

Modelling October 2013 bushfire pollution episode in New South Wales, Australia

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Abstract -

From mid-October 2013 to the beginning of November 2013, New South Wales (NSW) experienced a significant sustained bushfire spring period in the Blue Mountains, the Central Coast and the Southern Highland causing property damages in those areas, and high pollution (particle and ozone) episodes over the metropolitan areas of Sydney.

This paper studied the extent of the air pollution due to the October 2013 bushfire using data from various sources as well as meteorological modelling to understand the course of bushfire and its effect on air quality in Sydney. Satellite images of smokes and burned areas obtained from MODIS Terra/Aqua satellites together with predicted wind from the WRF (Weather Research Forecast) model at different height levels and the measured meteorological and air quality data collected from the monitoring stations in the Sydney region will be used to give a complete picture of the extent of the effect of bushfire on air quality in the Sydney and surrounding areas..

Keywords -

NSW bushfire, WRF meteorological model, particle air pollution, MODIS Aqua/Terra satellites.

Introduction

Australia, except in the north east, is mostly a dry continent. The weather, especially rainfall, is driven by the four main climate drivers: the ENSO (El-Nino Southern Oscillation), the SAM (Southern Annular Mode), the PDO (Pacific Decadal Oscillation) and the IOD (Indian Ocean Dipole). On the East Coast of Australia, the ENSO strongly affect the rainfall pattern. During the El-Nino period, drought occurs throughout most of regions in New South Wales and Victoria. And bushfires have been a part of life in Australia for

millions of years, particularly in the south east of the country which is regarded as perhaps the most bushfire-prone region on the planet. Serious fires occurred frequently and depending on location with return period ranging from 10 years for the Blue Mountains, NSW to 13 years in Victoria (Cunningham, 1984).

On October 17th 2013, NSW experienced one of its worst bushfire day in 100 years, with major fires threatening property across NSW, including the Central Coast, Southern Highlands and the Blue Mountains. On October 23rd, the fires in the Blue Mountains had destroyed 208 properties, of which 193 homes were destroyed in the lower Blue Mountains town of Winmalee.

Three distinct phases of activity took place across this bushfire episode; from October 17-18, from October 23-27 and on November 2nd. Whilst spring bushfire episodes are uncommon, they are not unexpected in eastern NSW, as spring is part of the peak bushfire season (BOM, 2009). However, a significant proportion of media attention surrounding these fires revolved around the potential role of climate change in their occurrence. Whilst it is still difficult to attribute anthropogenic climate change to any particular climatic or meteorological event (Peterson et al, 2013), Australia's Climate Commission notes that parameters responsible for extreme bushfire weather in the country's south east have increased over the last third of a century. These conditions are anticipated to increase the frequency and intensity of bushfires in Australia as the climate changes (Hughes and Steffen, 2013).

As a direct consequence of bushfire activity, air quality in the Sydney Metropolitan area deteriorated as concentrations of PM_{2.5}, PM₁₀ (Particulate Matter less than 2.5 and 10µm) and ozone (O₃) increased. These observed augmentations in pollution concentrations are synchronous with the three phases of activity noted above.

The elevated concentration of air pollutants during high pollution episodes, such as bushfires, is strongly associated with high mortality and hospitalisation rates due to respiratory and cardiac diseases in the exposed population.

It is important to study these high pollution days in detail as this provides the basis to further develop the health exposure studies and to verify the development and prediction of the air quality modelling system.

The use of NOAA AVHRR and MODIS Terra/Aqua satellite images, observed data from monitoring sites in the Sydney Metropolitan area and wind modelling from the WRF meteorological model resulted in the ability to determine the meteorology responsible for the fire conditions and the fire's effect on air quality. The satellite images also allow the determination of the burned areas from which the emission rates of various air pollutants can be estimated based on the fuel load and emission factors.

The meteorological and emission modelling data will then be used to drive the air quality dispersion modelling system which is currently under development at the Office of Environment and Heritage, NSW (OEH, NSW). This air quality modelling system, based on a chemical transport model (CTM), will be able to predict the ozone and particles (PM_{10} and $PM_{2.5}$) in temporal and spatial domains under various meteorological and emission scenarios.

The bushfire of 2013 is a good case study to test and verify the air quality modelling system for the Sydney airshed.

Data sources for the bushfire studies

The NSW Office of Environment & Heritage (OEH NSW) operates and maintains a comprehensive ambient air quality monitoring network in NSW. Most stations measure the following air pollutants: particles (PM_{10} and $PM_{2.5}$), visibility (nephelometer), oxides of nitrogen NO_2 and NO , ozone, sulphur dioxide and carbon monoxide.

The Sydney basin currently has 14 monitoring stations scattered throughout the Sydney metropolitan region from the coastal area in the east to the edge of the Blue Mountain in the northwest and in the west (Duc et al., 2012). During late spring and summer period, usually in the morning after sunrise, onshore sea breeze flow from the east and north east flowing across Sydney towards the southwest causes an elevated level of ozone in the southwest and west of Sydney in the afternoon (Hart et al., 2006). In the evening and night-time, drainage flow of cold air from the mountains in the west is directed to the coastal east and from southwest to the north.

Figure 1 shows the concentration of particles (PM_{10} , $PM_{2.5}$ and visibility) and gaseous air pollutants (ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide) during the bushfire period of 17th October to 11th November 2013. All particles standards (daily PM_{10} at $50 \mu g/m^3$, daily $PM_{2.5}$ at $25 \mu g/m^3$, nephelometer back

scattering index of 2.1 Bsp) were exceeded during this the bushfire period.

Among the gaseous pollutants standards (hourly ozone at 10 pphm or parts per hundred millions, nitrogen dioxide at 12 pphm, 8 hourly carbon monoxide at 9 ppm or parts per million and sulphur dioxide at 20 pphm for hourly and 8 pphm for daily) only the ozone standard was exceeded.

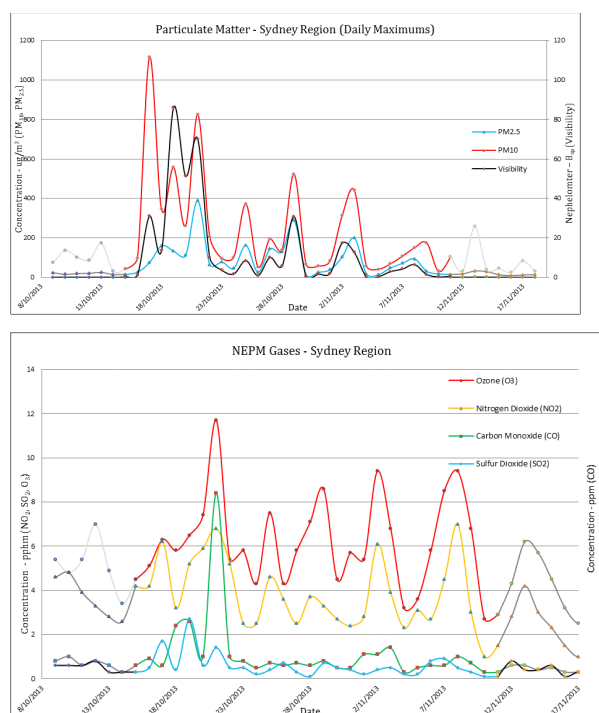


Figure 1 – Particles (PM_{10} , $PM_{2.5}$ and visibility) and gaseous air pollutants (ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide) concentrations during the bush fire periods of 17th October to 11th November 2013.

The NOAA AVHRR satellite images and the hot spots as determined from the MODIS Terra/Aqua images were obtained during the bushfire periods. By combining these using ArcGIS for the 16th October to 11th November 2013 bushfire period, we are able to locate accurately the sources of the fires causing smoke plumes. An example of this is presented in Figure 2.

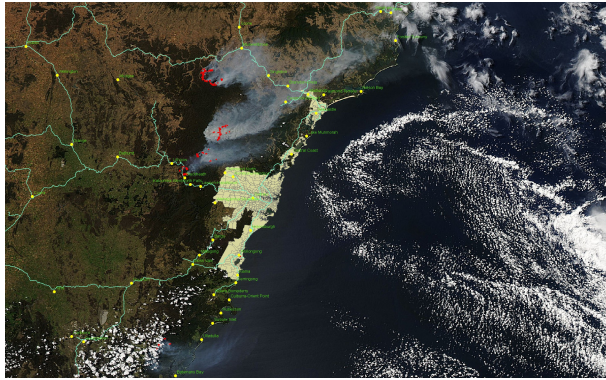


Figure 2 - Bushfire on 26/10/2013 as captured by NOAA AVHRR satellite and MODIS thermal hot spot detection.

Data analysis of air pollutants from ground-based monitoring stations and WRF model

The end goal of the project is to model the air pollution from the October 2013 bushfire period in NSW, Australia. However, in order to do that, the amount of biomass burned needs to be calculated. In the first instance, this involves the collection of burn-scar and hotspot data. This was done using shape file images and Terra and Aqua MODIS GeoTiff images for the burn-scar and hotspot data respectively – both from NASA.

The hotspot data was collected for two purposes. The first was to gain an understanding of the total number of hotspots in the month of October, whilst the second purpose was to determine the number of hotspots that occurred on each day of the bushfire episode – from 17th October to 3rd November.

In order to see if these two data sets matched up with the modelled wind meteorology from the WRF (Weather Research Forecast) model, both maps were layered together in ArcGIS. To gain a better understanding of the spatial variation of the hotspot and burn-scar data, these were layered with roads, towns and suburbs of the surrounding locales.

The next step of this process is to analyse the 1 hour average of a number of the pollutants from each of the OEH's 15 monitoring sites around Sydney. The parameters collected for analysis were $PM_{2.5}$, PM_{10} , ozone (O_3).

The data analysis is to be undertaken using the OpenAir open-source tools for the analysis of air pollution data. This is a package library in the R statistical program. Having identified the sites of highest concentration for each pollutant, polar plots and concentration plots were constructed using OpenAir. Following this, the source of the pollutants was tracked

using the back trajectory function. The GoogleMapsPlot function was used to spatially identify areas of greatest concentration within the 15 monitoring sites in the Sydney Metro area.

Summary analysis of air pollutant data

Time series and summary statistics of air pollutants are analysed using Excel spreadsheet and R statistical package for all the days during the bushfire period. Figure 3 shows the plot of ozone concentrations at all stations in Sydney.

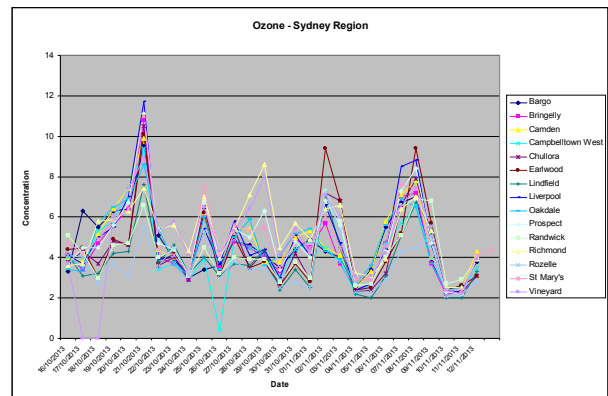


Figure 3 – Ozone concentration as measured at Sydney monitoring stations during the bush fire period. Ozone exceeds the standard (10 pphm) on the 21 Oct 2013 and very high (above 8 pphm) on the other days.

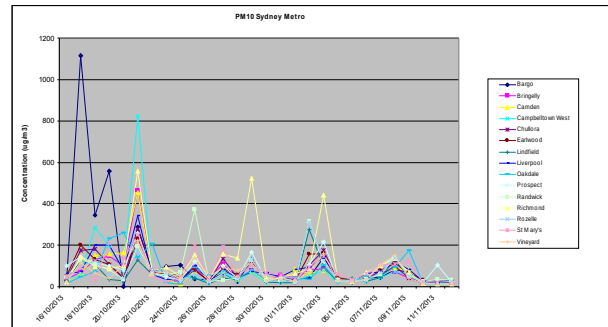


Figure 4 – Particle concentrations (hourly averages) as measured at Sydney monitoring stations during the bush fire period.

To accommodate the spatial variability of the concentration, the plots of concentration statistics at the stations are overlayed on the Sydney map using OpenAir. An example of the spatial plot is given in Figure 4.

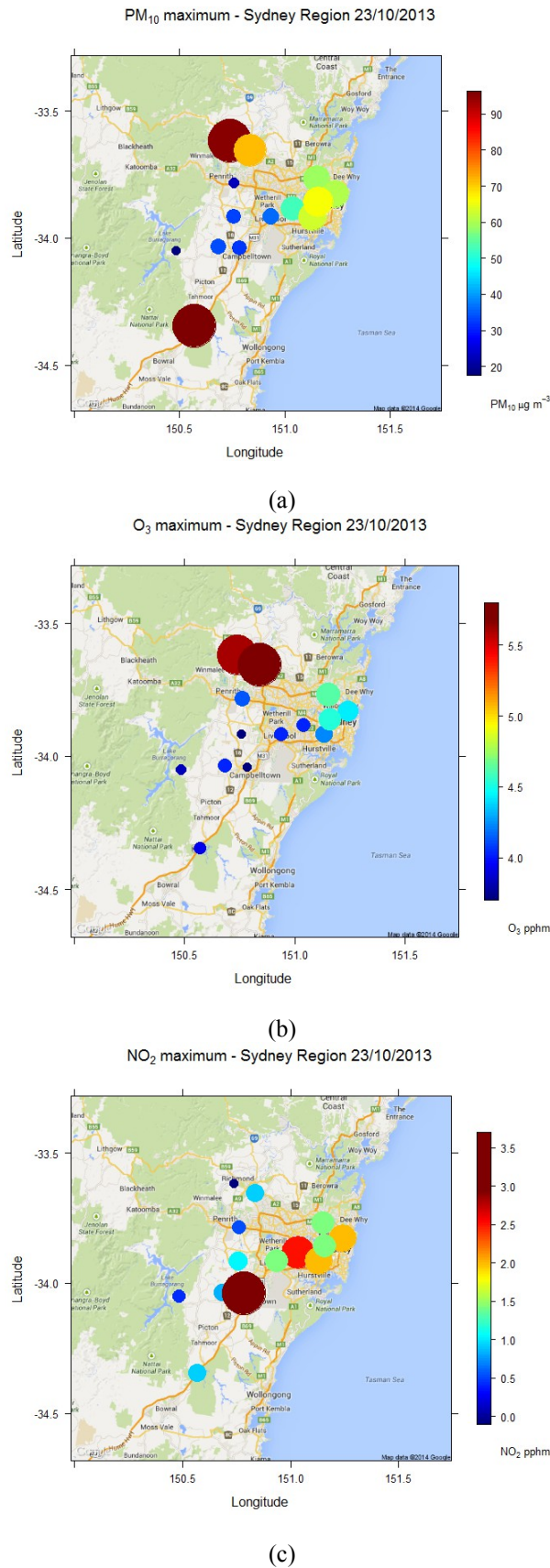


Figure 4 – Panel (a) shows the 24 hour maximum PM₁₀ across the 16 monitoring site in the Sydney region for the 23rd November using the GoogleMapsPlot function in Openair. Panels (b) and (c) show the same for ozone (O₃) and nitrogen dioxide (NO₂) respectively.

Weather Research Forecasting (WRF) Model

There are a number of regional meteorological models that are available for modelling the meteorology over the Sydney and surrounding areas. The CCAM (Cubic Conformal Atmospheric Model) and the TAPM (The Air Pollution Model) models were developed by CSIRO (Commonwealth Scientific and Industrial Research Organisation) in Australia and are commonly used in a number of countries. The Weather Research Forecast (WRF) model is developed by NCAR (National Center for Atmospheric Research) in the US. As a community model, it is very popular and is widely used by many organisations in the world. The WRF model is used by many organisations in the world including national weather bureau in some countries for real-time forecasting. In this paper, we will use the WRF for modelling the October 2013 bushfire period.

WRF is a mesoscale weather model prediction system. It is a 3-D model with dynamic advection, physics including various convection, radiation, boundary layer and cloud microphysics options. As the WRF model is a mesoscale regional model, its use is to downscale the coarse global forecasting model (GFS) such as NCEP GFS or Global Climate Model (GCM) prediction to a finer resolution applicable to a region (eg Eastern Australia).

We used the WRF with the defined options for the forecasting of meteorological variables at different height during the bush fires period of 17 Oct to the 3rd November 2013. The defined options are single-Moment (WSM) 3-class simple ice scheme for microphysics, Rapid Radiative Transfer Model (RRTM) scheme for longwave radiation, Dudhia scheme for shortwave radiation, Monin-Obukhov similarity scheme for surface layer physics, Noah Land-Surface Model for land surface, YSU scheme for boundary layer, Kain-Fritsch (new Eta) scheme for cumulus cloud physics and 4 soil layers in land surface model.

The domain is 74 by 61 grids with grid size at 37.5 km in x and y direction and 30 vertical levels with pressure at top is 500hPa.

The initial and boundary conditions and coarse data are the NCEP GFS global analysis data downloaded from NCEP GFS to drive the WRF model run.

An example of the WRF prediction which is

compared with satellite images is given in Figure 5 and 6. Figure 5 shows the satellite image on 23/10/2013 at 3 UTC (1pm local time) and Figure 6 shows the WRF predicted wind at cloud level overlayed with satellite image using the IDV software.

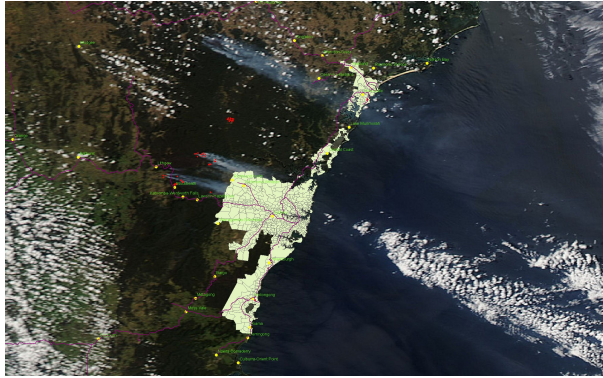


Figure 5 - Bushfire on 23/10/2013 at 3 UTC time as captured by NOAA AVHRR satellite and MODIS thermal hot spot detection

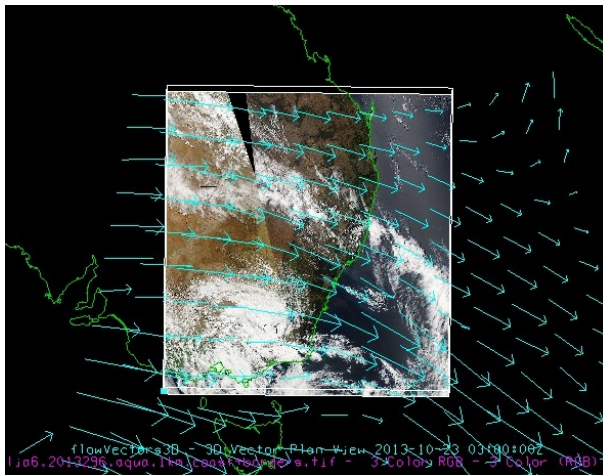


Figure 6 - The cloud level (~3000m) wind on 23 Oct 2013 at 3UTC as predicted from the WRF model and is overlayed on the satellite image and hot spots from MODIS on the same day and time.

It can be seen from Figure 5 and 6 that the WRF prediction of wind at cloud level is fairly accurate. Furthermore the spatial pattern of the maximum concentration of air pollutants at Sydney stations as shown above follows closely the path of plumes in the North West direction.

Radiosonde upper air data as measured at Mascot airport on the coast show a temperature inversion at about 300 hPa (~9000m) in the morning at 6am. The smoke cloud was expected at most at this inversion height.

Conclusion

The extent of the air pollution due to the October 2013 bushfire has been shown using data from the monitoring stations and satellite images. Meteorological modelling using WRF give predicted wind field at different high levels.

The WRF wind predictions are compared with satellite images of smokes and burned areas obtained from MODIS Terra/Aqua satellites. The results show that the WRF wind prediction is reasonably accurate. This allows us to use the WRF predicted wind field at different hour to show the extent and evolution of the bushfire plumes during the October 2013 bushfire period in the surrounding areas of Sydney.

The next step in the study is to estimate the daily emission rates of various pollutants (gases and particles) from the burned areas as derived from satellite images and the development and verification of a chemical transport model, using the bushfire period of October 2013 as a case study, for the Greater Metropolitan Areas which include Sydney, the Lower Hunter (north of Sydney) and the Illawarra (south of Sydney).

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