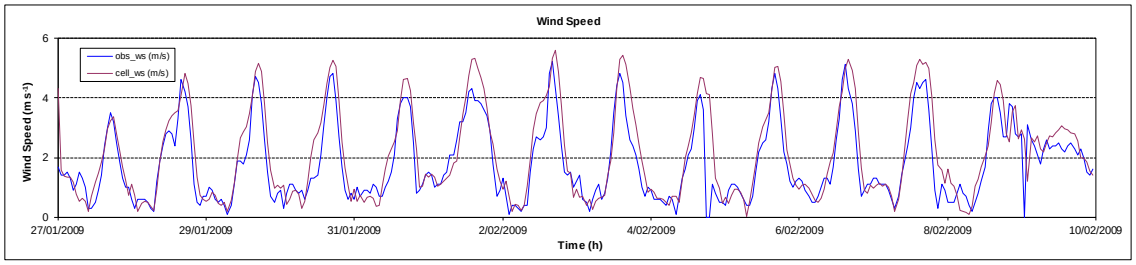


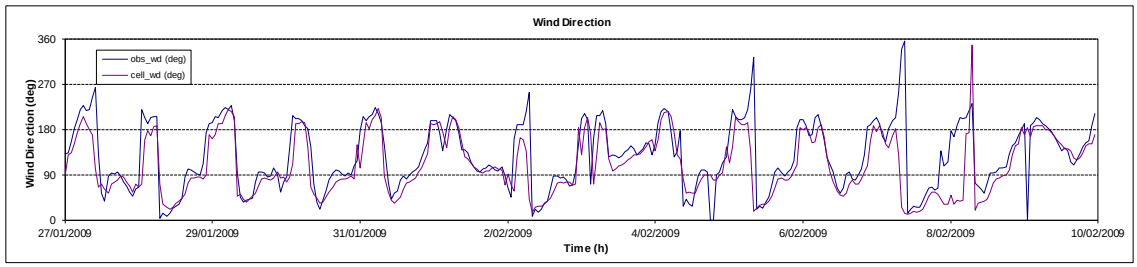


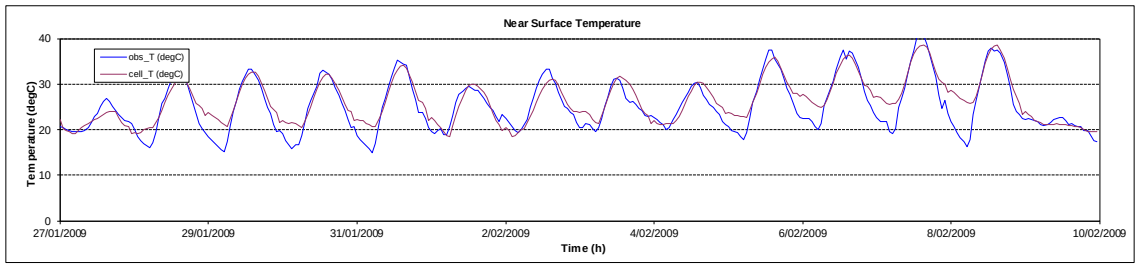


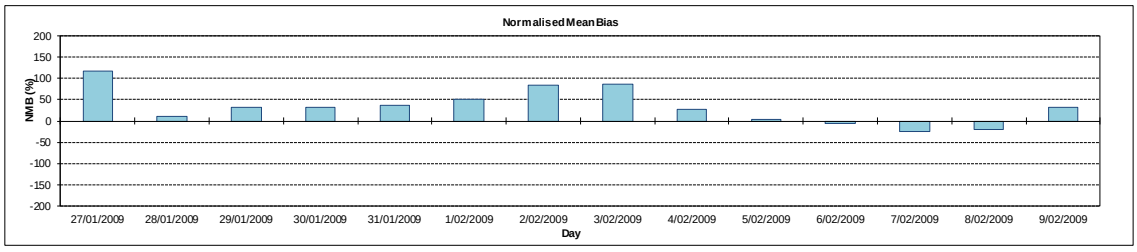
C.3.3 Bringelly – NO_2

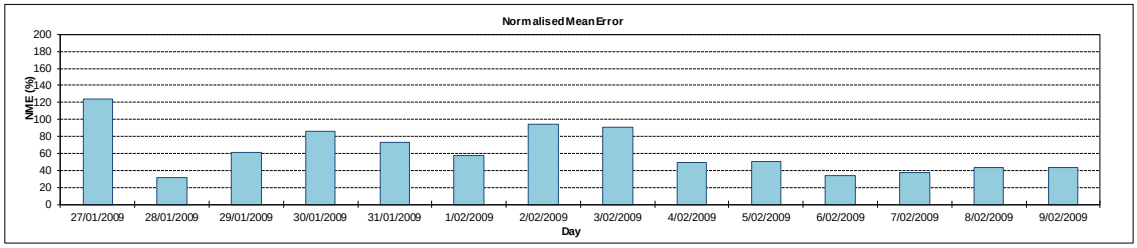




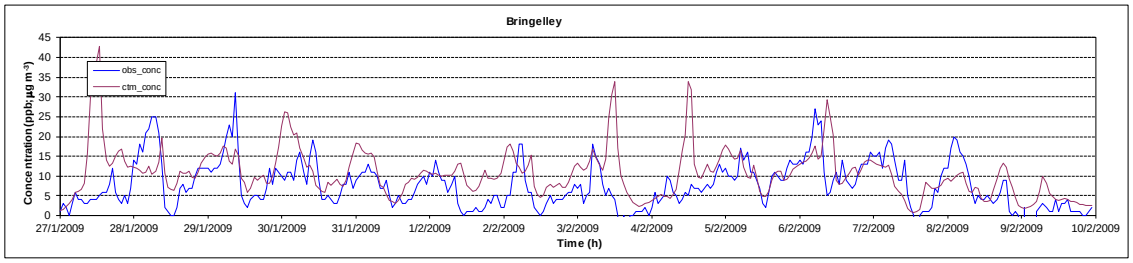


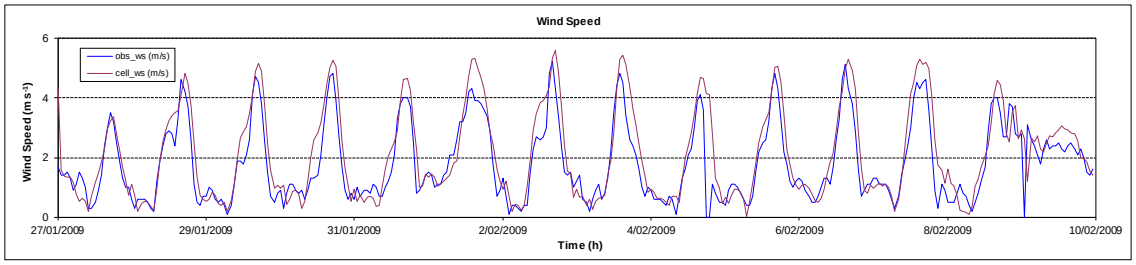


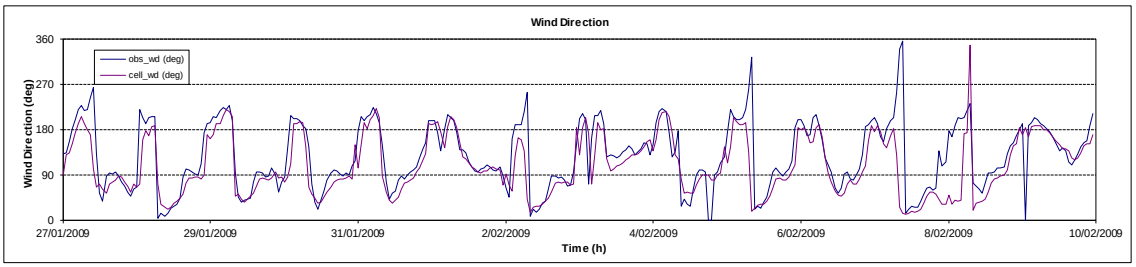


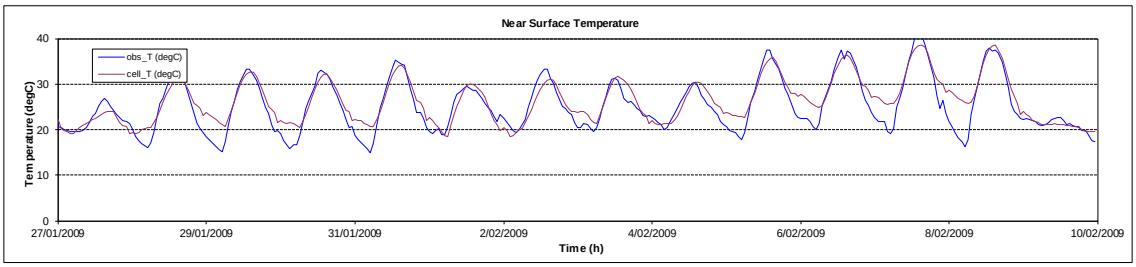


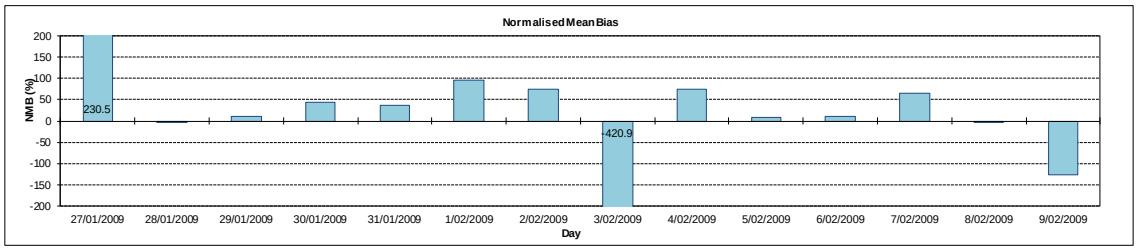
C.3.4 Bringelly – NO_x

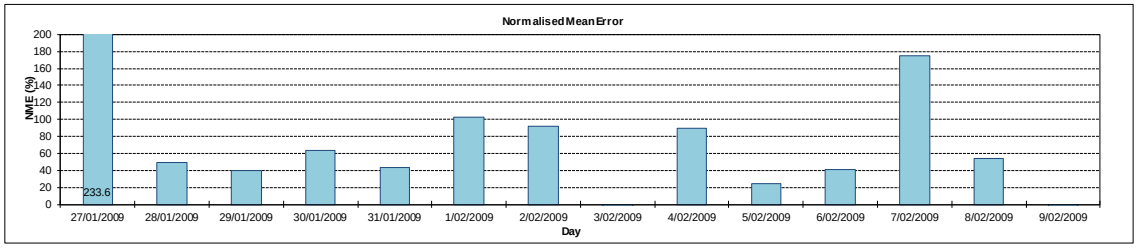




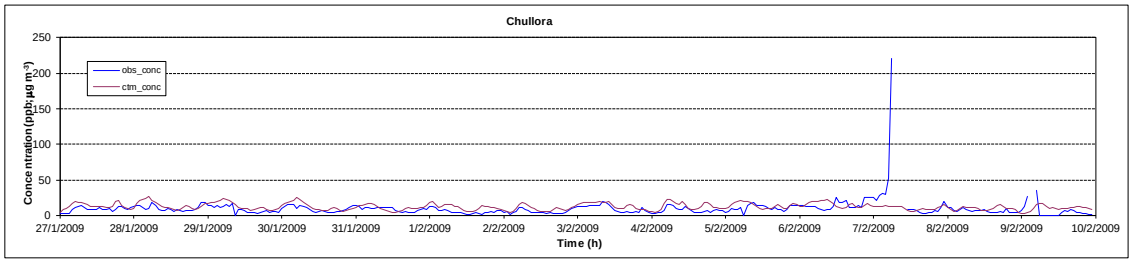


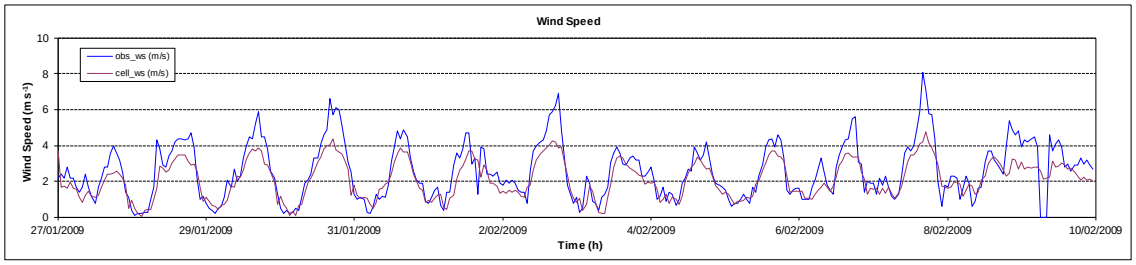


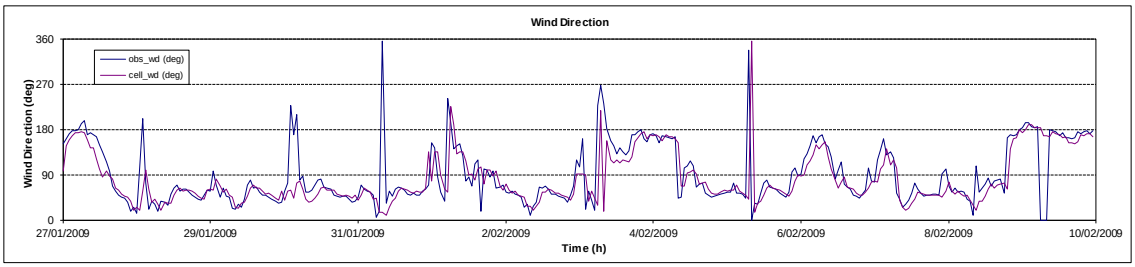


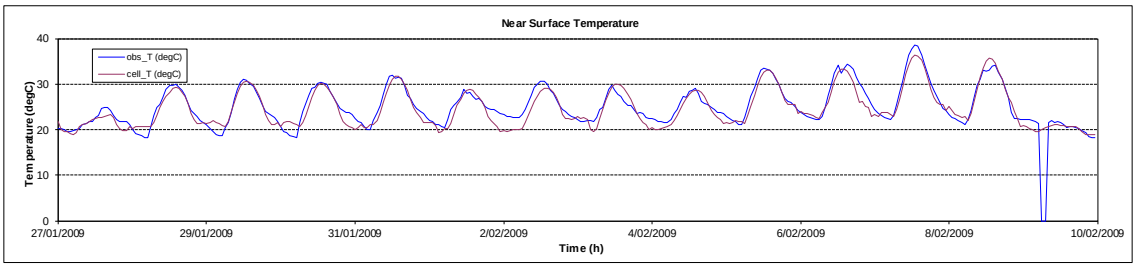


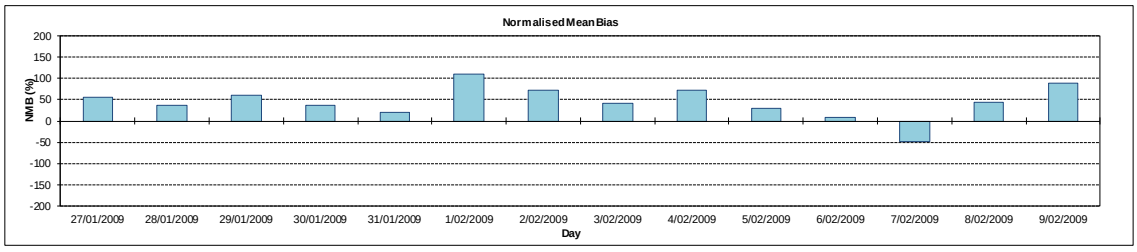
C.3.5 Chullora – NO_2

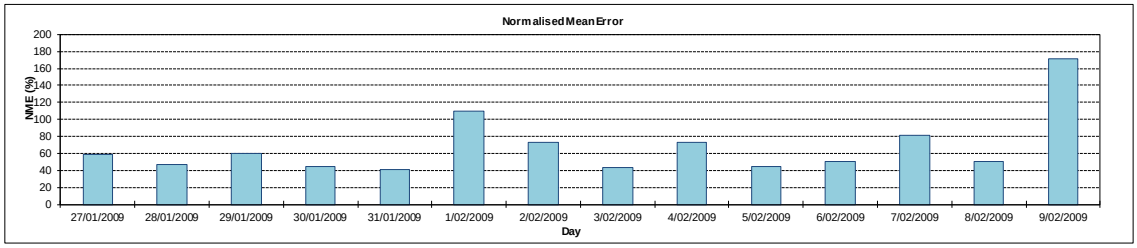




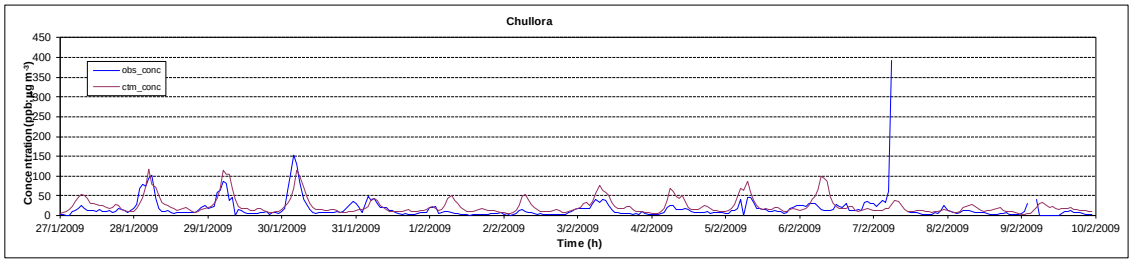


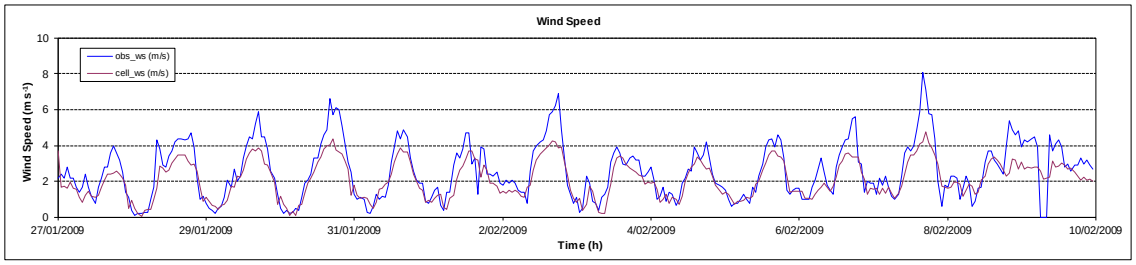


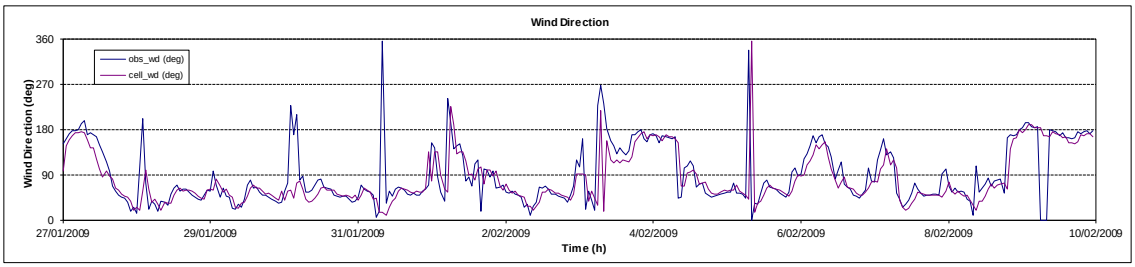


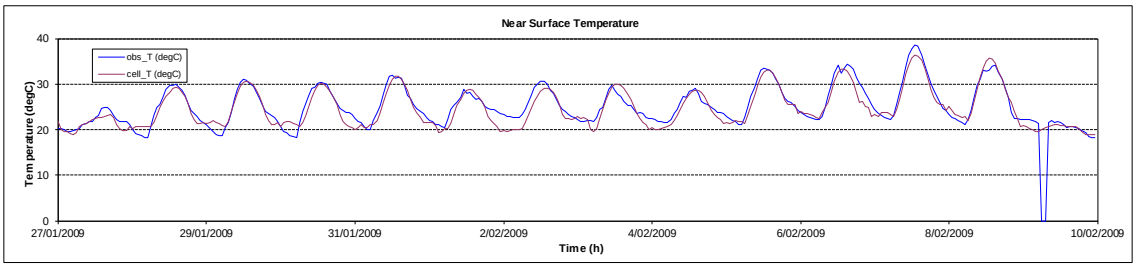


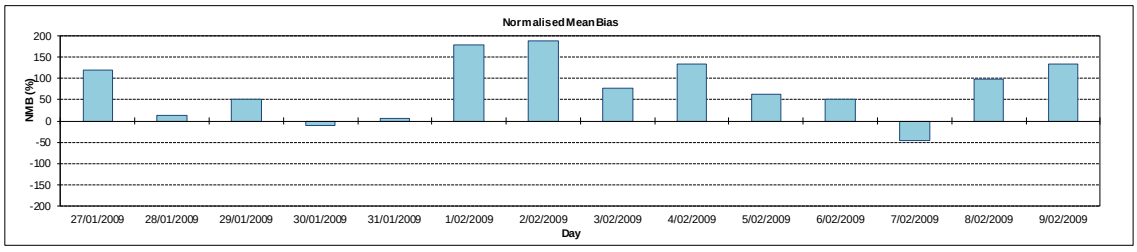
C.3.6 Chullora – NO_x

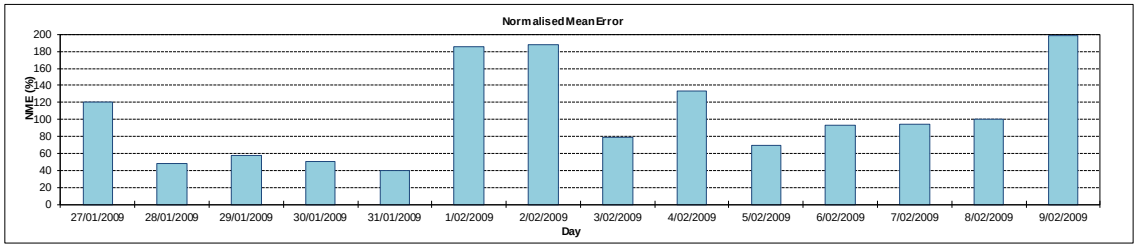




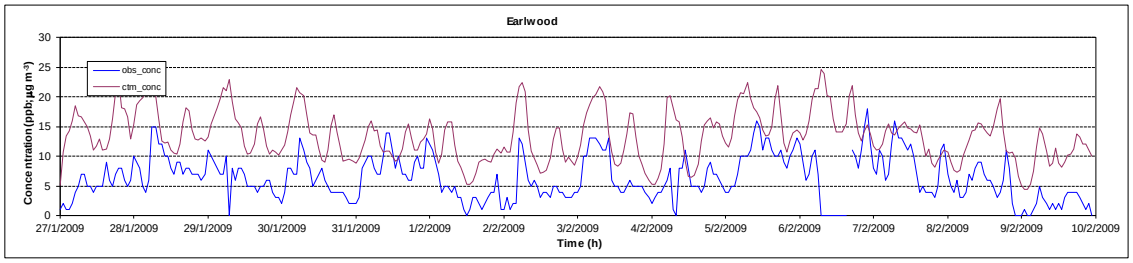


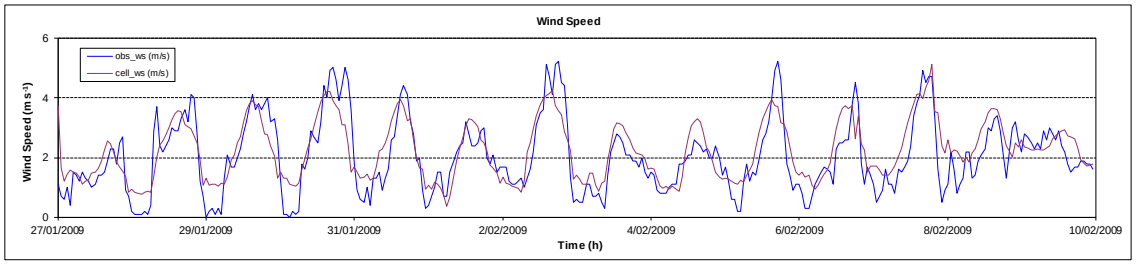


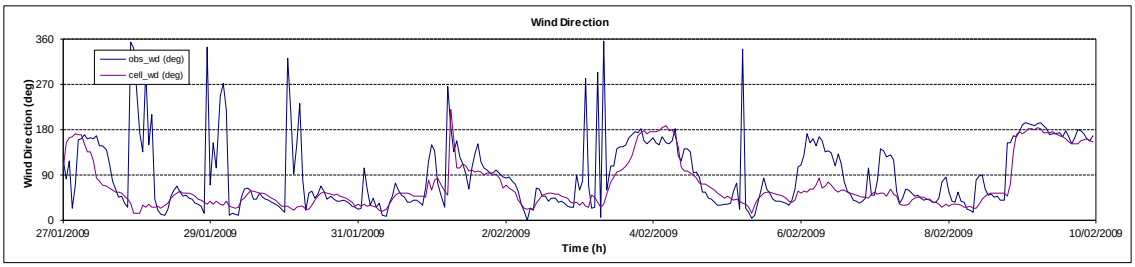


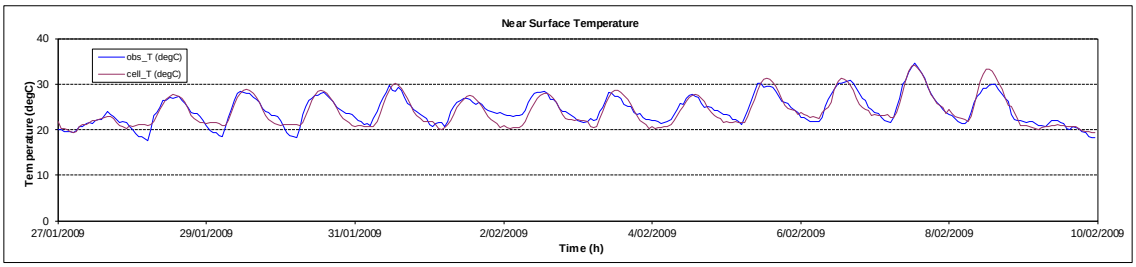


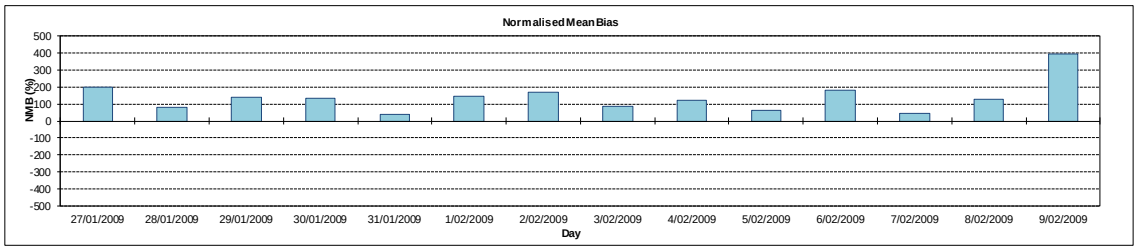
C.3.7 Earlwood – NO_2

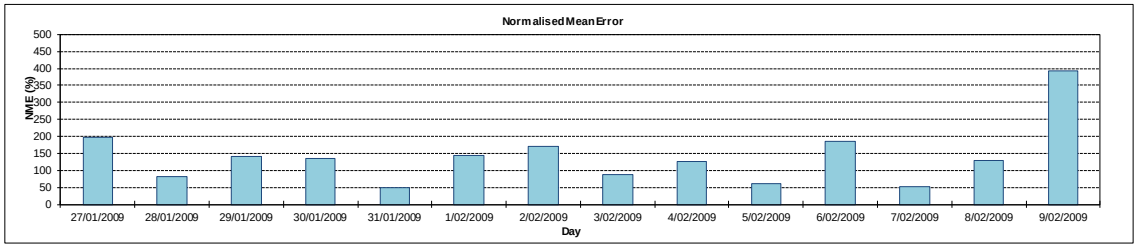




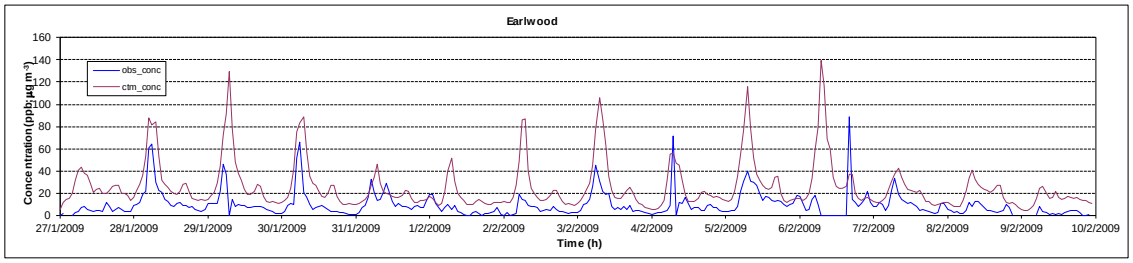


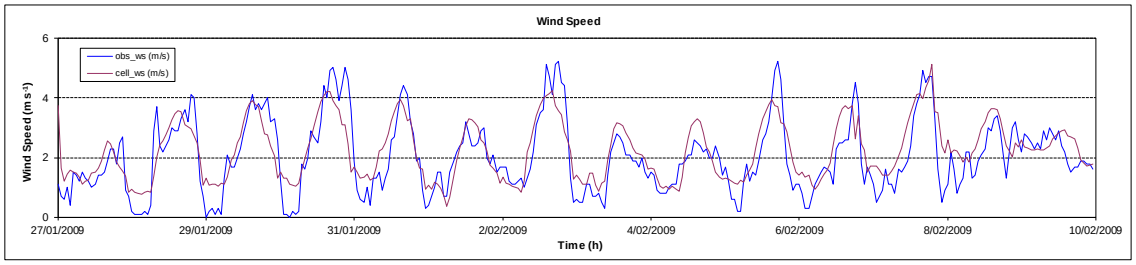


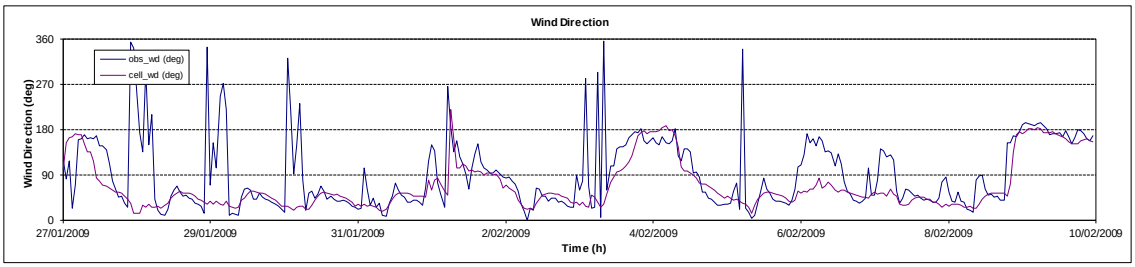


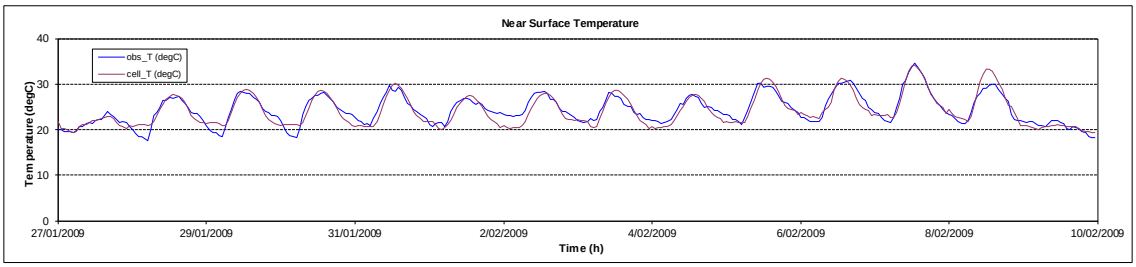


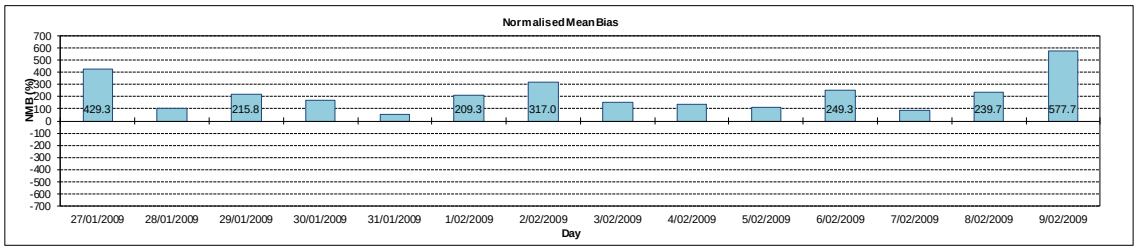
C.3.8 Earlwood – NO_x

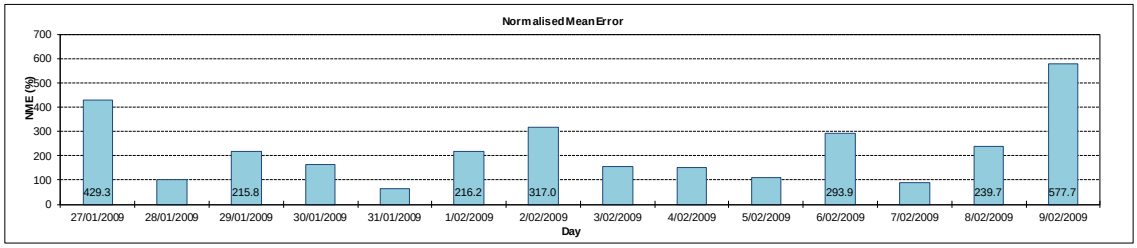




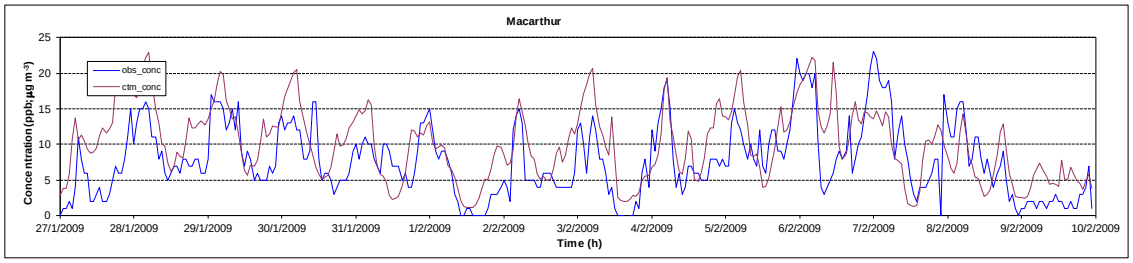


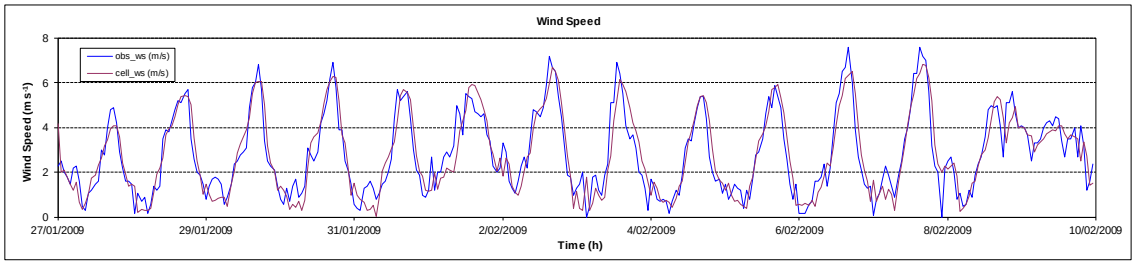


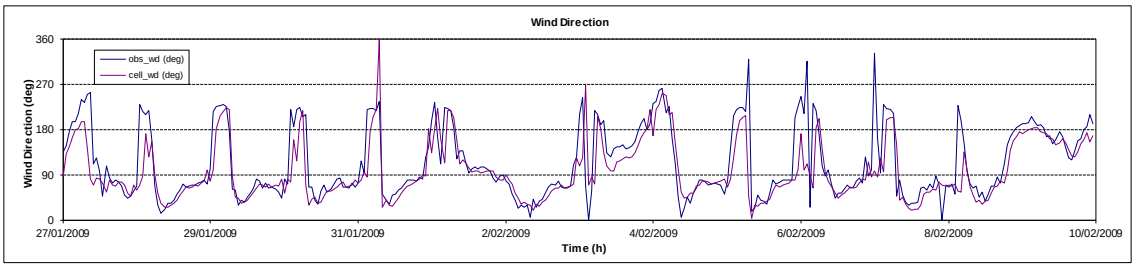


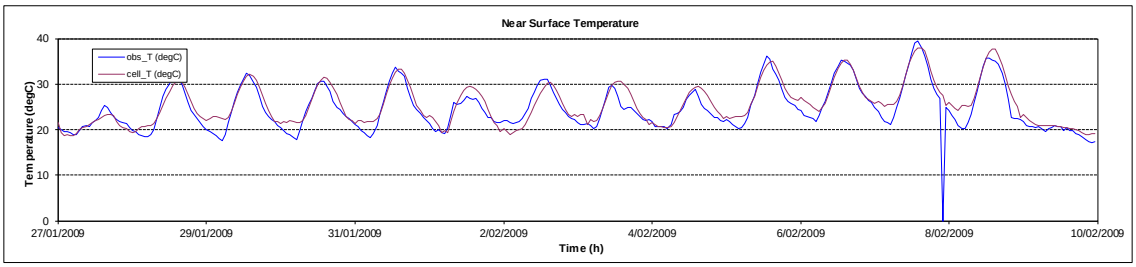


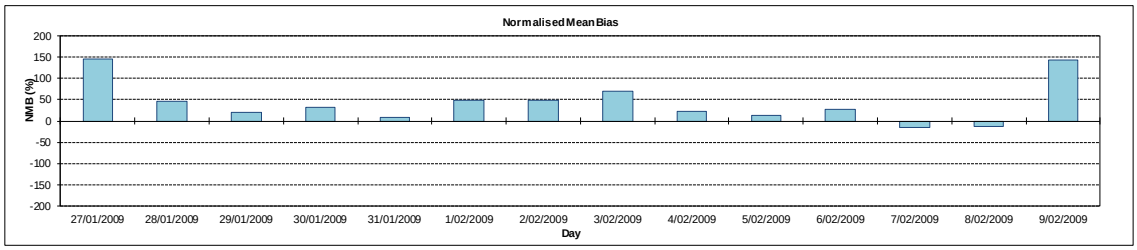
C.3.9 Macarthur – NO_2

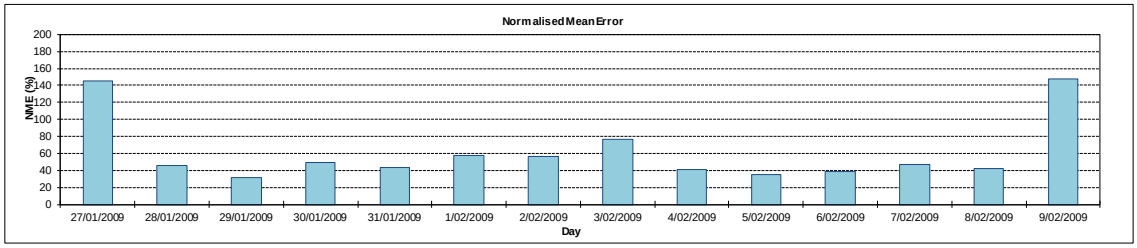




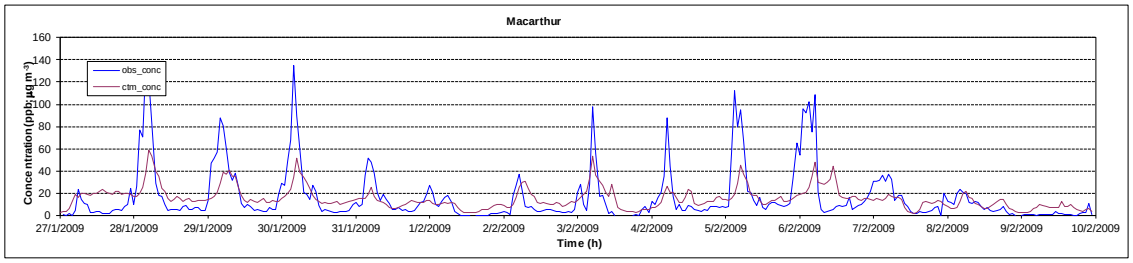


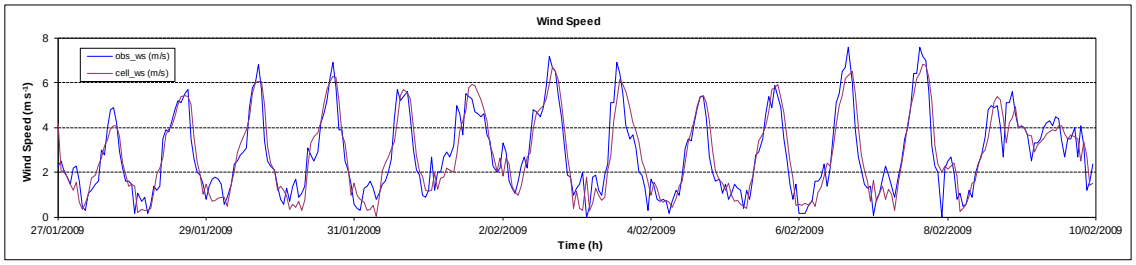


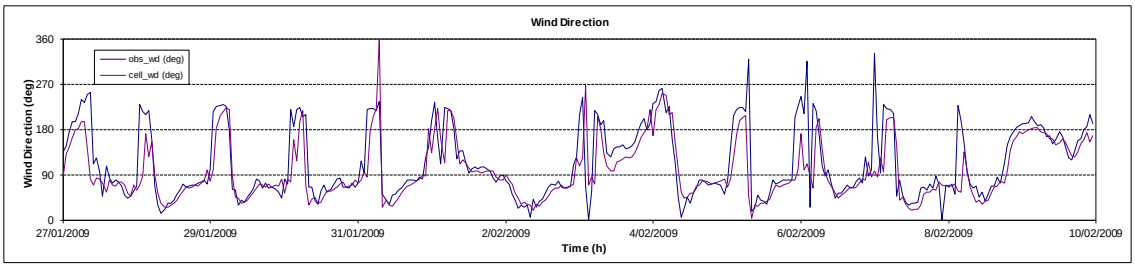


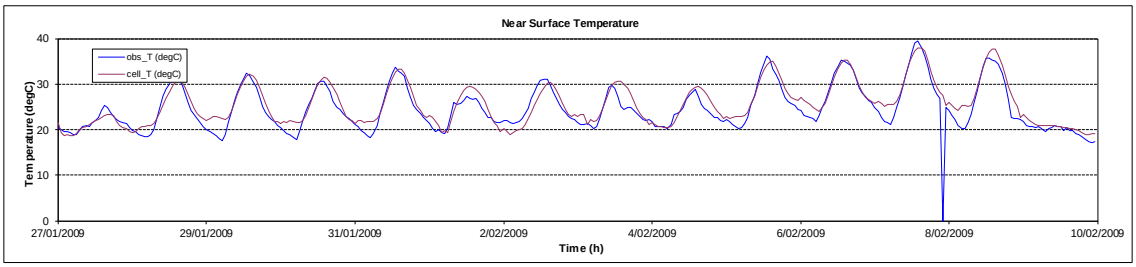


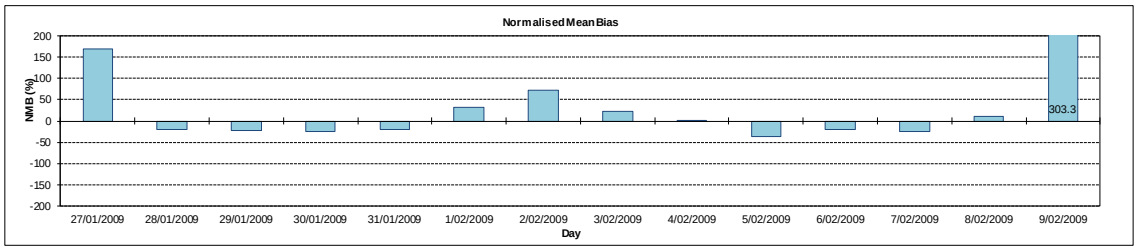
C.3.10 Macarthur – NO_x

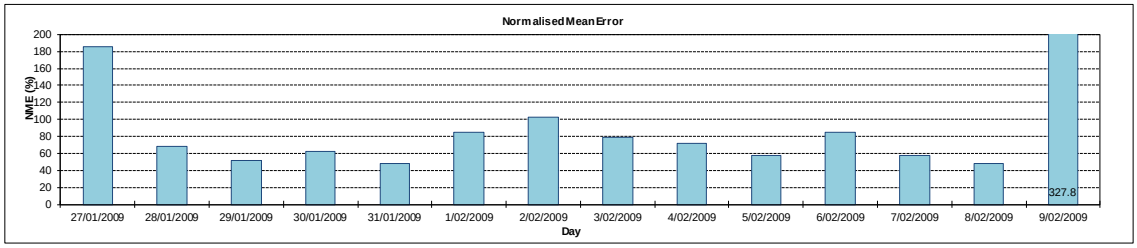




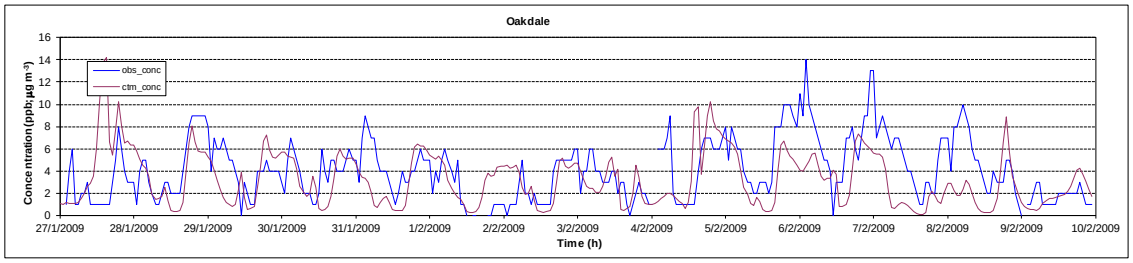


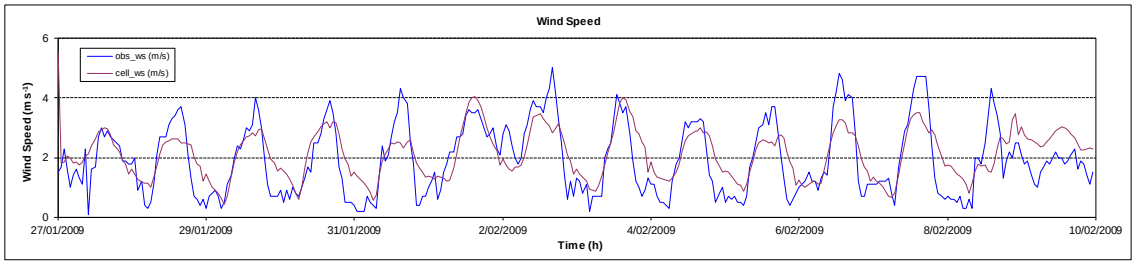


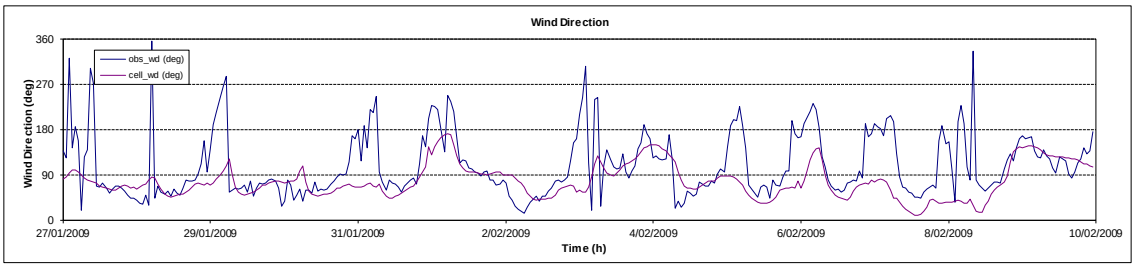


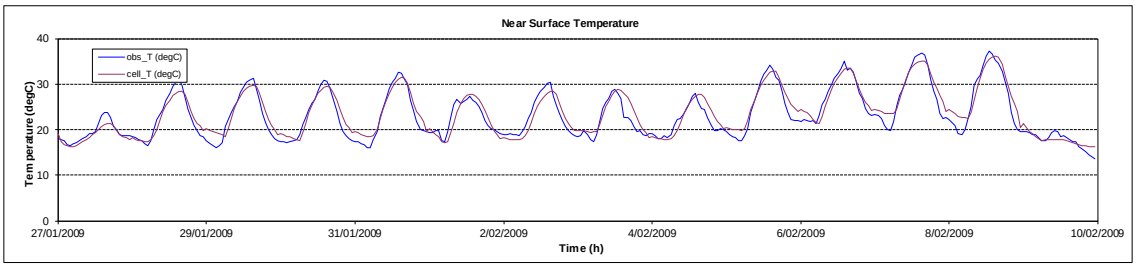


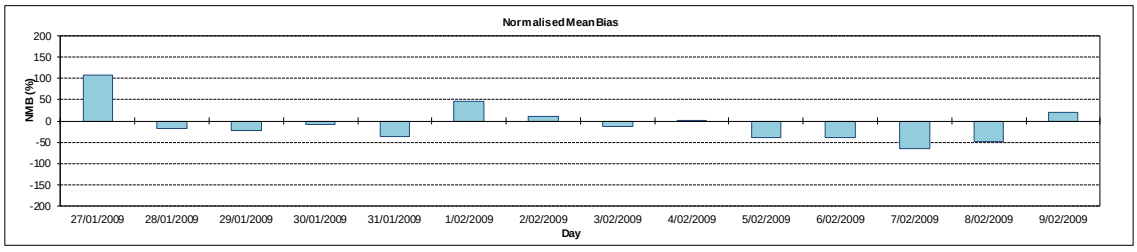
C.3.11 Oakdale – NO_2

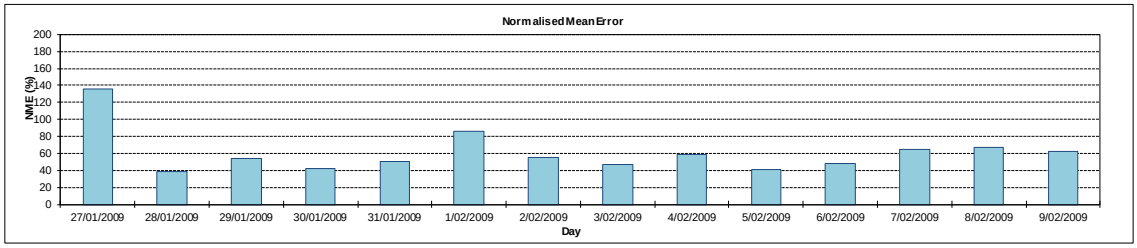




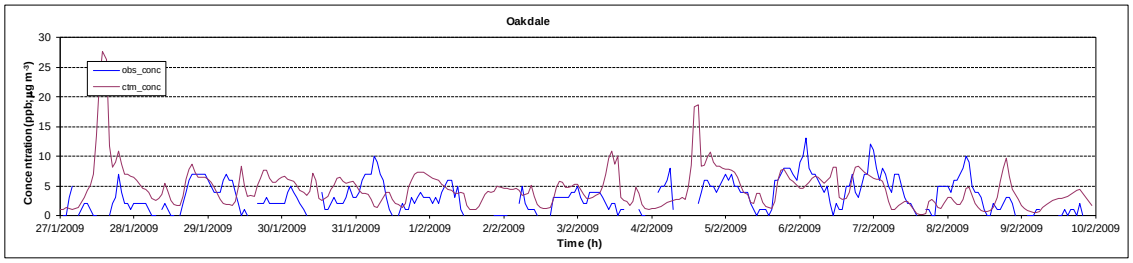


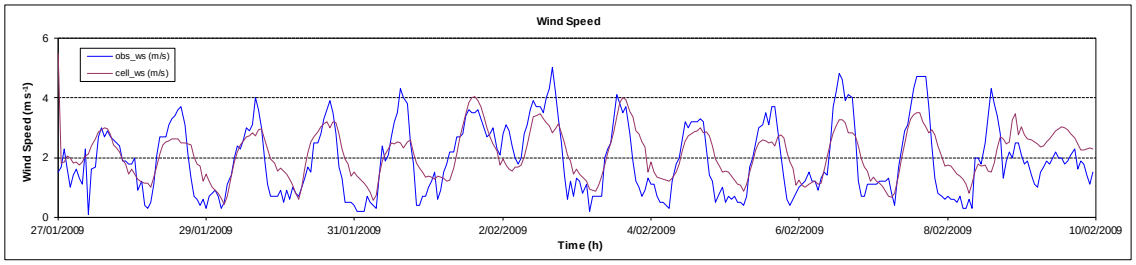


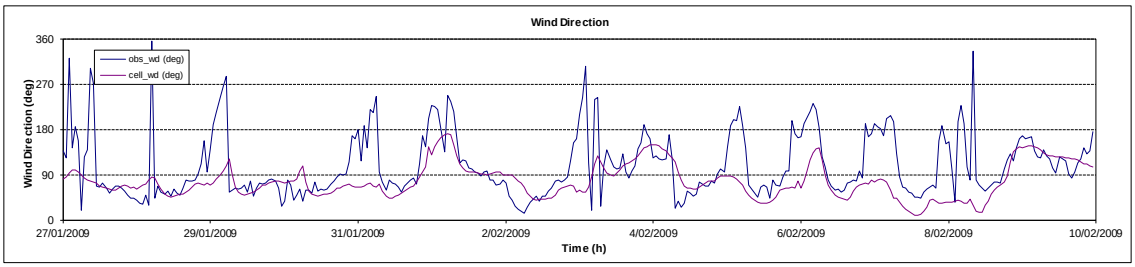


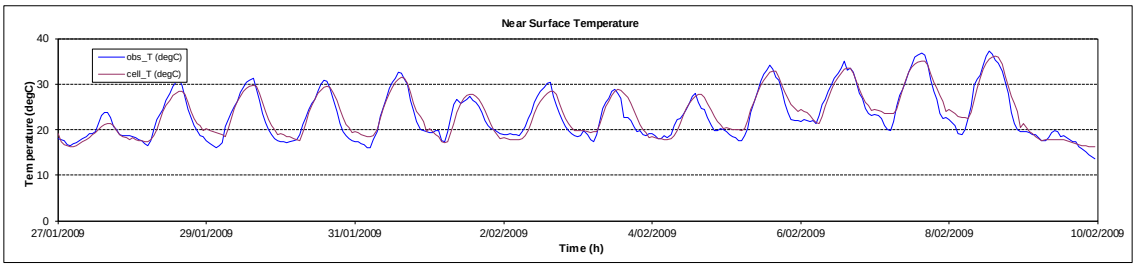


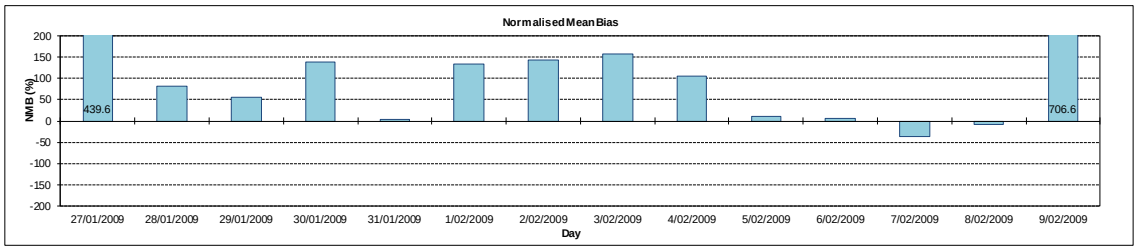
C.3.12 Oakdale – NO_x

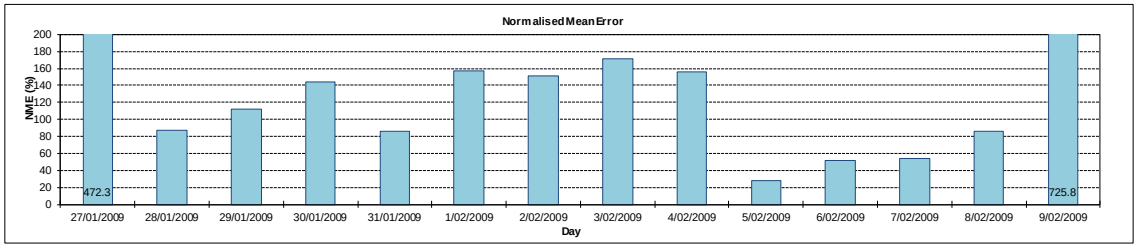




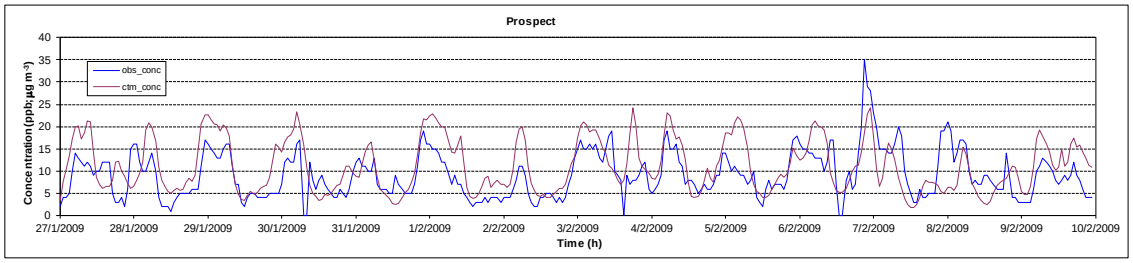


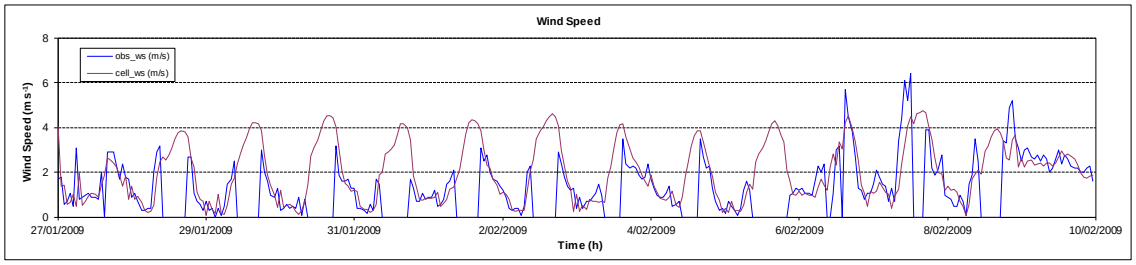


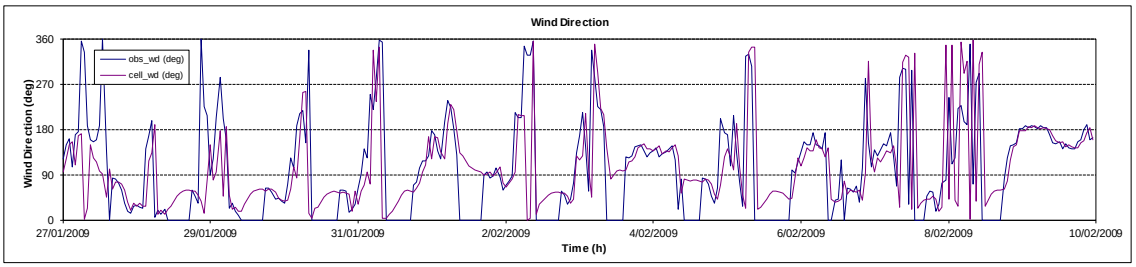


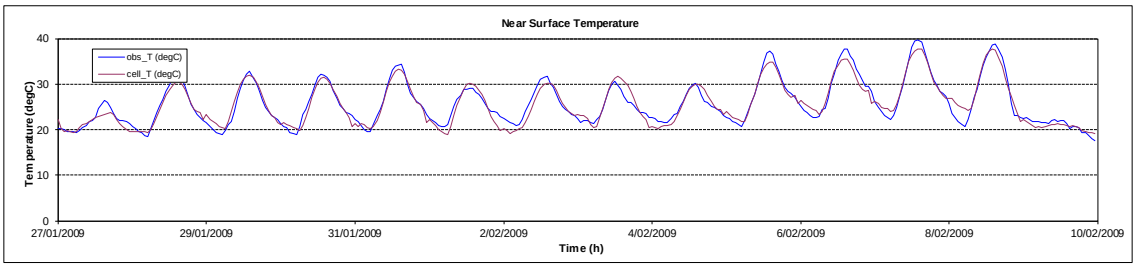


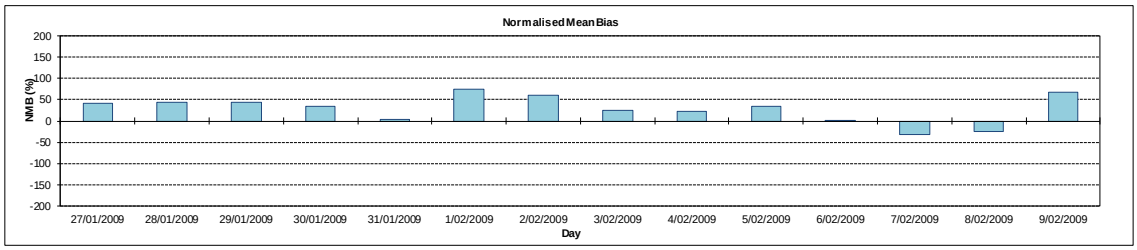
C.3.13 Prospect – NO_2

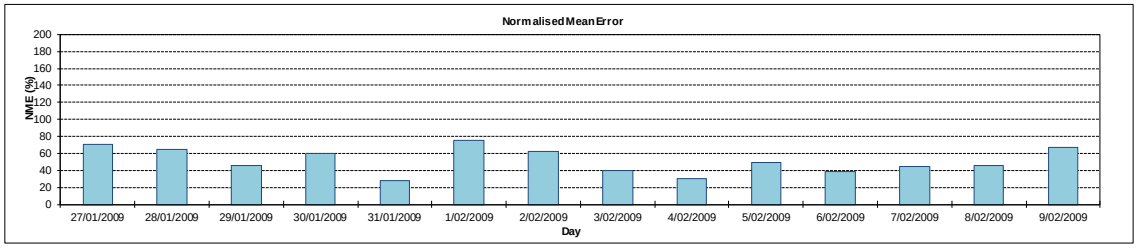




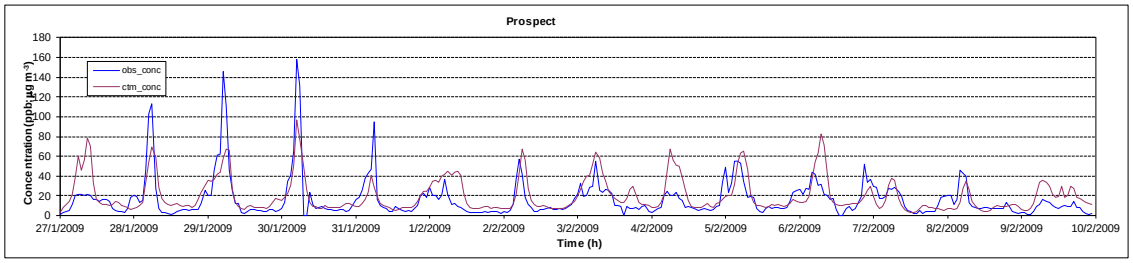


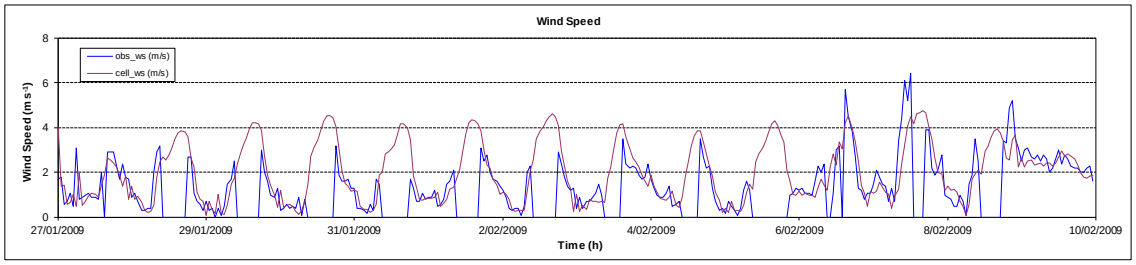


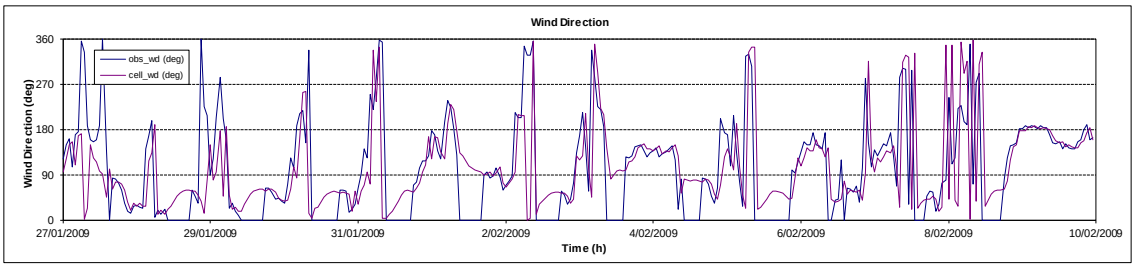


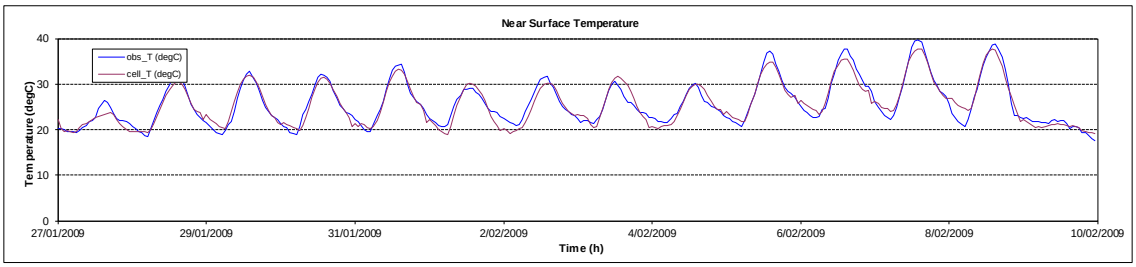


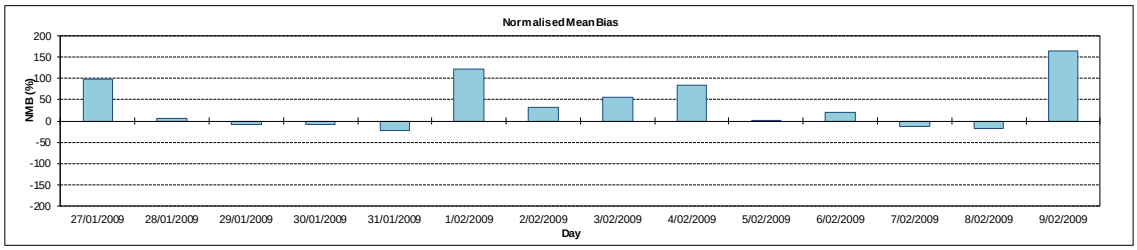
C.3.14 Prospect – NO_x

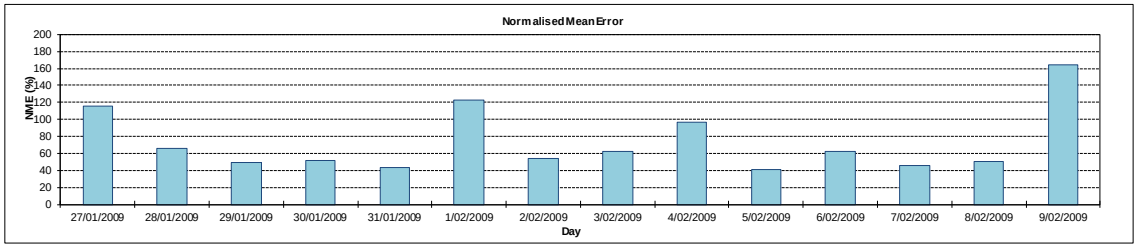




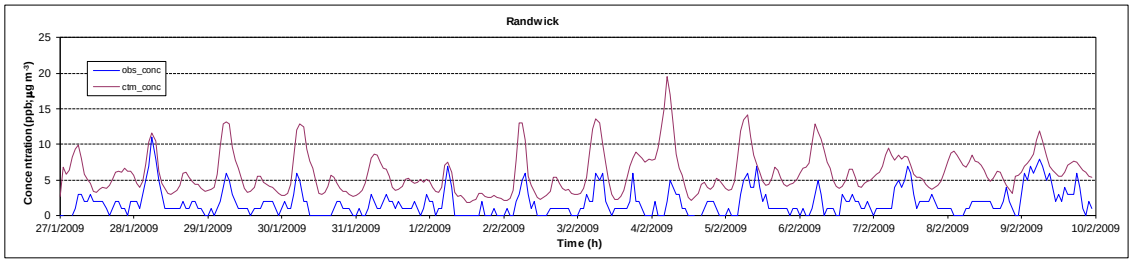


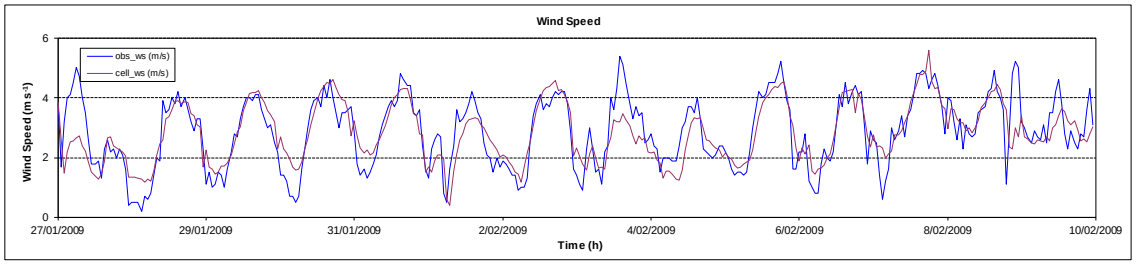


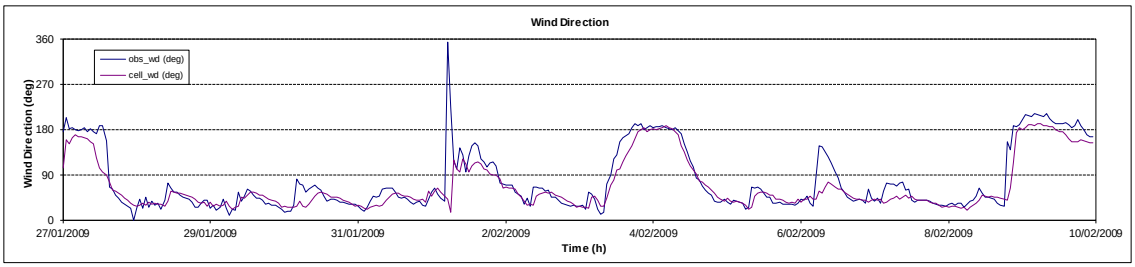


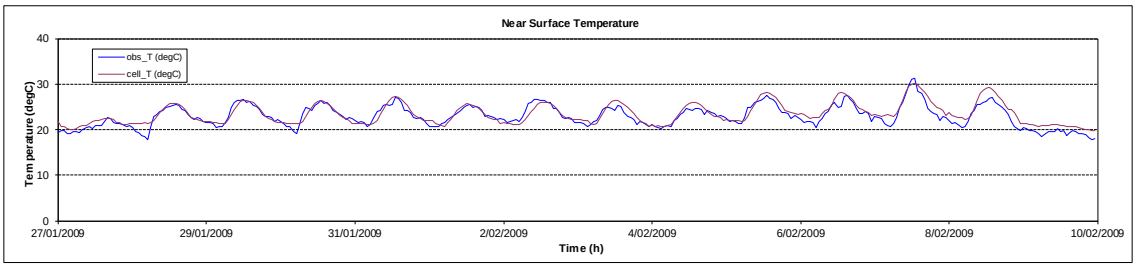


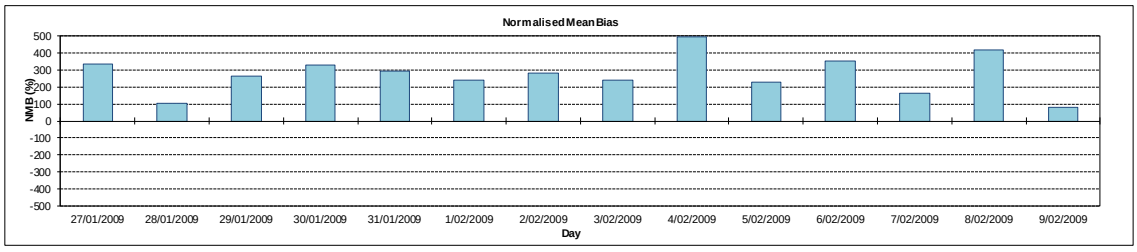
C.3.15 Randwick – NO_2

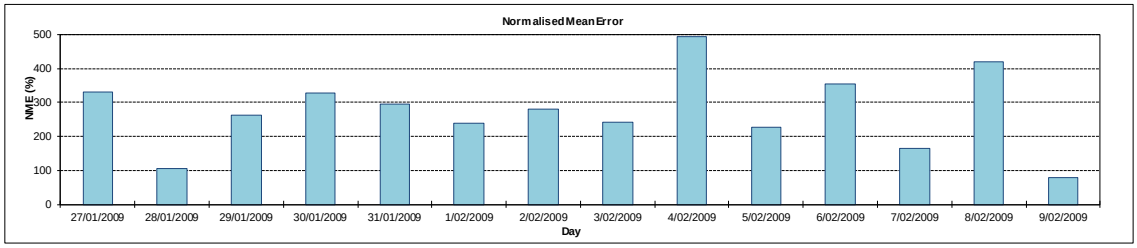




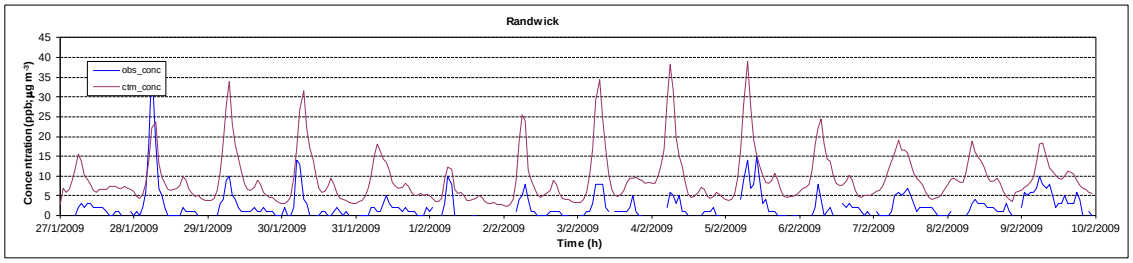


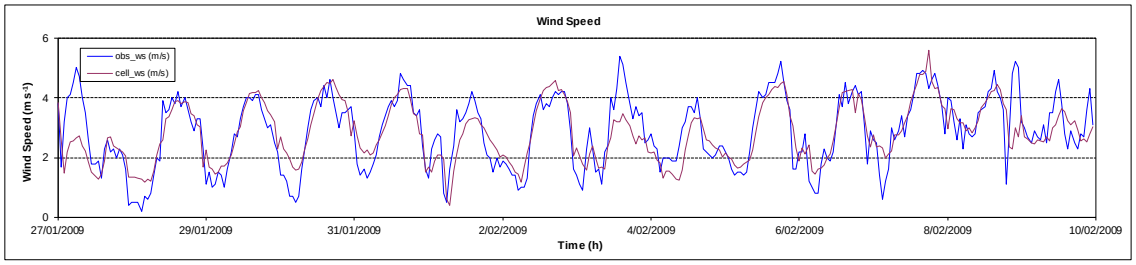


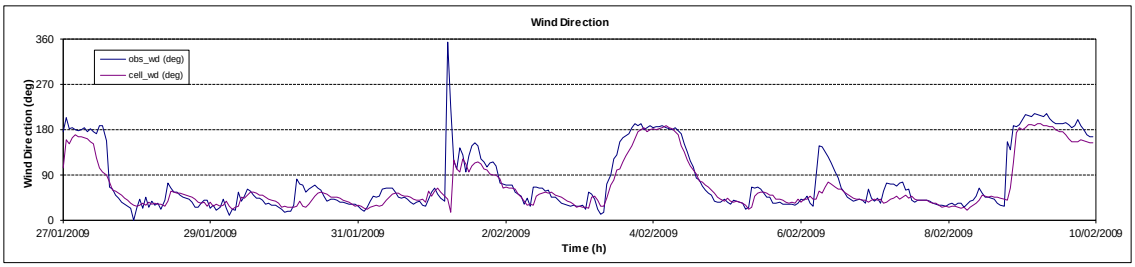


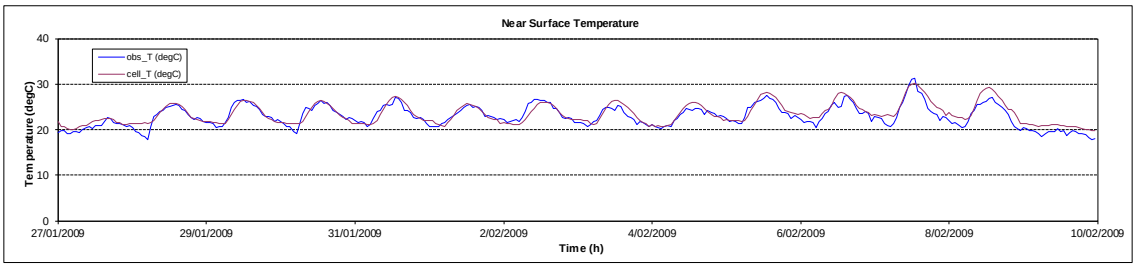


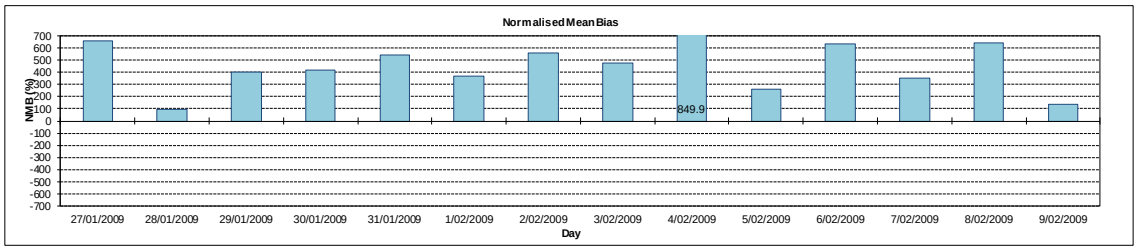
C.3.16 Randwick – NO_x

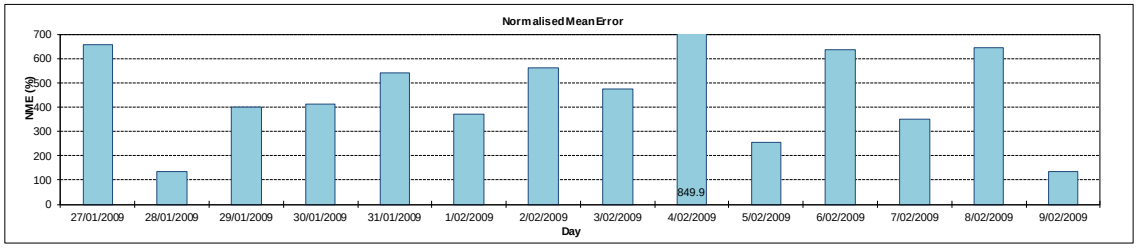




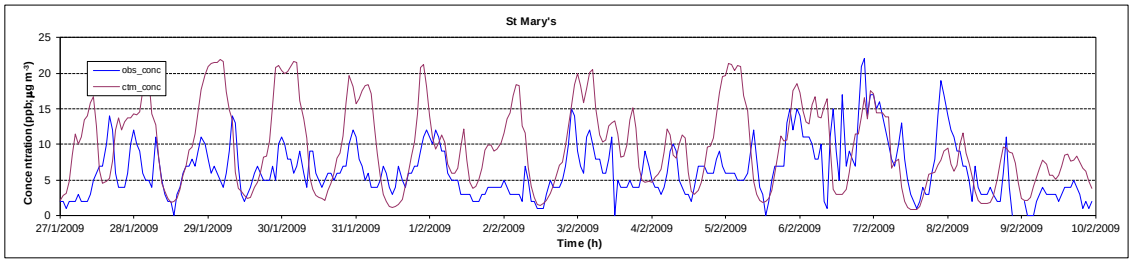


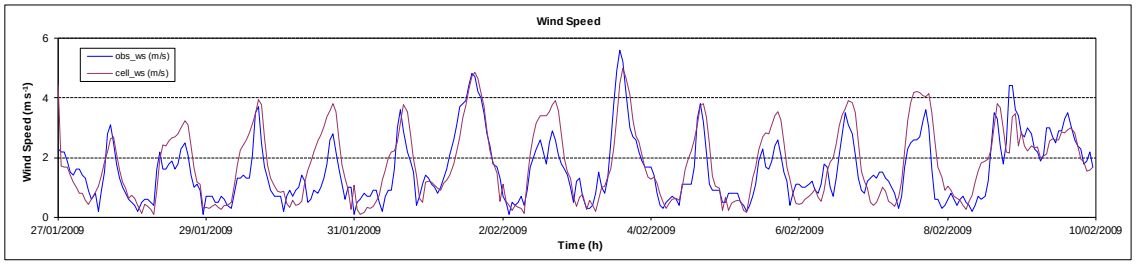


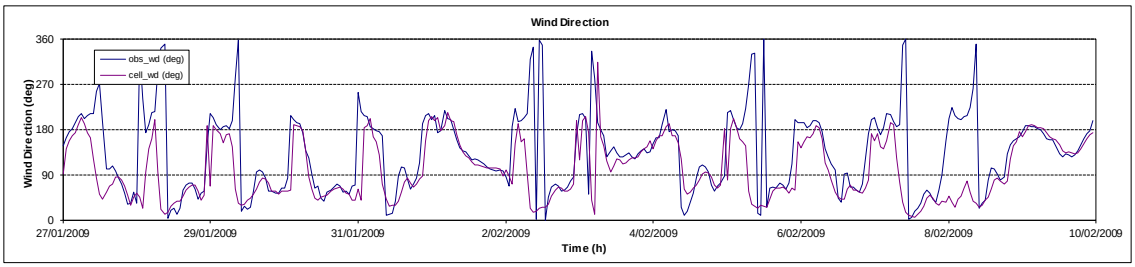


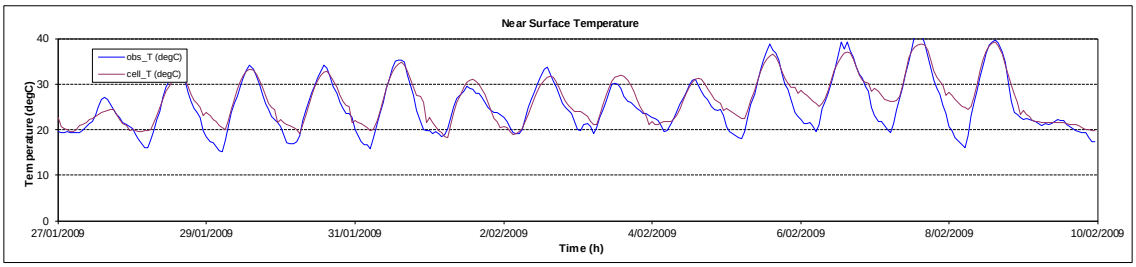


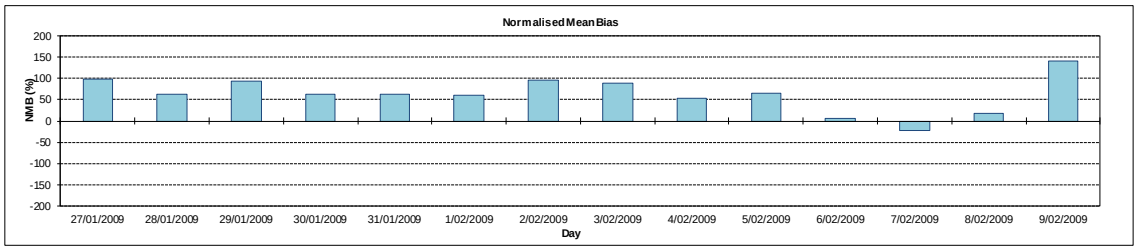
C.3.17 St Marys – NO_2

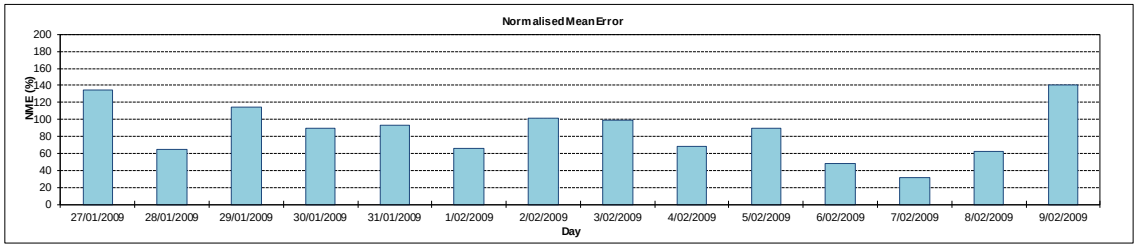




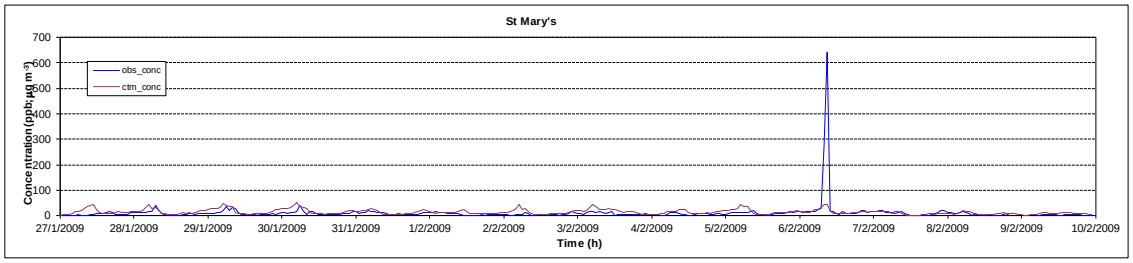


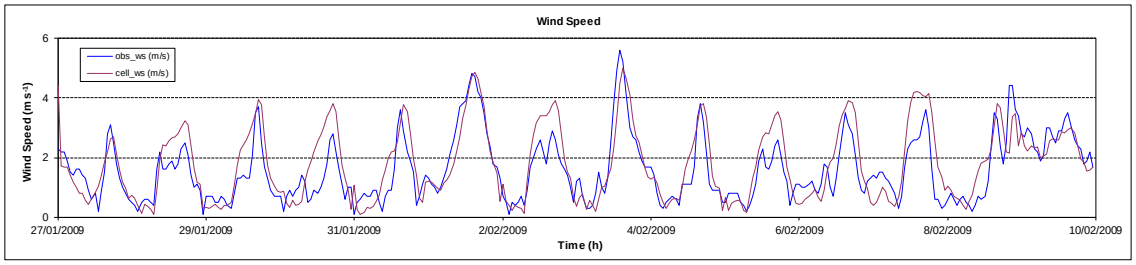


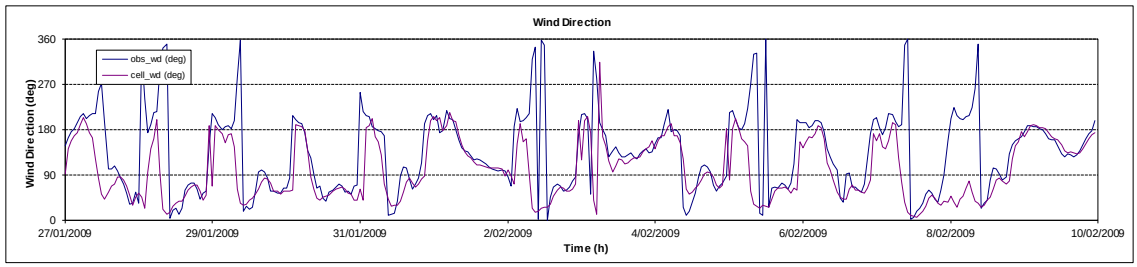


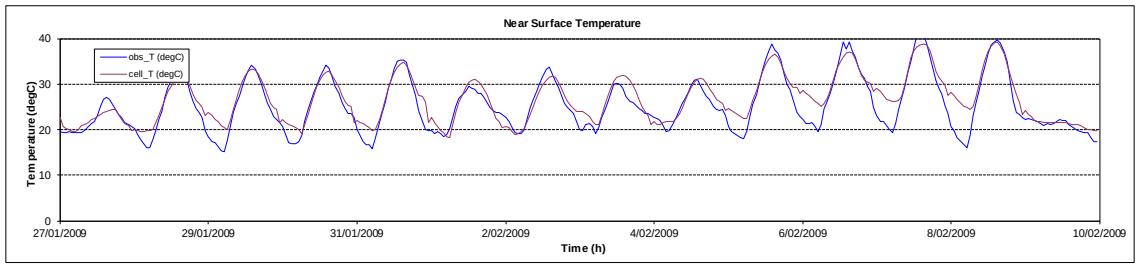


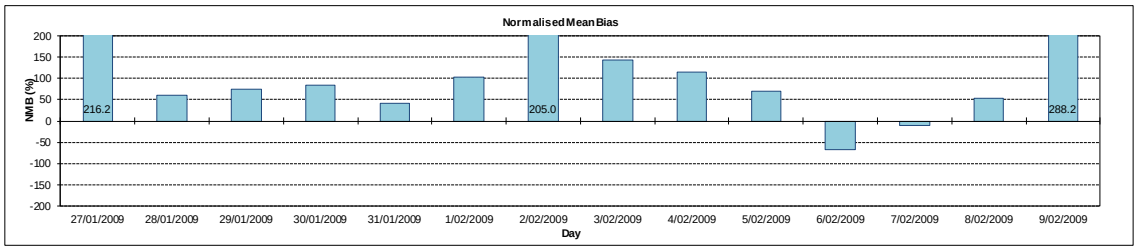
C.3.18 St Marys – NO_x

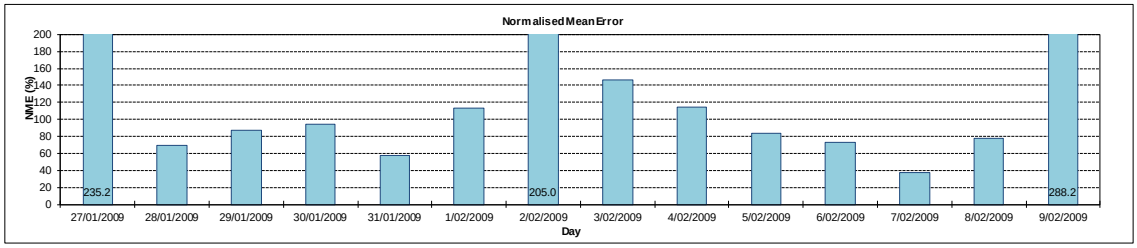




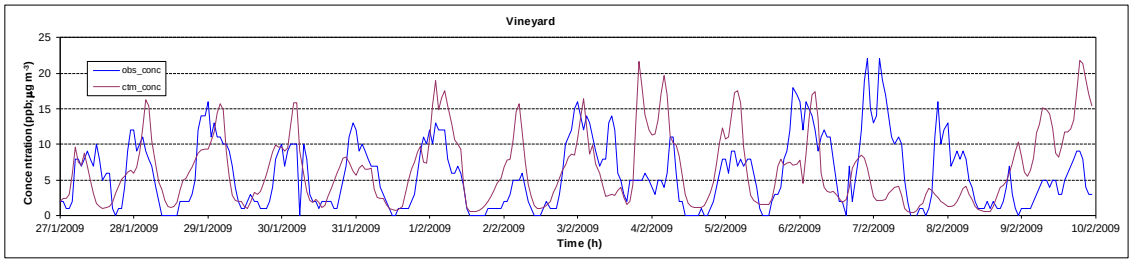


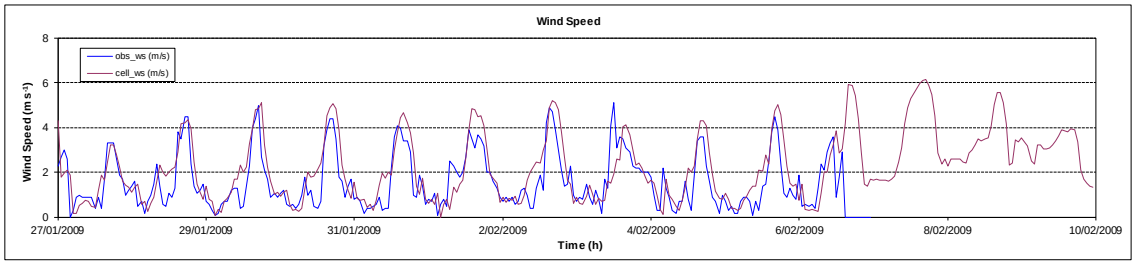


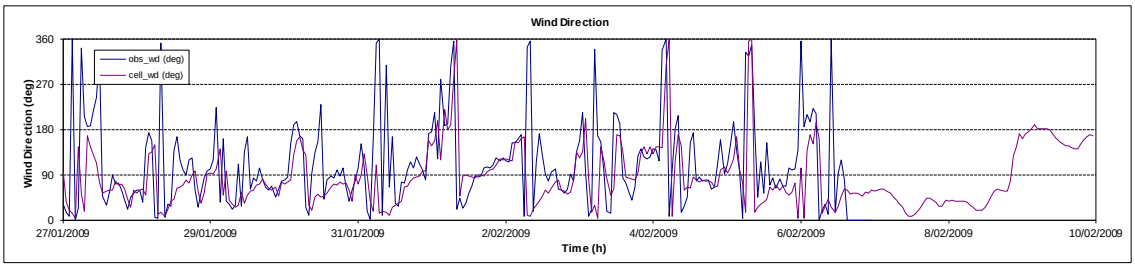


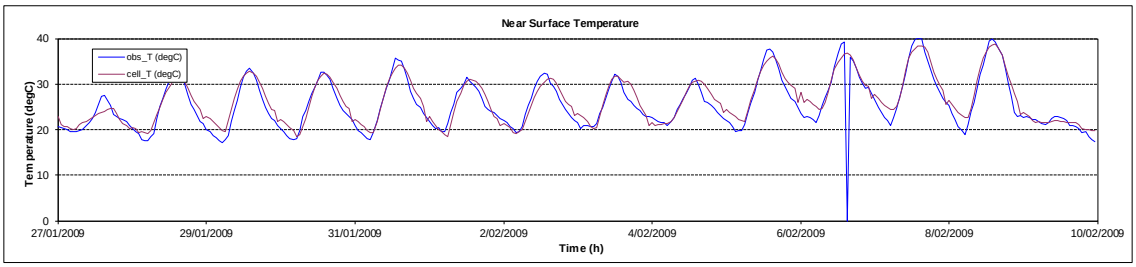


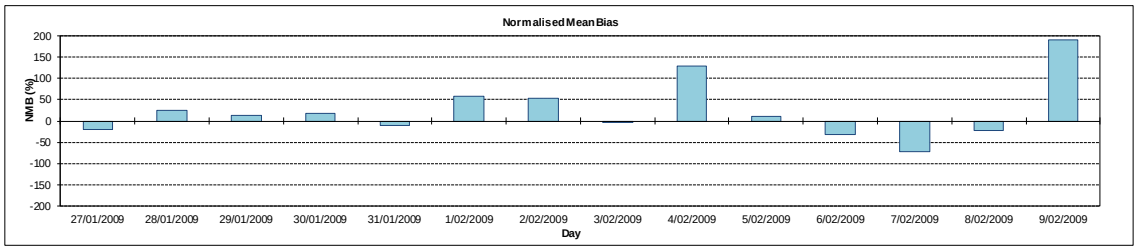
C.3.19 Vineyard – NO_2

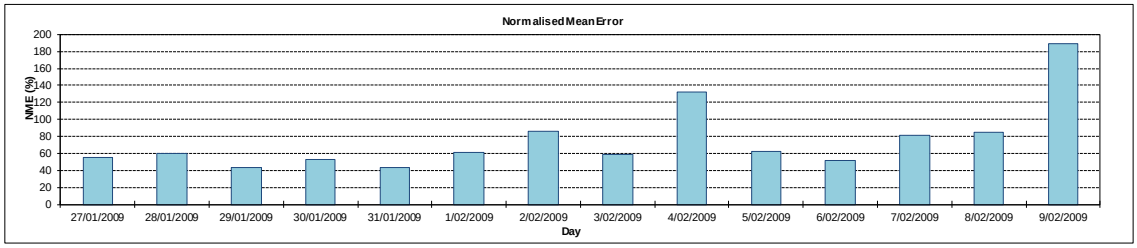




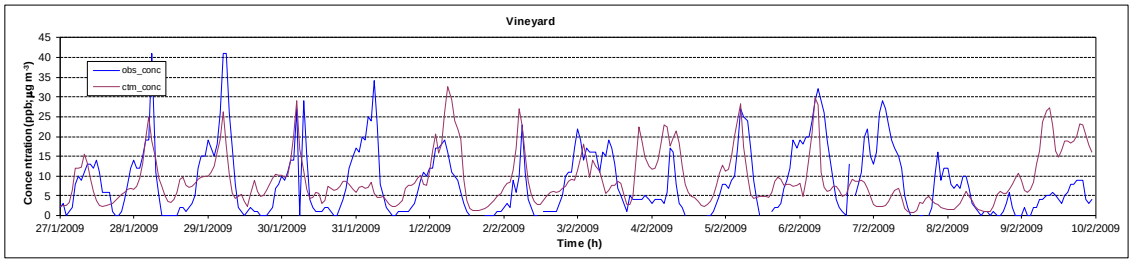


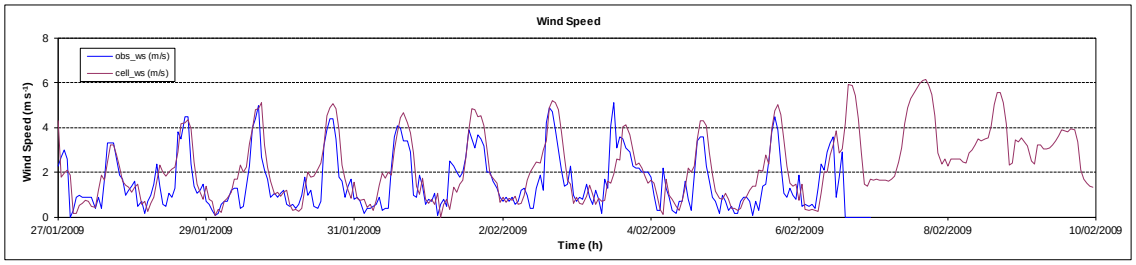


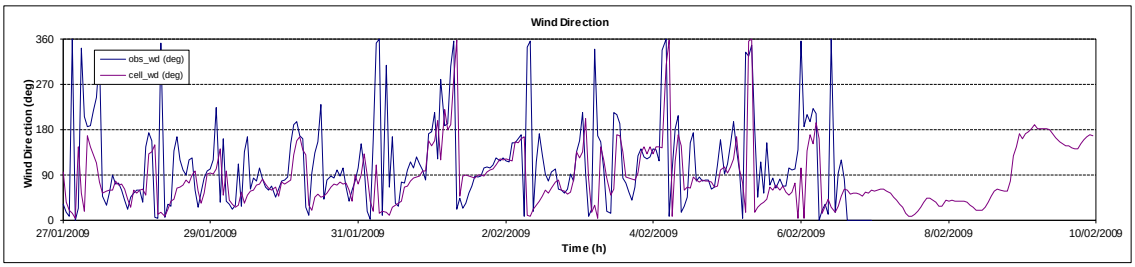


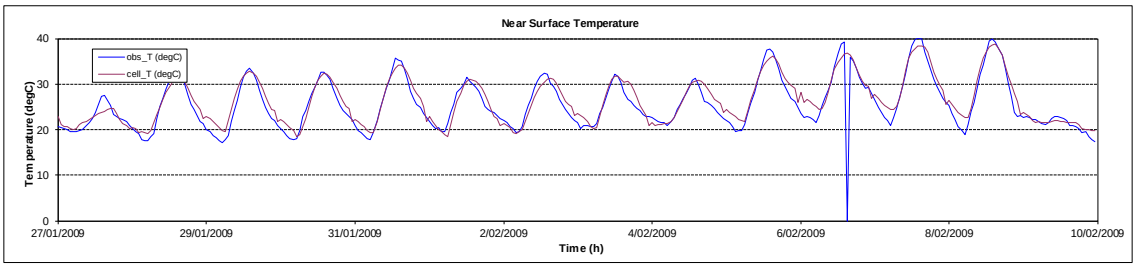


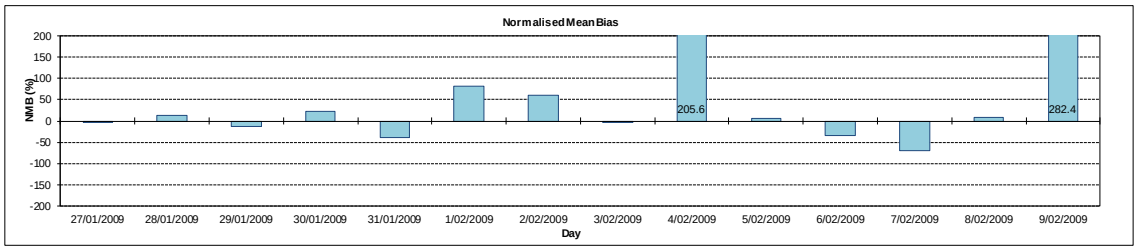
C.3.20 Vineyard – NO_x

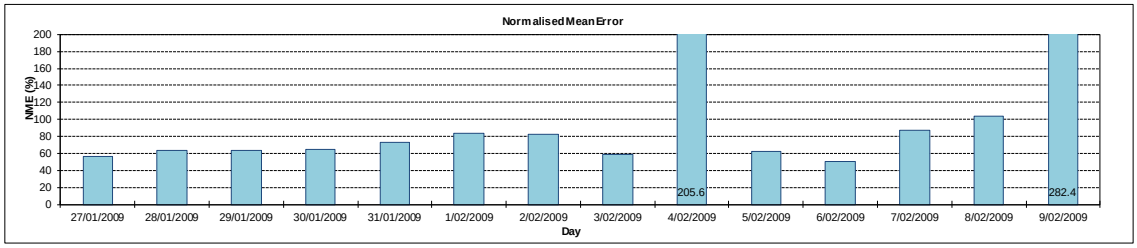






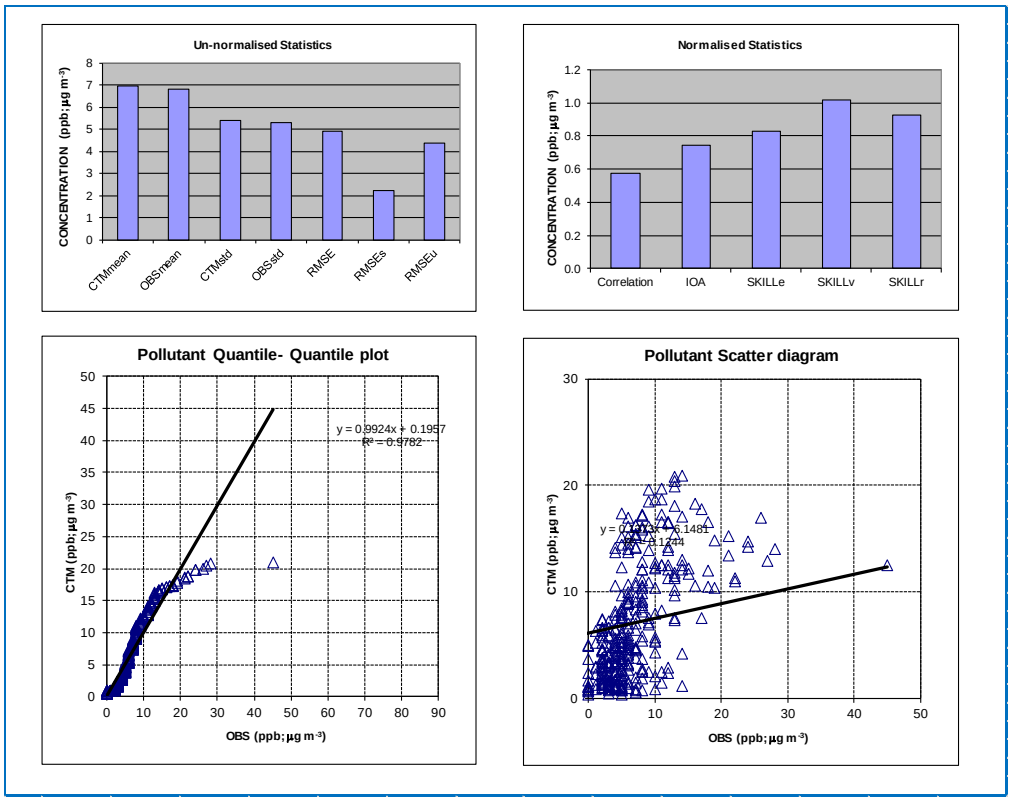




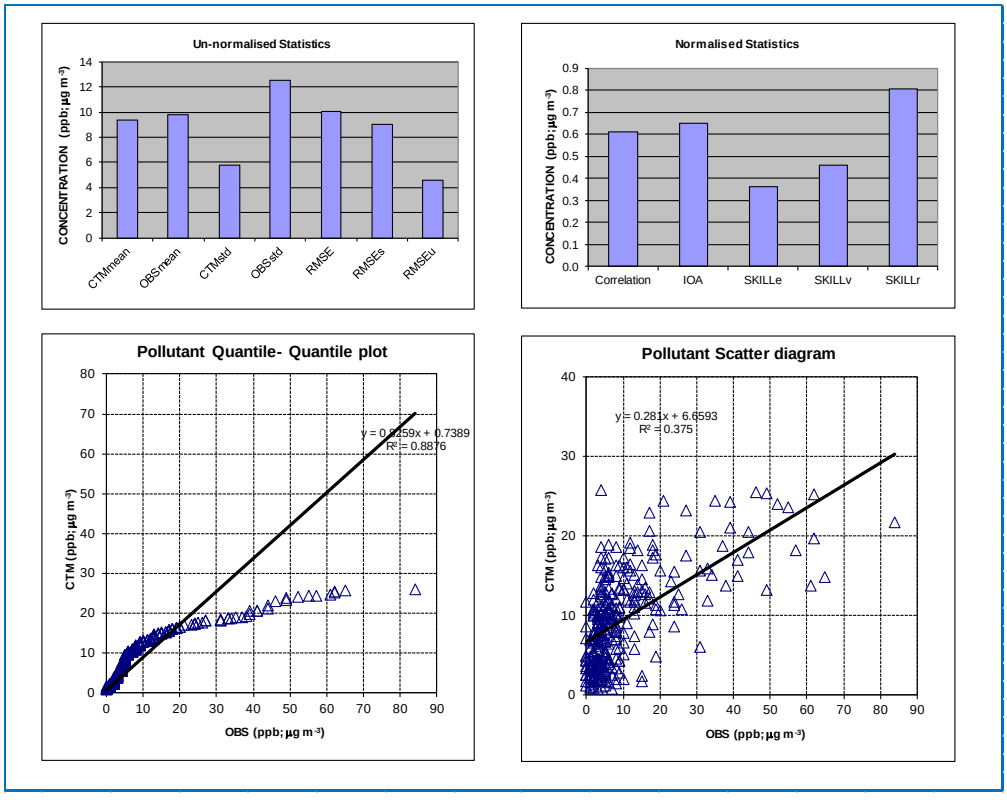


C.4 STATISTICAL EVALUATION OF OBSERVED AND PREDICTED

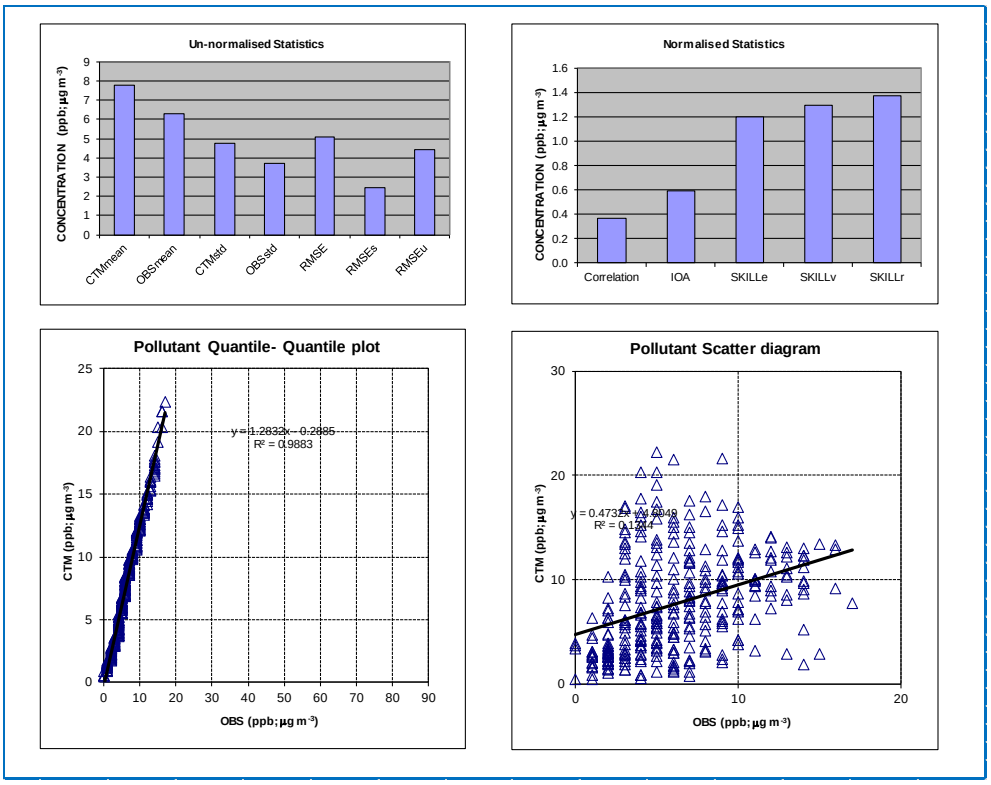
C.4.1 Bargo – NO_2



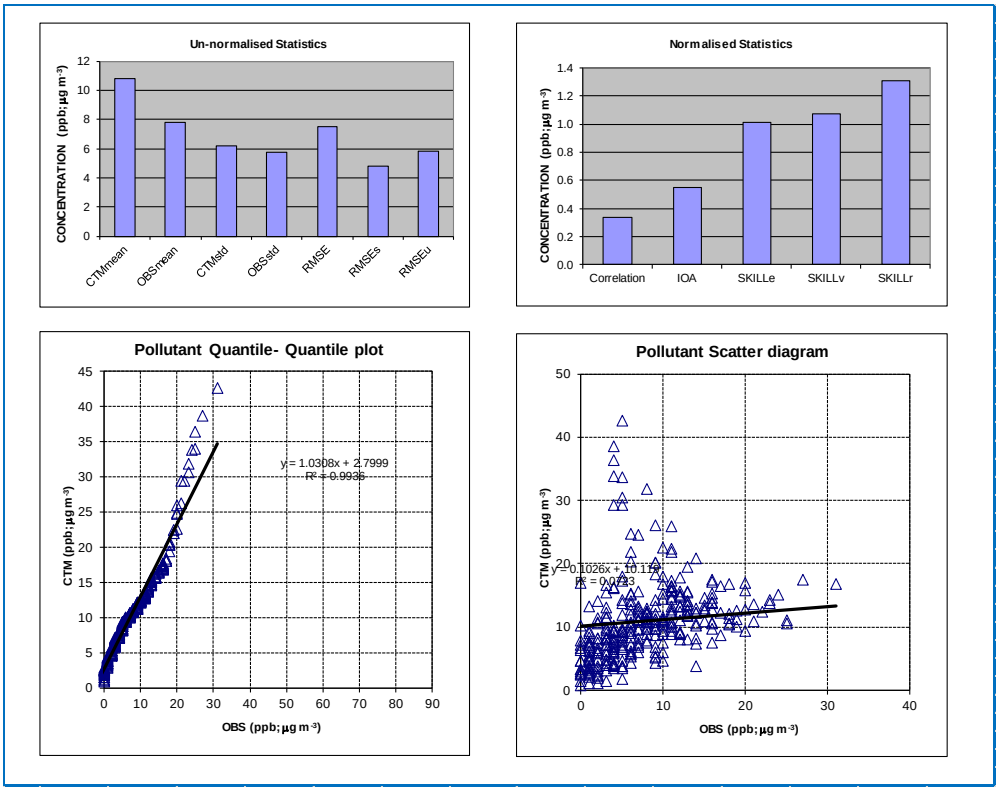
C.4.2 Bargo – NO_x



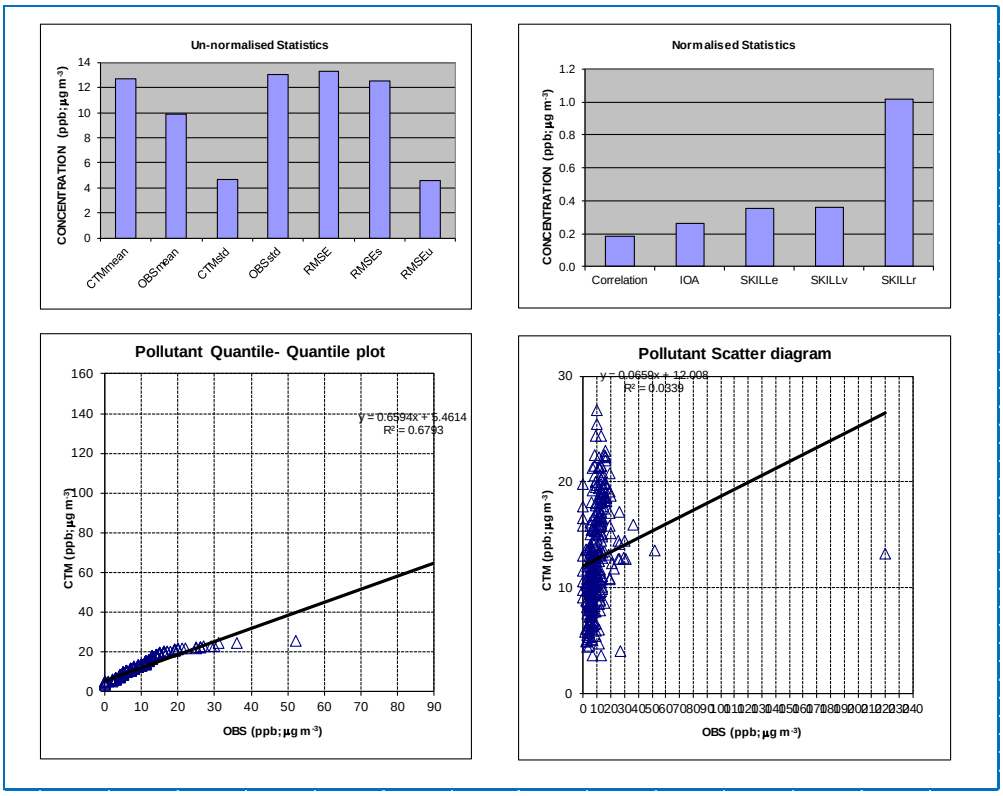
C.4.3 Bringelley – NO_2



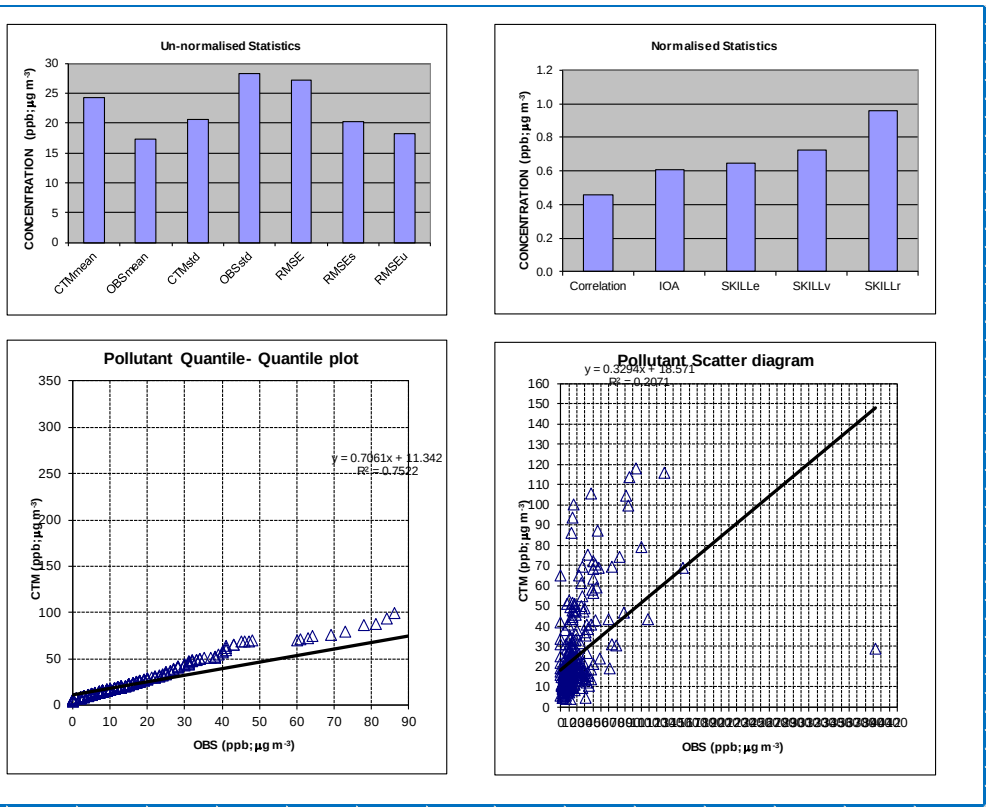
C.4.4 Bringelley – NO_x



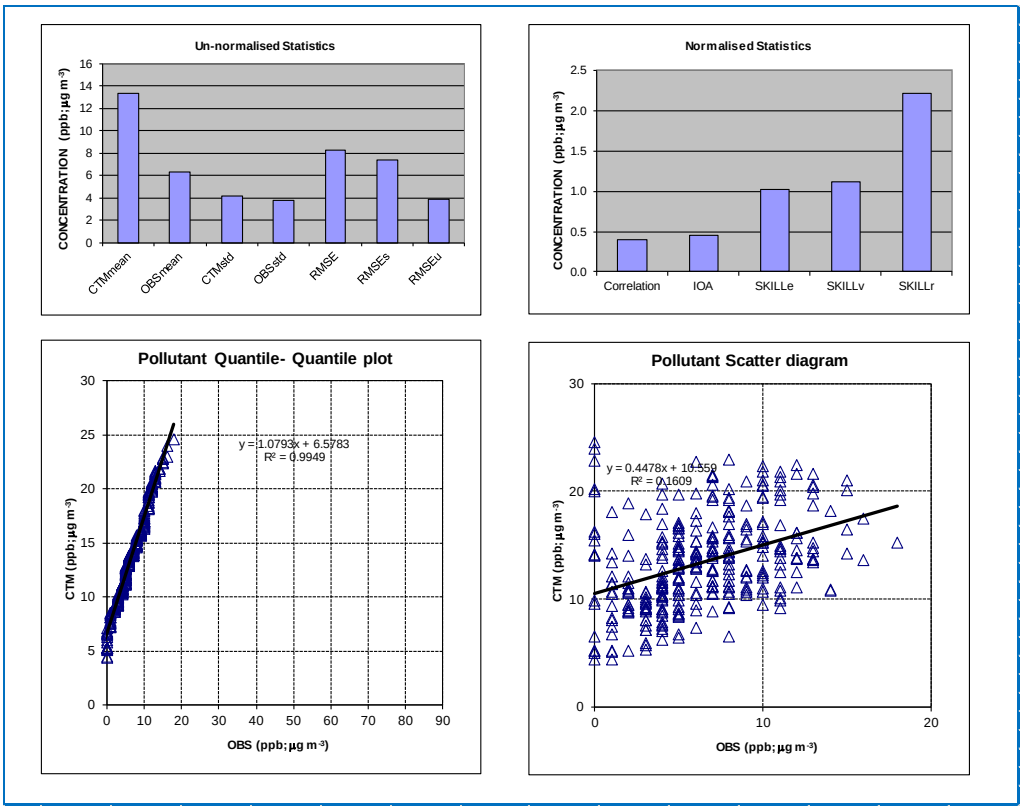
C.4.5 Chullora – NO_2



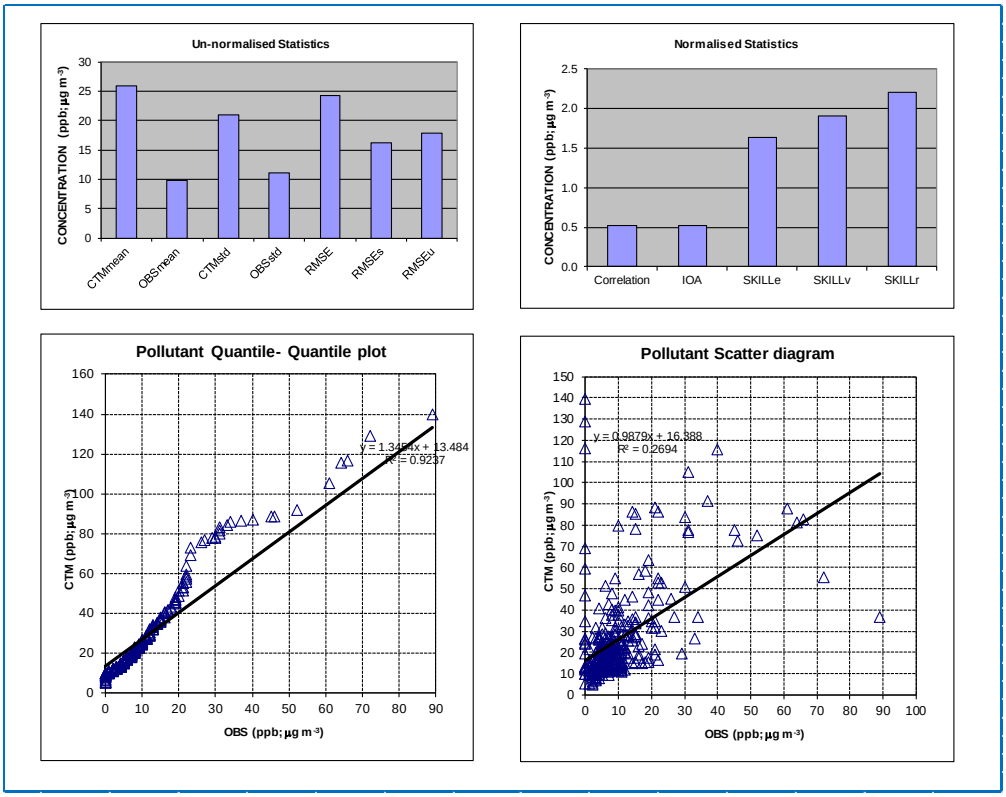
C.4.6 Chullora – NO_x



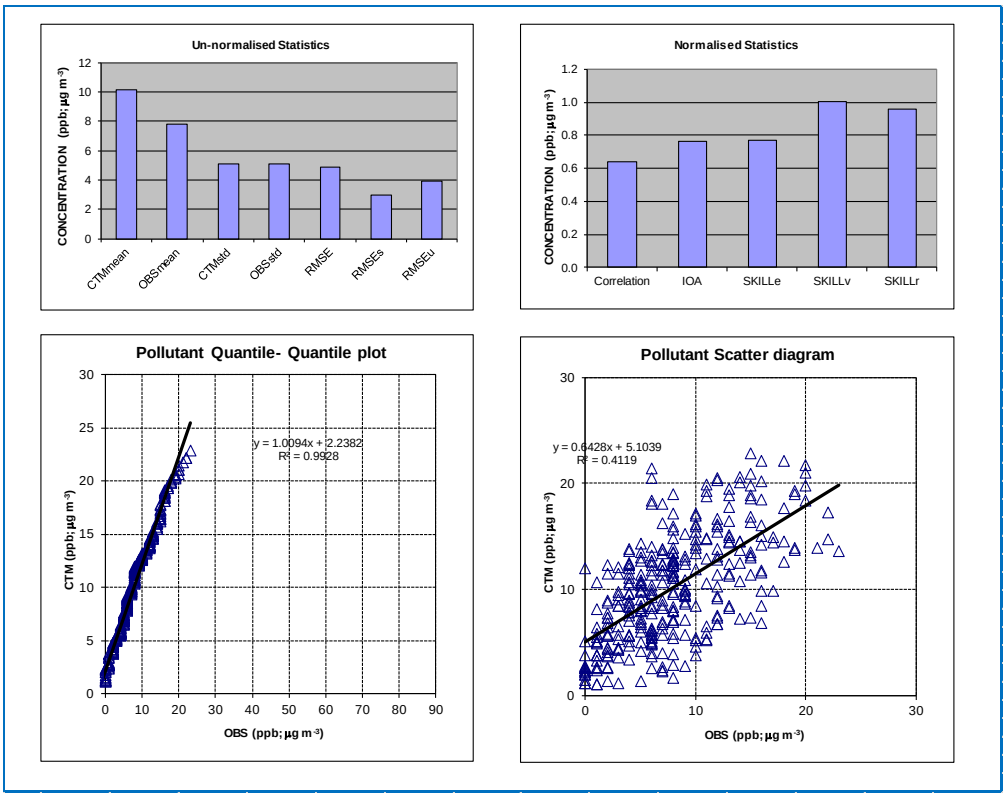
C.4.7 Earlwood – NO_2



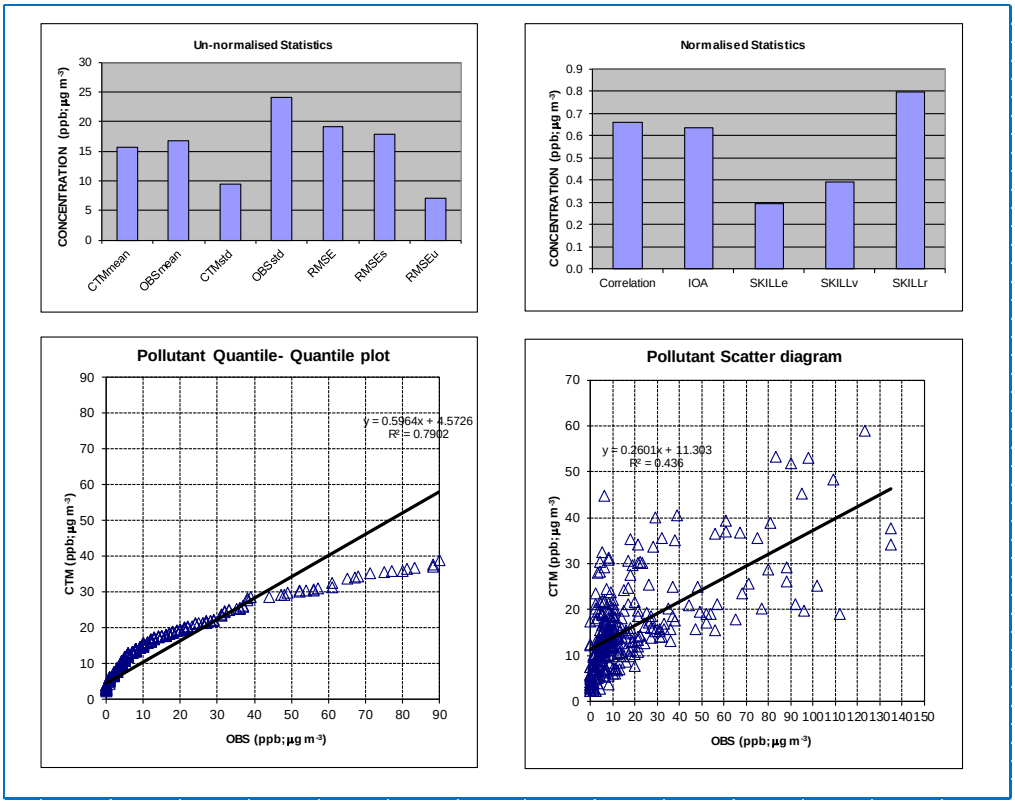
C.4.8 Earlwood – NO_x



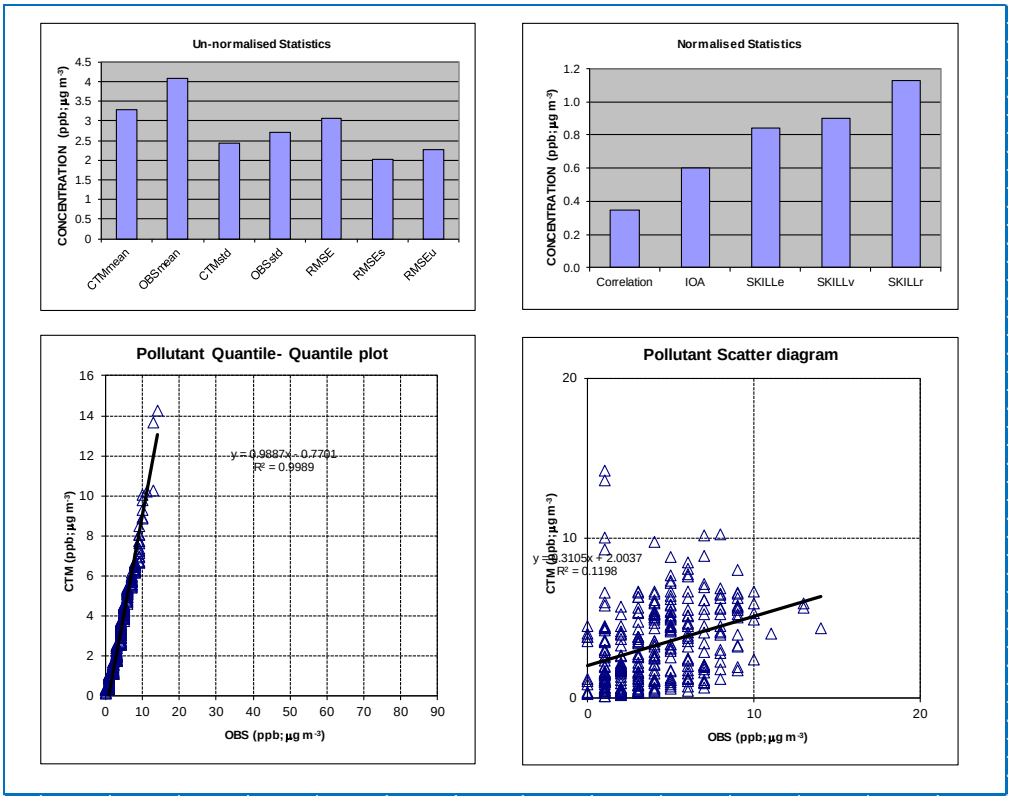
C.4.9 Macarthur – NO_2



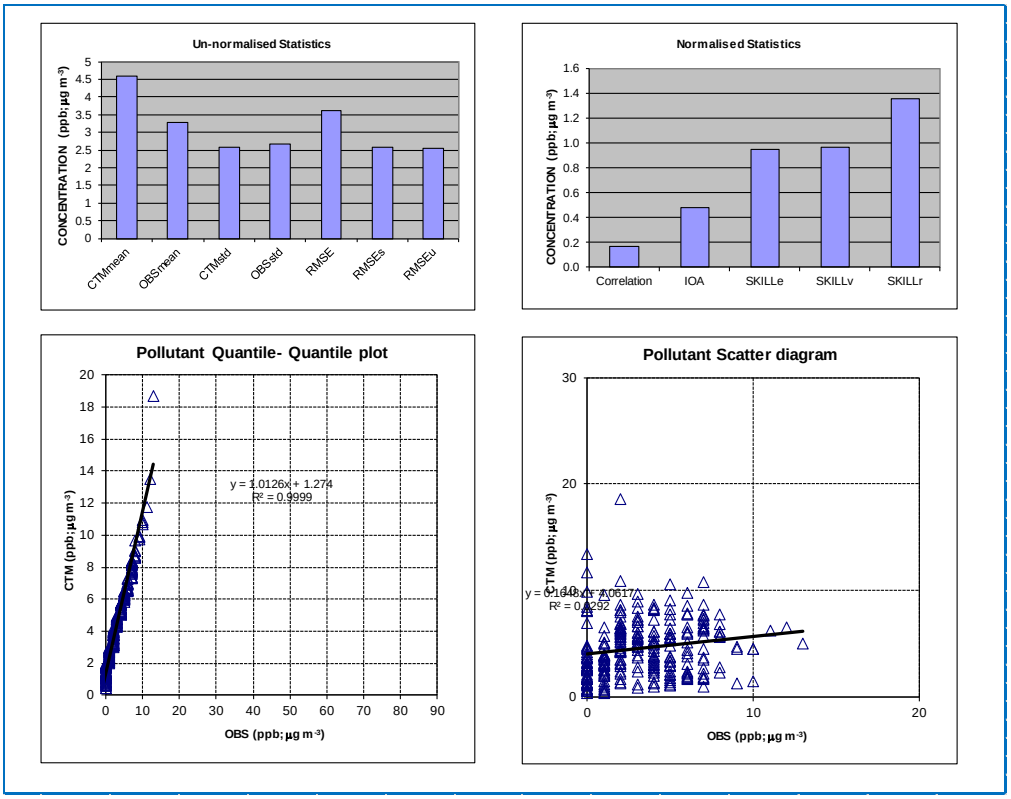
C.4.10 Macarthur – NO_x



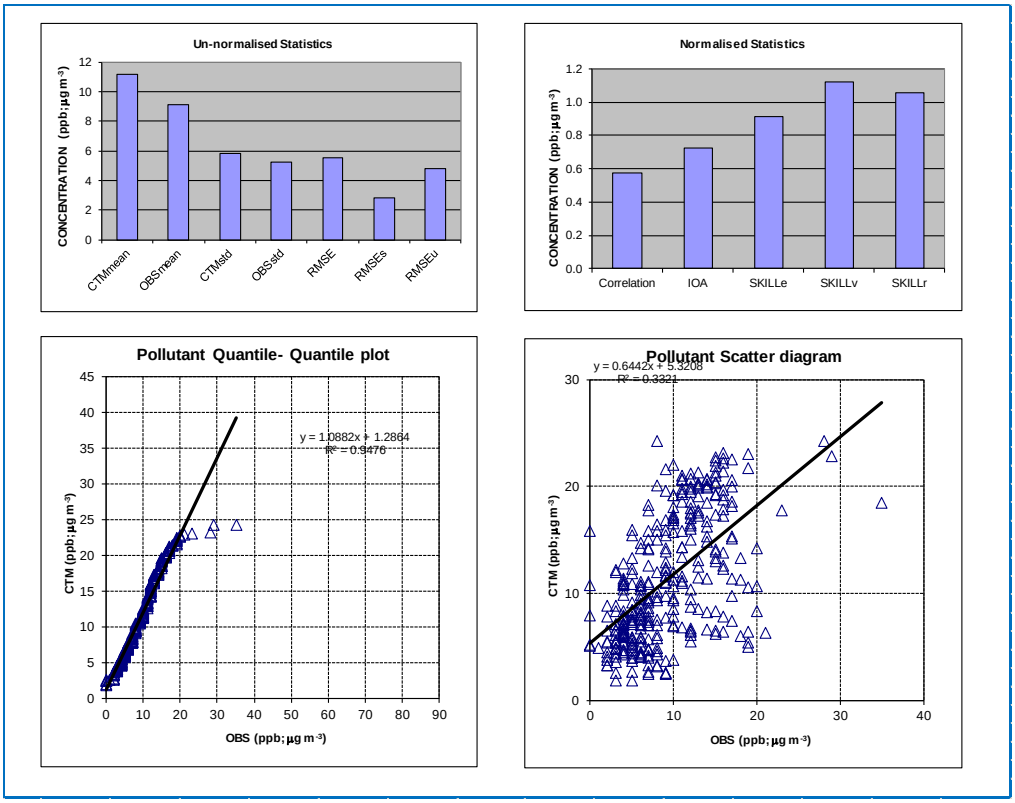
C.4.11 Oakdale – NO_2



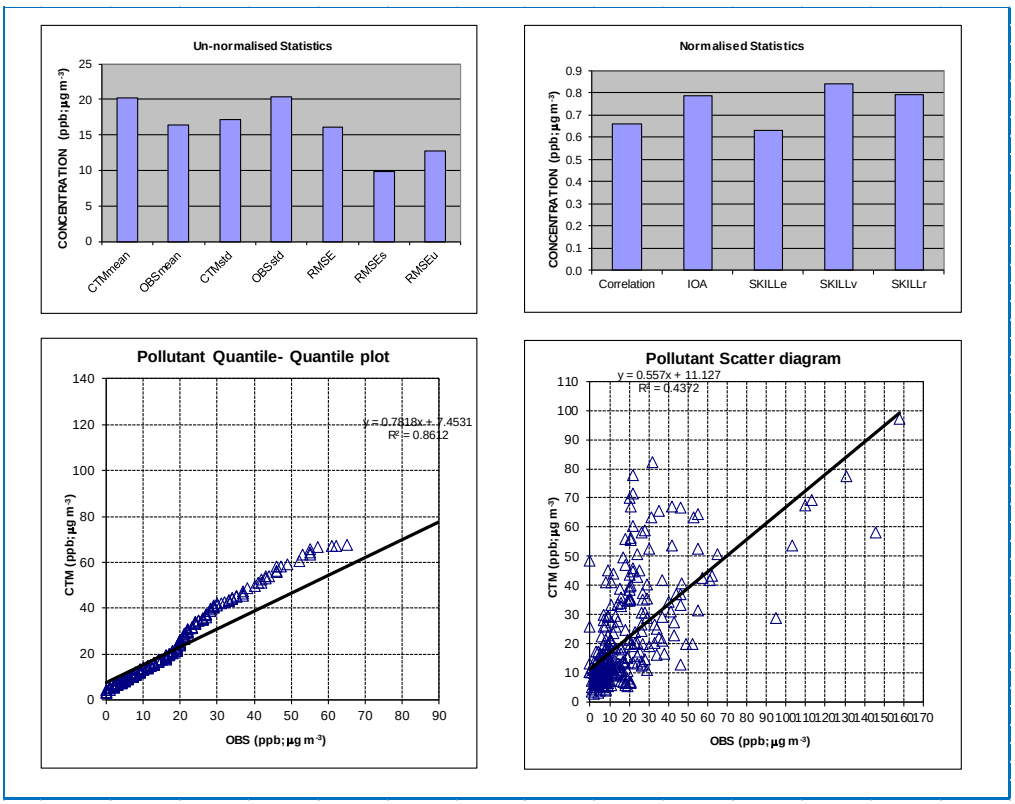
C.4.12 Oakdale – NO_x



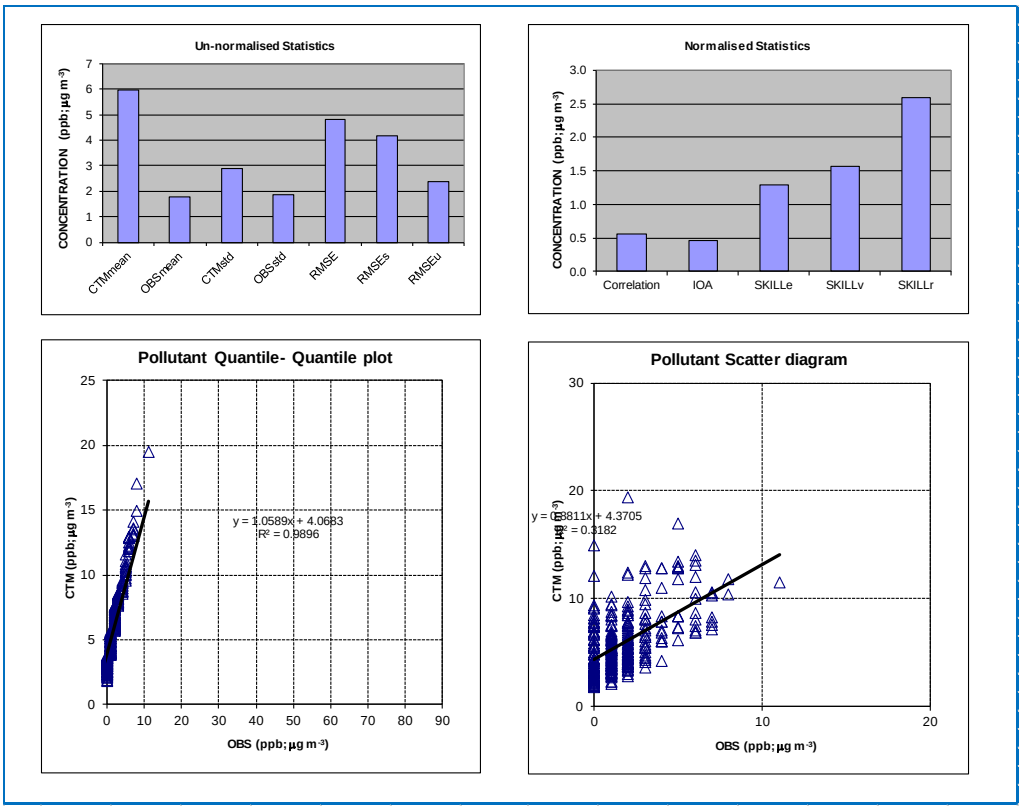
C.4.13 Prospect – NO_2



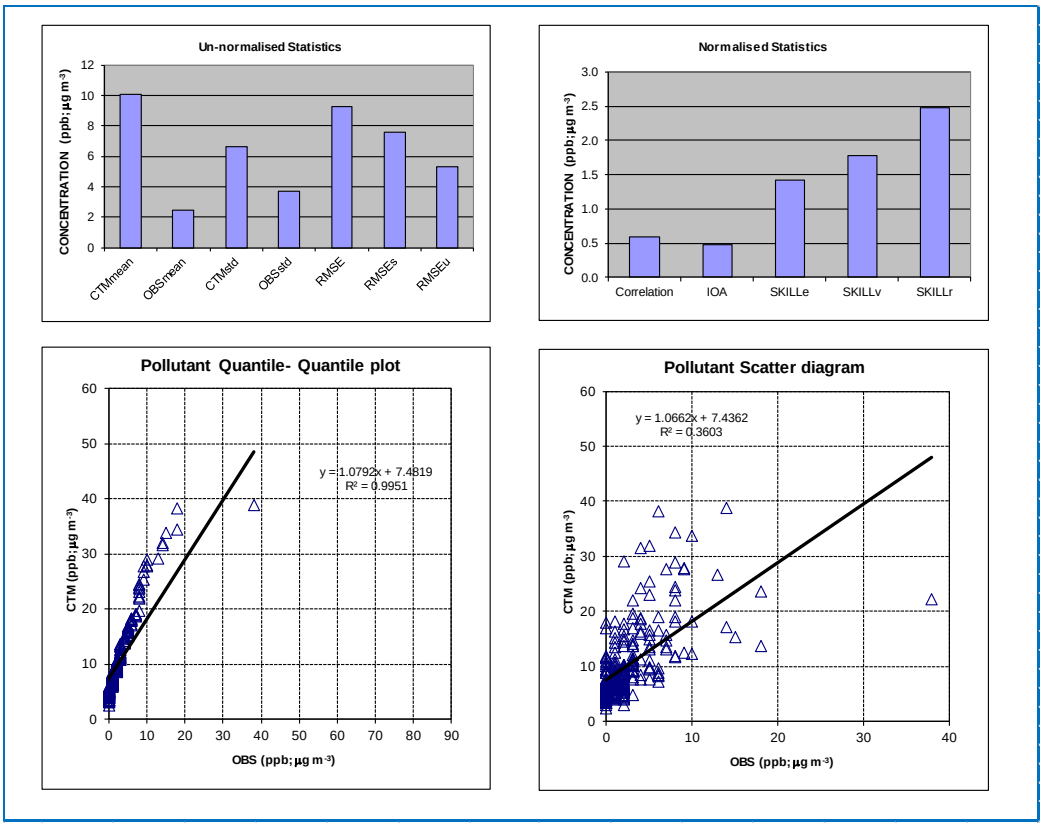
C.4.14 Prospect – NO_x



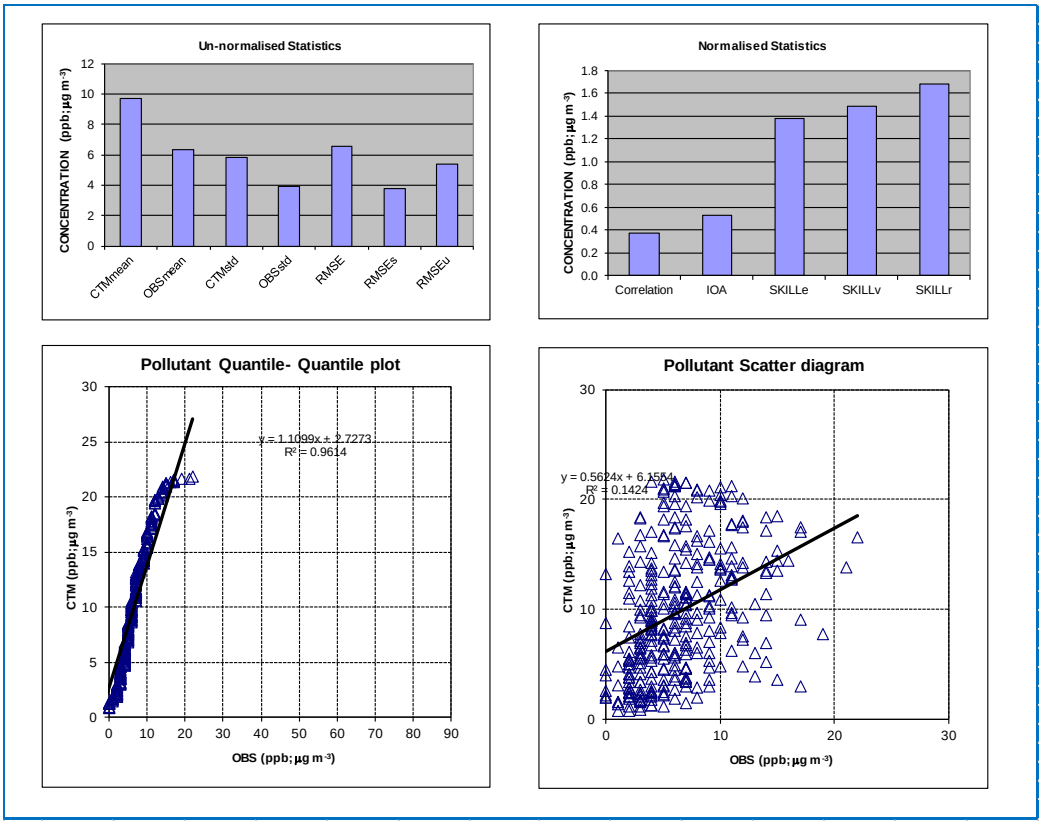
C.4.15 Randwick – NO_2



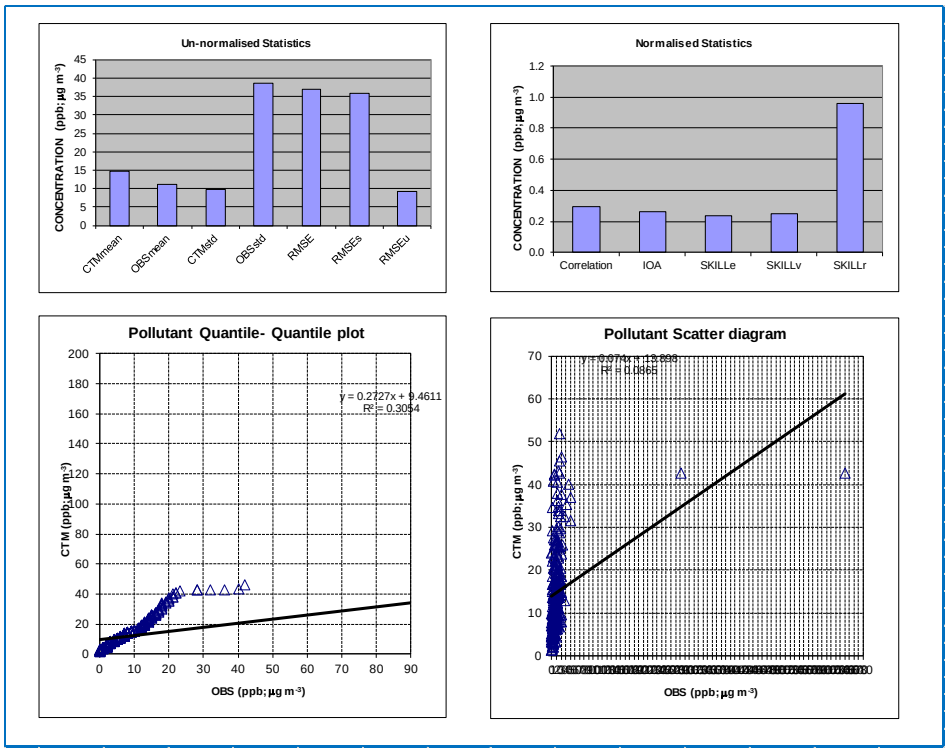
C.4.16 Randwick – NO_x



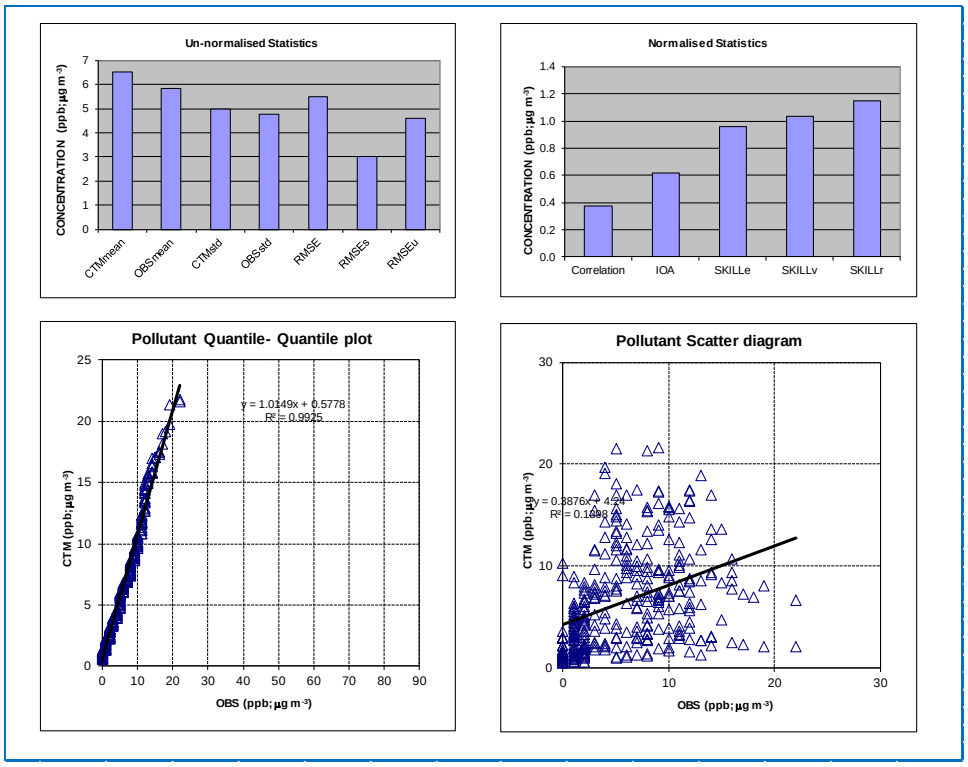
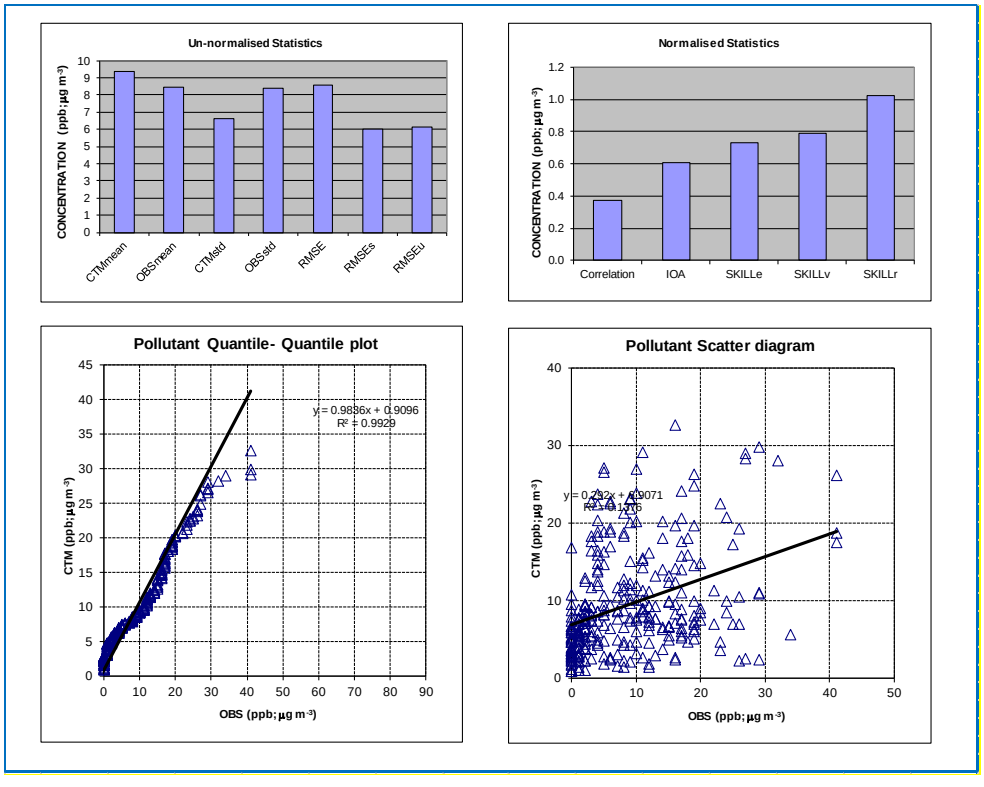
C.4.17 St Marys – NO_2



C.4.18 St Marys – NO_x



C.4.19 Vineyard – NO_2



C.4.20 Vineyard – NO_x