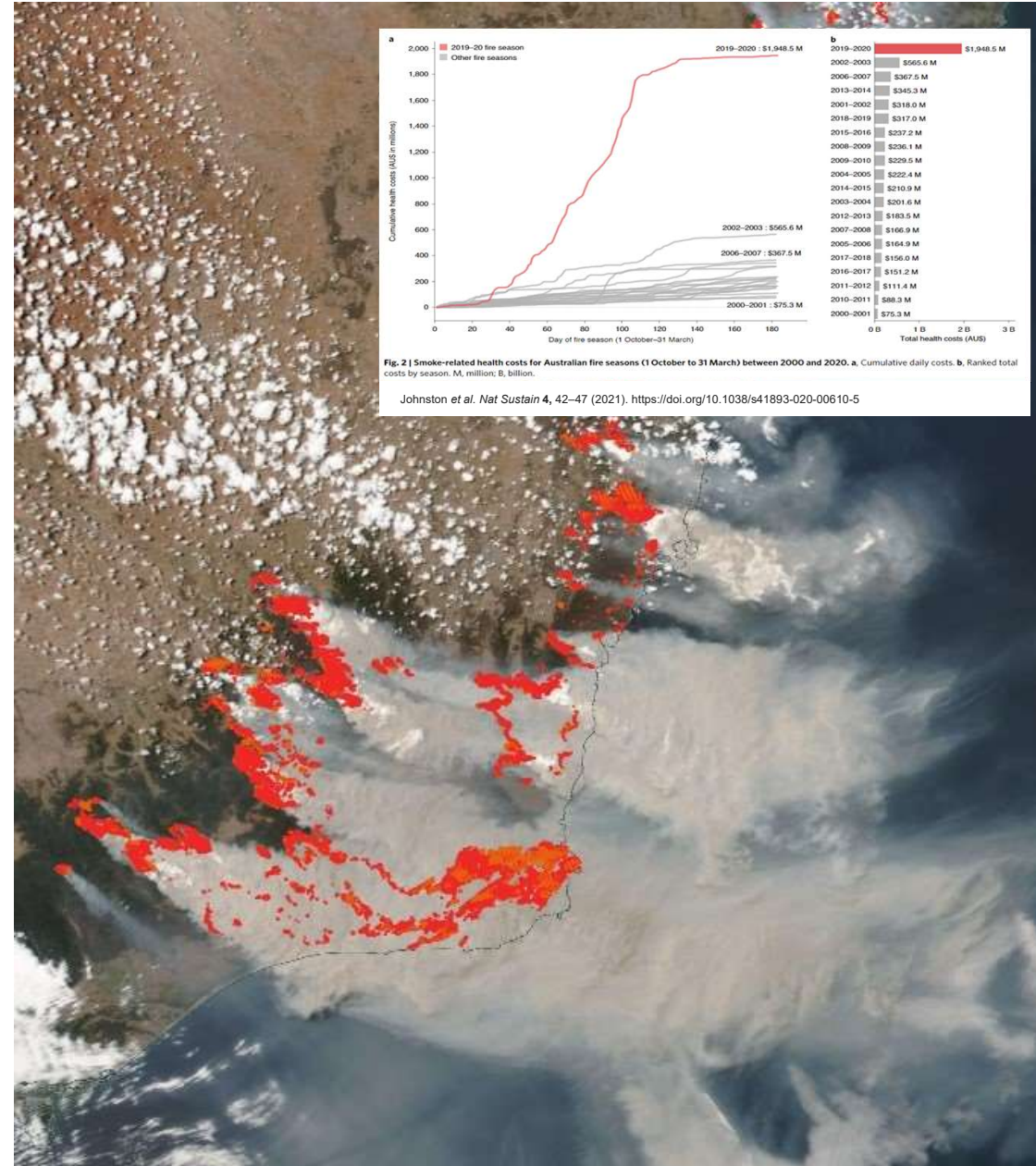




# AQFx- a national smoke forecasting system: From emissions to forewarning

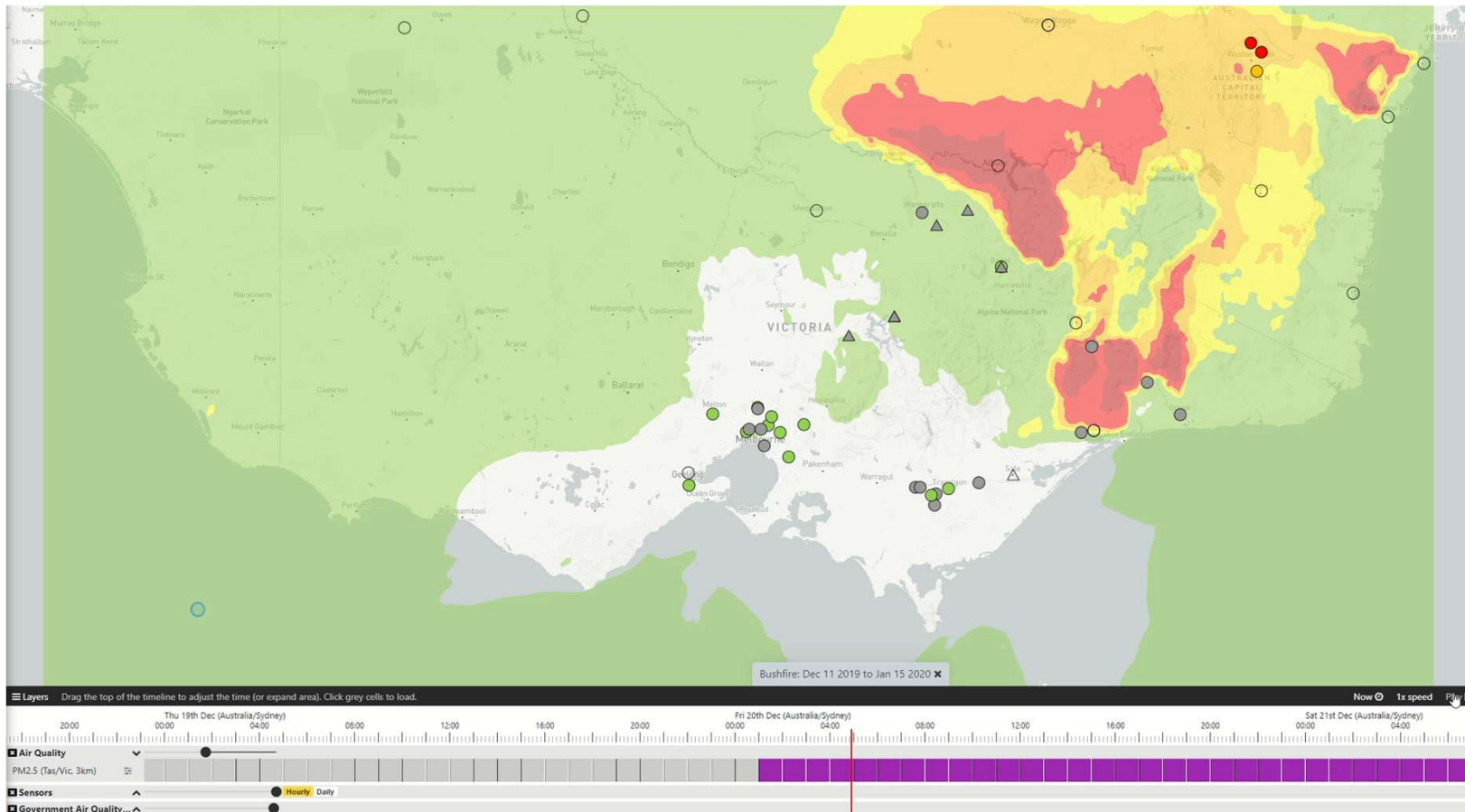
Fabienne Reisen (on behalf of the AQFx project team)  
20 February 2024

Australia's National Science Agency





# A tactical air quality forecasting tool – an aid for managing population exposure to smoke



Provide forecast advisories of when smoke will impact communities

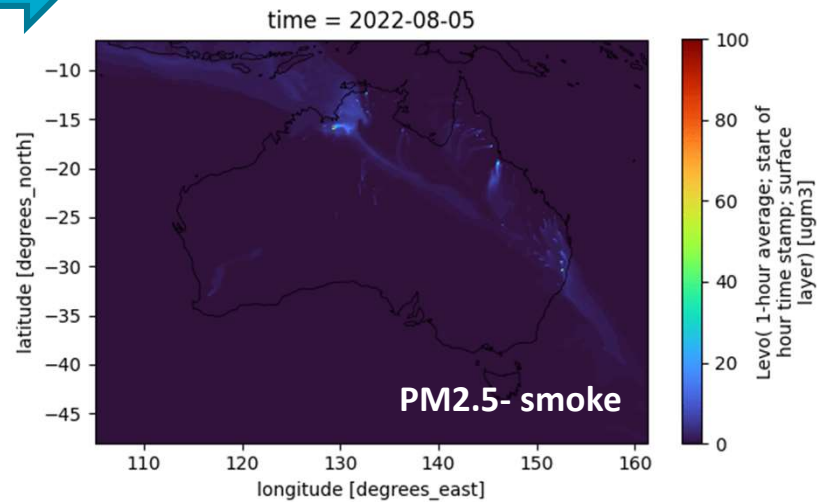
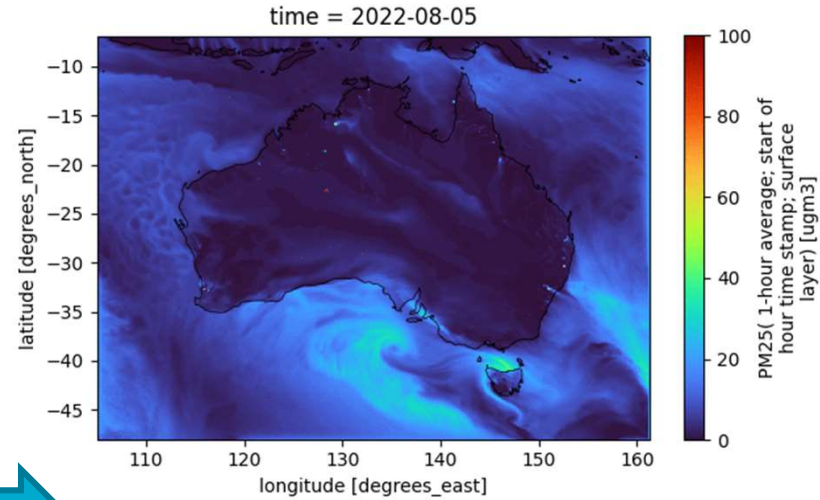
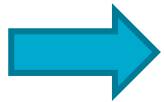
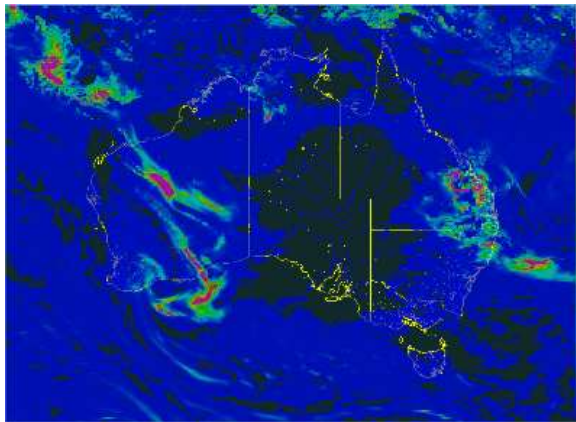
Enable preventative actions  
Better planning for burn-offs

Reduce population health risk from smoke exposure  
Minimise agricultural impacts

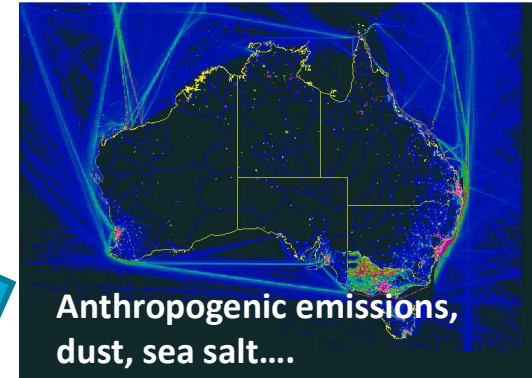


# How are forecasts generated?

Weather forecasts  
(Bureau of Meteorology)

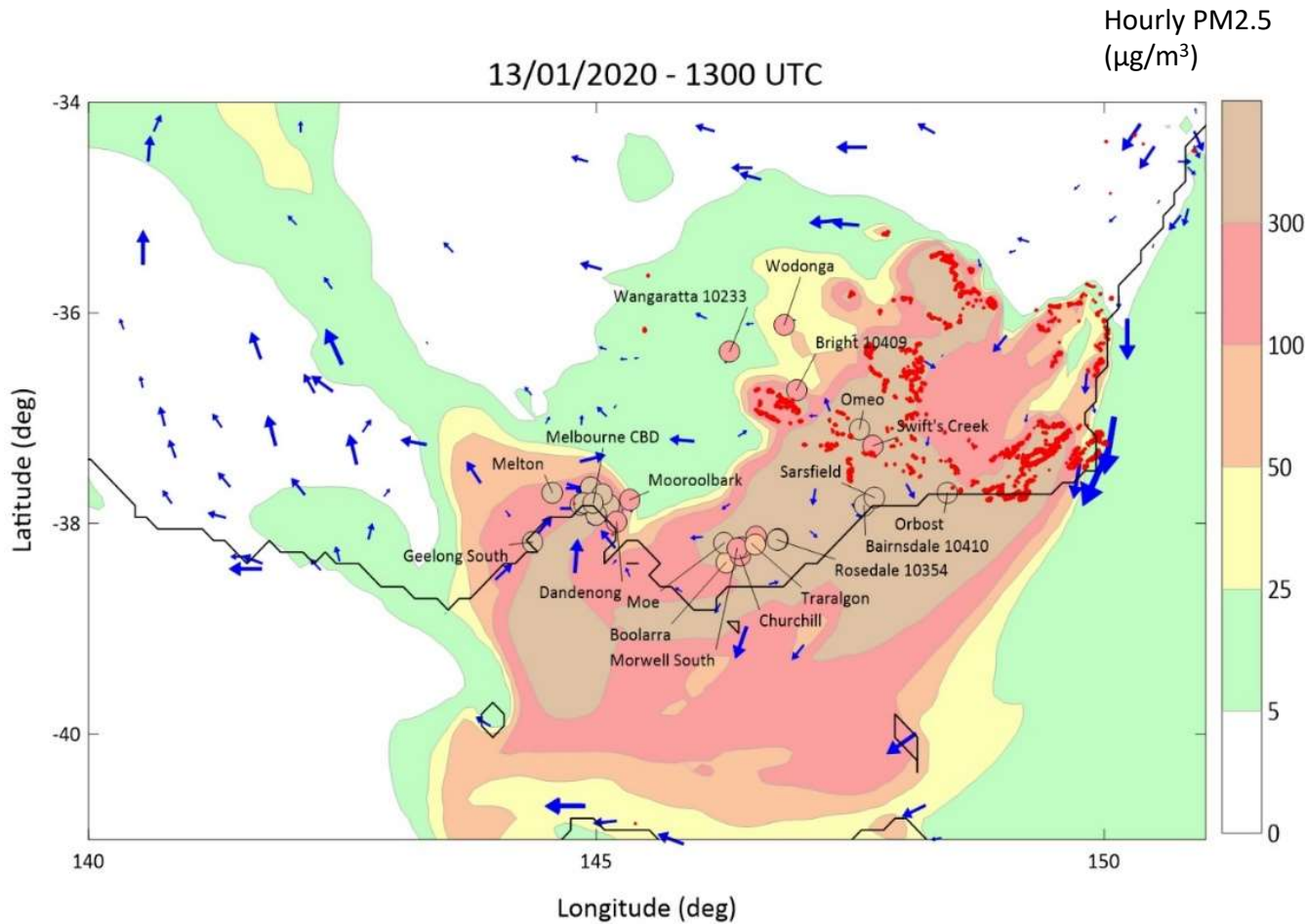


National emissions





# Major uncertainties in smoke forecasts



Smoke plays havoc as Australian Open qualifier suffers coughing fit

- Slovenian Dalila Jakupovic suffers breathing difficulties
- Match at Kooyong involving Maria Sharapova abandoned

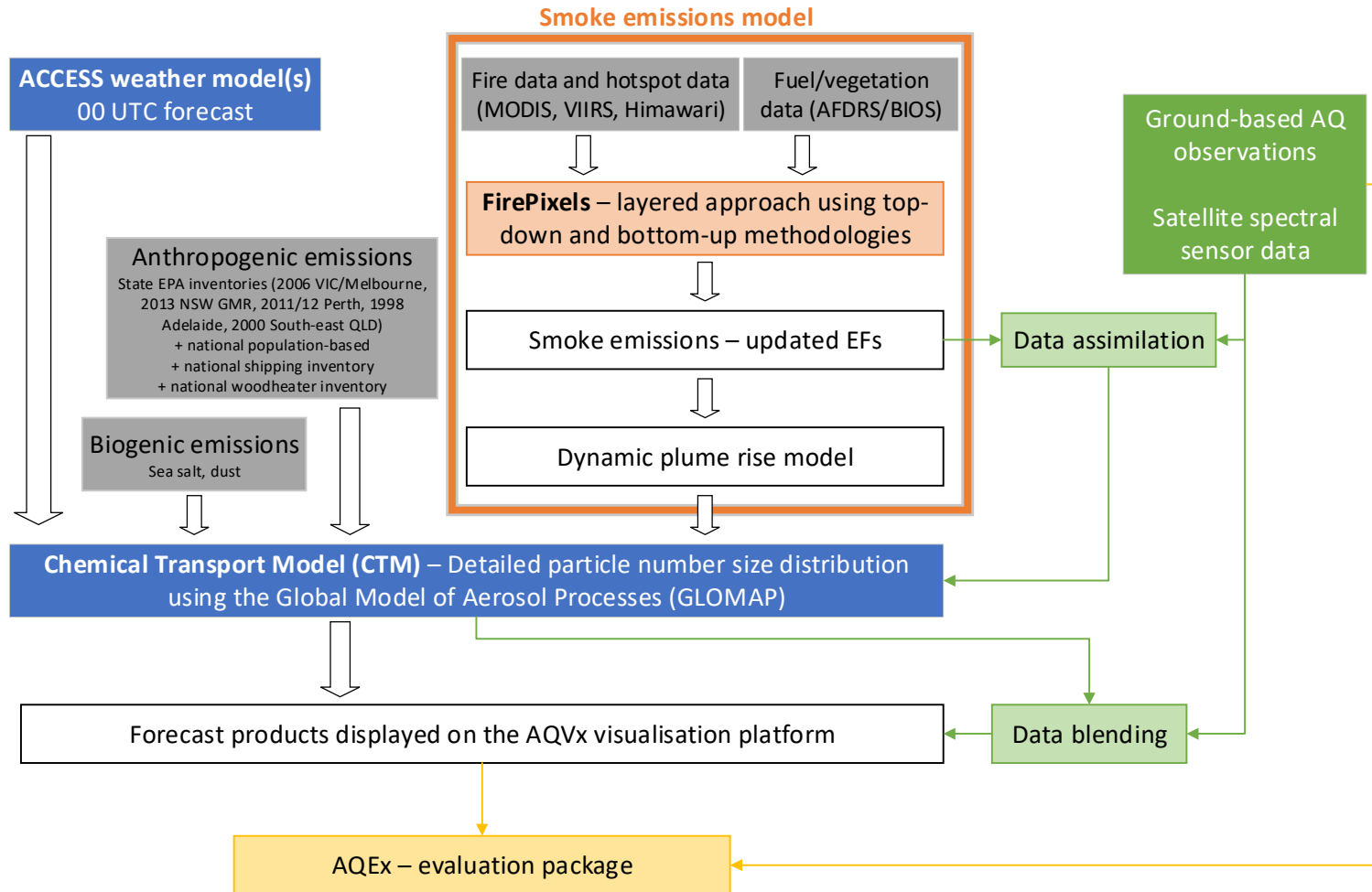


Source: The Guardian  
(14<sup>th</sup> Jan 2020)

- Complicated wind patterns which can affect the onset and duration of smoke events
- Timely identification and location of fires
- Complexity and variability in fuel loads and fuel consumption
- Temporal distribution of emissions
- Plume rise which affects smoke plume dispersion



# Workflow diagram of the CSIRO Prototype National Air Quality Forecast System (AQFx\_p)





# How are smoke emissions derived?

Top – down approach:

$$\text{Emissions}_i = \alpha \times \int_{t_1}^{t_2} \text{FRP}(t) dt \times \mathbf{EF}_i$$

Smoke composition  
Emission fluxes

Plume rise  
models

Bottom – up approach:

$$\begin{aligned} \text{Emissions}_i &= \text{Area burned} \times \text{Biomass consumed} \times \mathbf{EF}_i \\ &= \text{Area burned} \times \text{Fuel load} \times \text{Burning efficiency} \times \mathbf{EF}_i \end{aligned}$$



# Input parameters, data and uncertainties

## Bottom-up approach

**Burn area** provided by fire agencies

- *potentially limited by agency capacity*

**Burn area** derived from satellite data (e.g., MODIS, VIIRS, H8/9).

- *Uncertainties around area burnt per hotspot*
- *Missing or inaccurate observations due to cloud, over-canopy layers, thick smoke, small and/or cool fires;*
- *Sparse temporal resolution for LEO satellites (MODIS/VIIRS);*
- *Low spatial resolution for Himawari.*

## Fuel load & consumption

- *potentially large uncertainties*
- *a single parameter of **burning efficiency** for bushfires and planned burns is a simplification.*

## Top-down approach

Relies on **reliable remote sensing data** from MODIS, VIIRS, H8/9.

**Fuel load & fuel consumption** are not required.





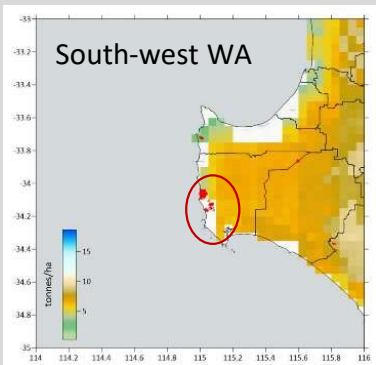
# Fuel load & consumption - source of uncertainty in forecast model

## AQFx\_p (v01)

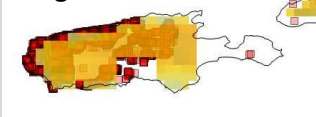
Empirical fuel load data & semi-empirical model VAST (Barrett, 2002)

### Problem:

coarse resolution of VAST fuel load data sets  
⇒ areas close to the coast with zero fuel load



## Kangaroo Island SA



## AQFx\_p (v02)

AFDRS fuel maps for fine fuel & process-based carbon cycle model BIOS2 for coarse fuel

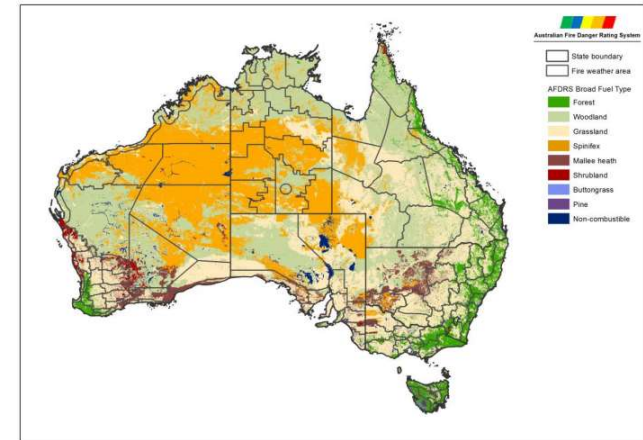
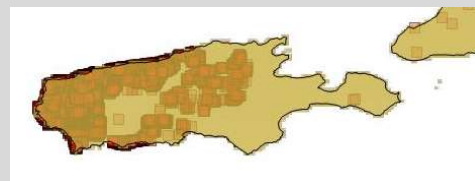
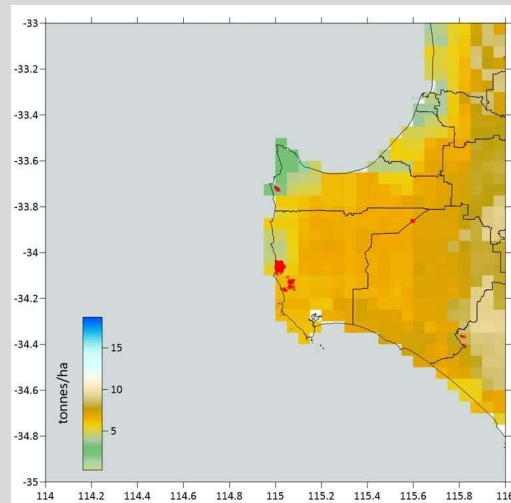
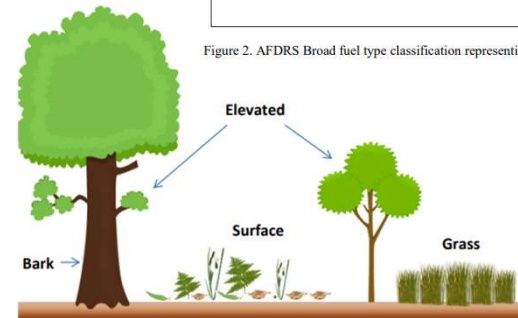


Figure 2. AFDRS Broad fuel type classification representing fire behaviour models

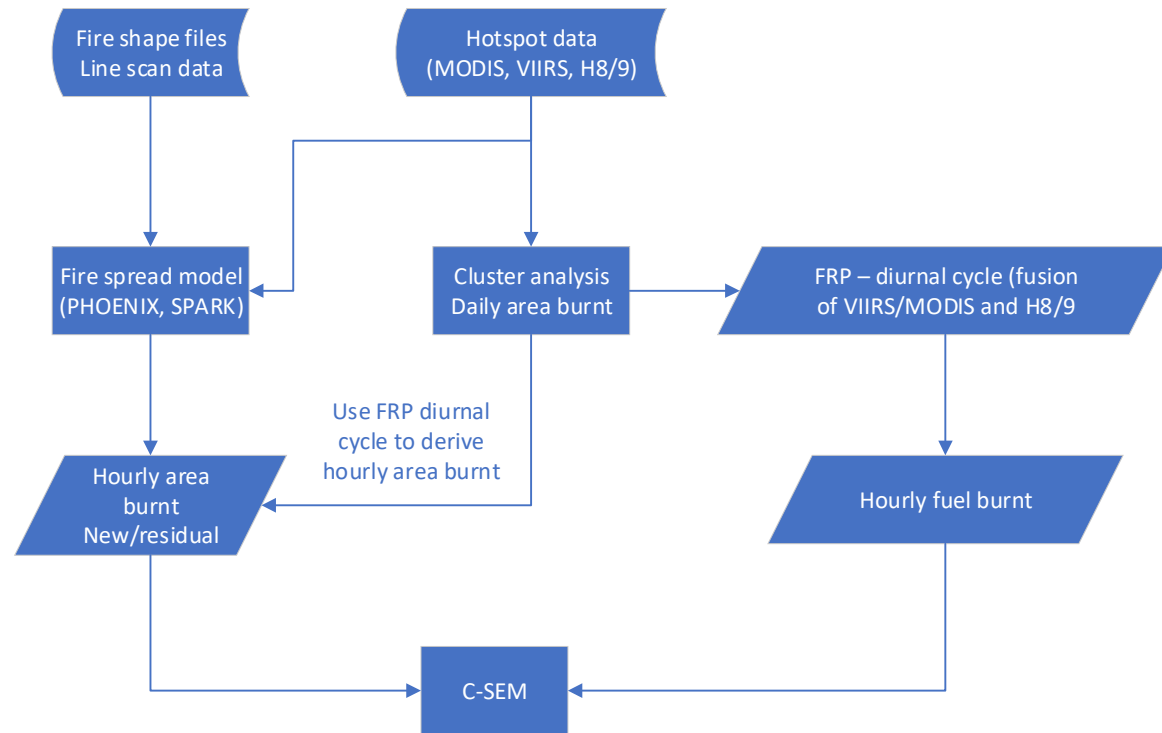
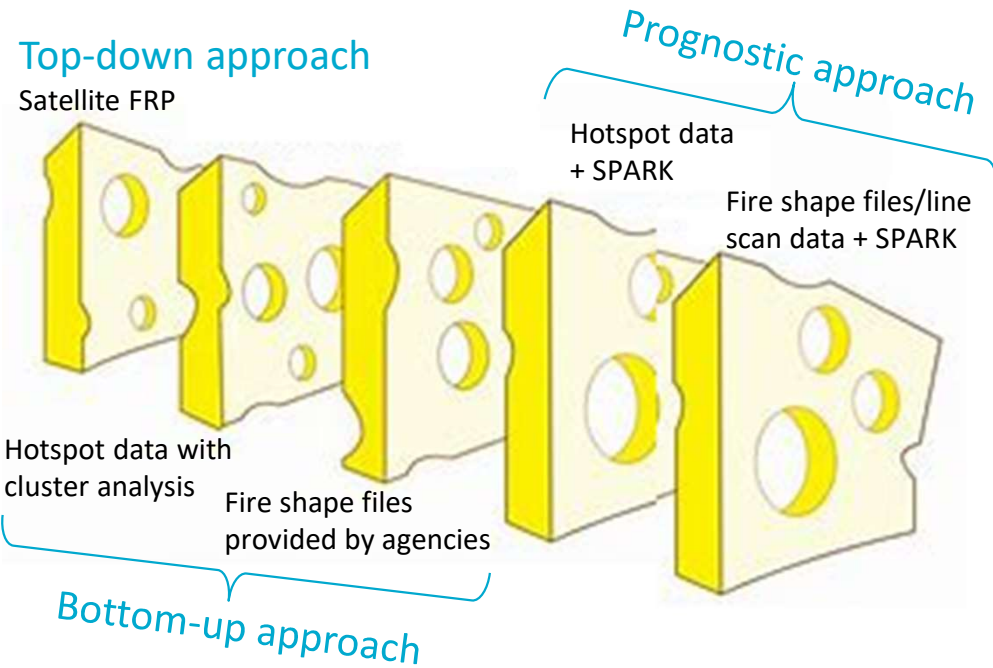






# Fire pixel - a layered approach to derive smoke emissions

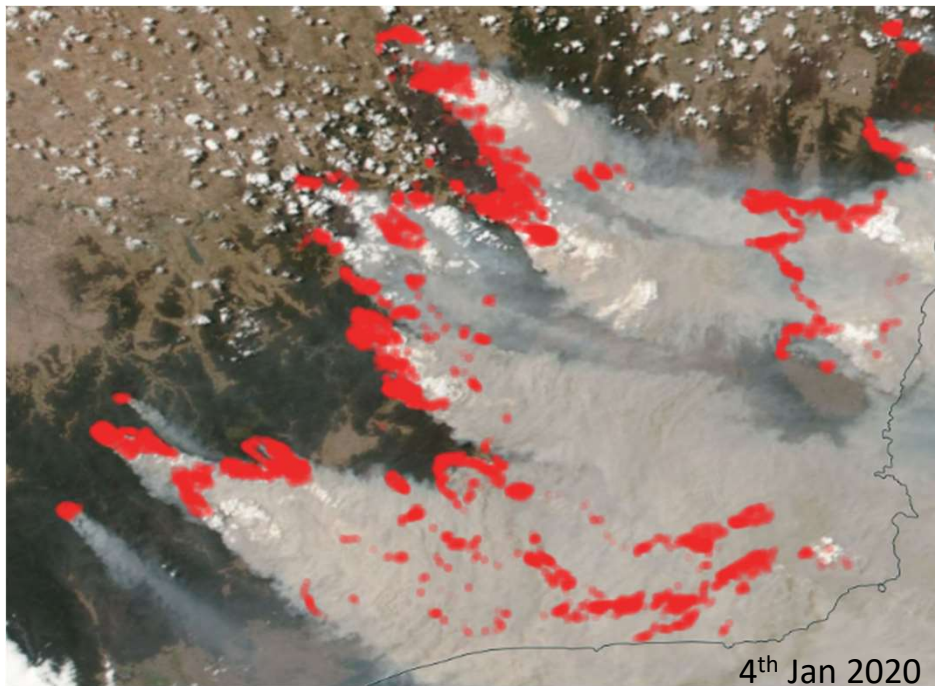
The data required to model smoke emissions are imperfect but can be improved by adopting a layered approach of different methodologies and data requirements.



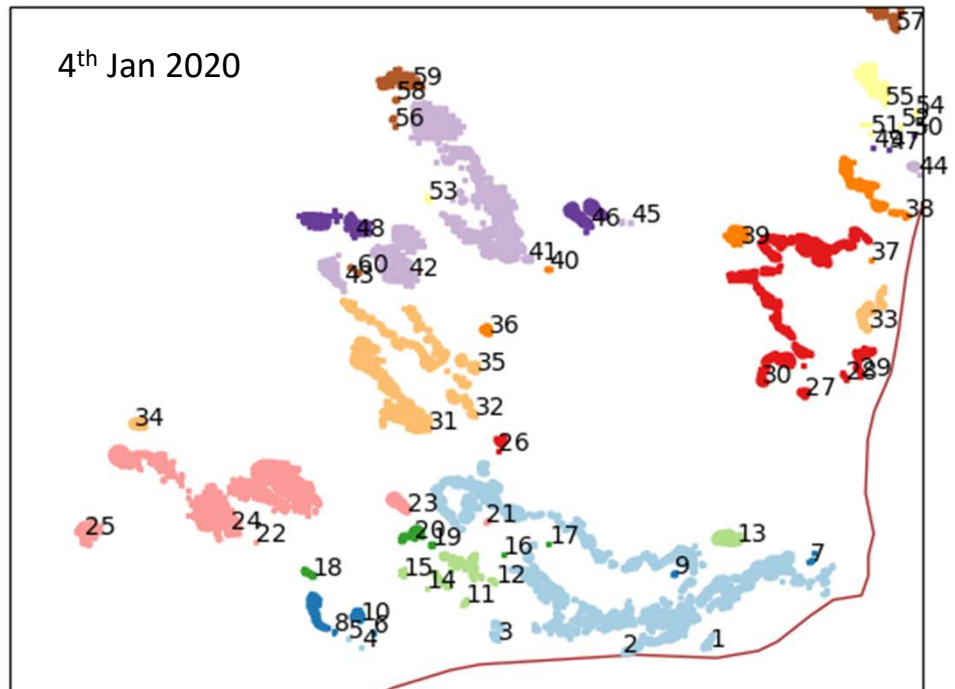


# Cluster analysis – Step 1

Identify individual fire fronts using a cluster analysis methodology.



Suomi NPP/VIIRS hotspots and visible reflectance. 1:30 pm EST

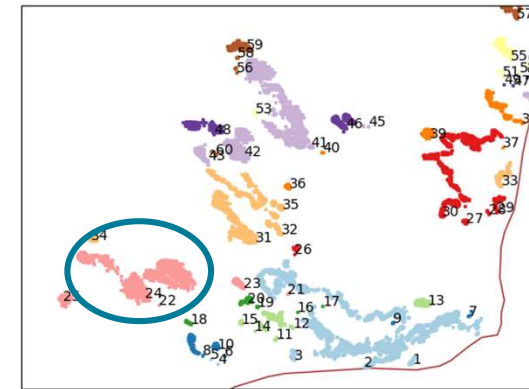
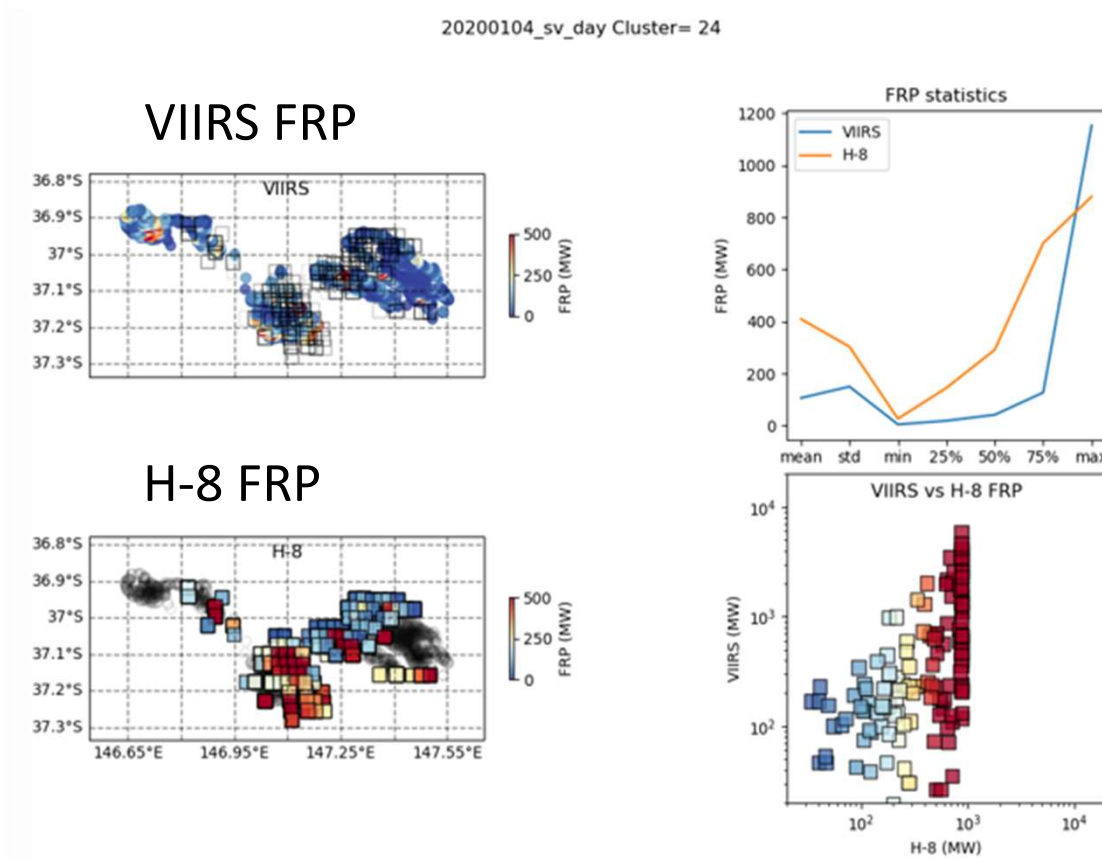


Cluster analysis results (60 fire clusters)



# Cluster analysis – Step 2

Identify clusters where VIIRS and Himawari-8 (H8) pixels overlap in time and space  
- quantify the ratio of VIIRS / H8 for later temporal interpolation

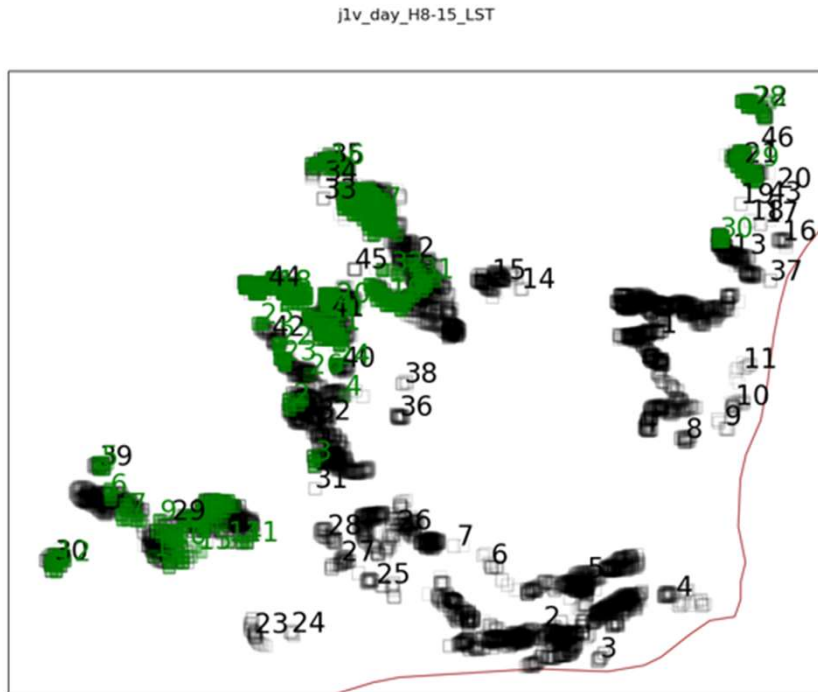


The scatter plot shows VIIRS FRP vs H8 FRP for coincident locations in space and time.  
Note how the H8 FRP saturates at about 1000 M- problem for big fires!

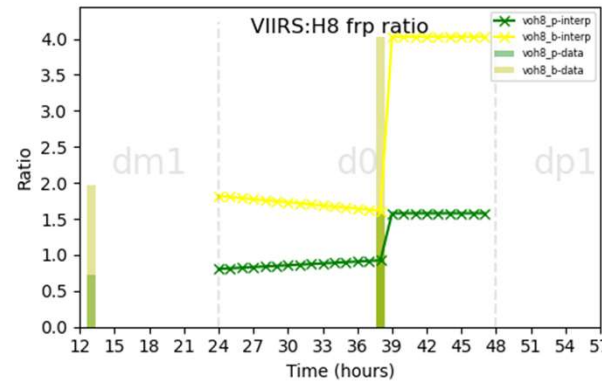


# Cluster analysis – Steps 3 & 4

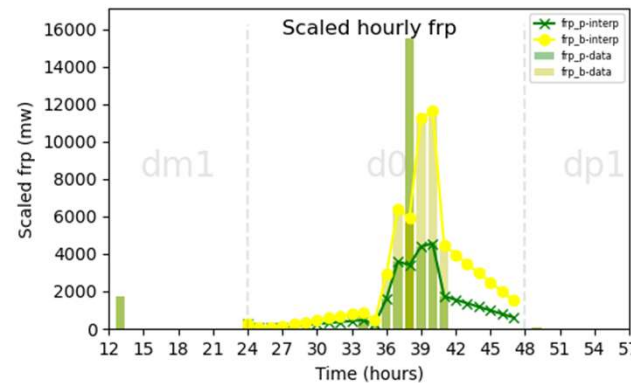
For a 24-h period, identify all 10-min H-8 data which spatially overlap a VIIRS cluster (the latter available at up to 4 time points in the day). Use the average 1-h H8 FRP data to estimate the hourly FRP, and hence FRE, and fuel burnt using the TD equation.



H8 clusters (green) for 3 pm EST which overlap VIIRS (black) 1:30 pm clusters



Two ratio estimates of VIIRS:H8 FRP for cluster 24



Estimated hourly FRP for cluster 24 using 10-min H8 data (here- simple linear interpolation)

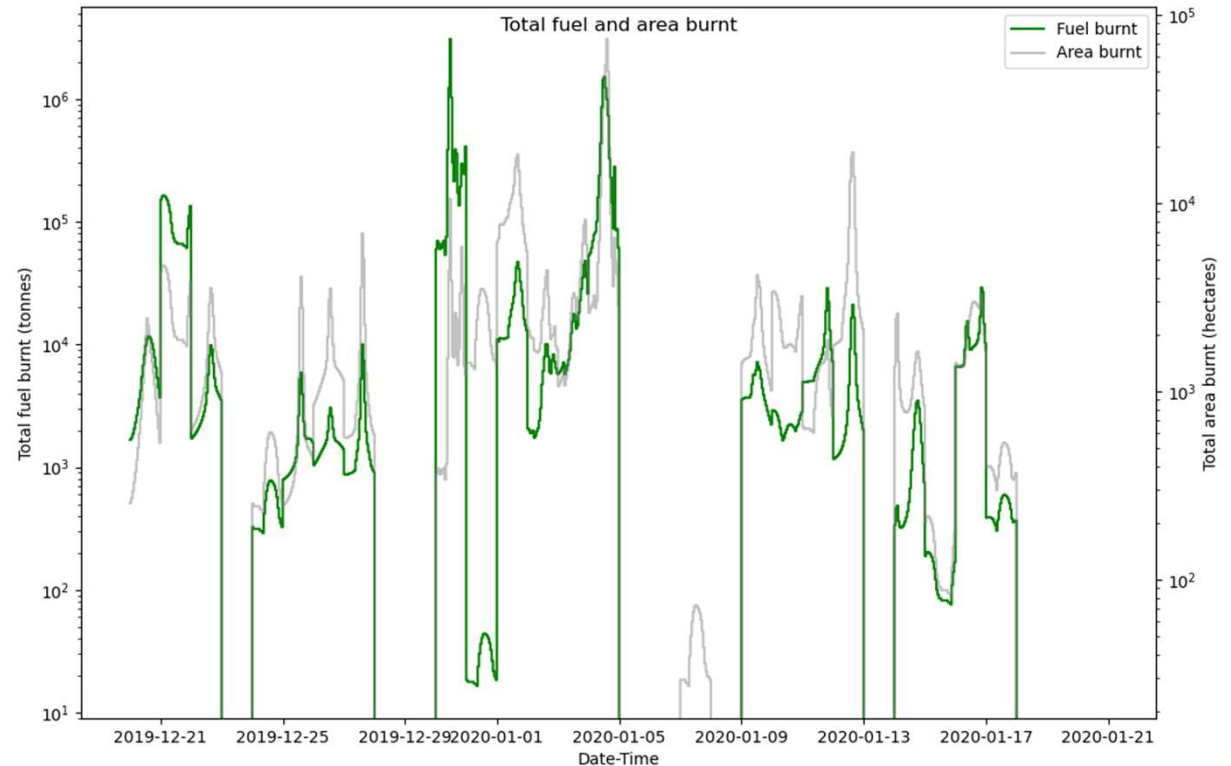


# Cluster analysis methodology

Steps 1-4 are repeated for all clusters in the study domain, for all days of the study period.

This plot shows the calculated hourly fuel burnt (and area burnt) for the entire study domain for the period 20 Dec 2019 to 20 Jan 2020.

The data gaps correspond to days with significant cloud or smoke cover when thermal anomalies are not detected. Data gaps are filled using a persistence assumption or prognostic modelling (Phoenix or SPARK).

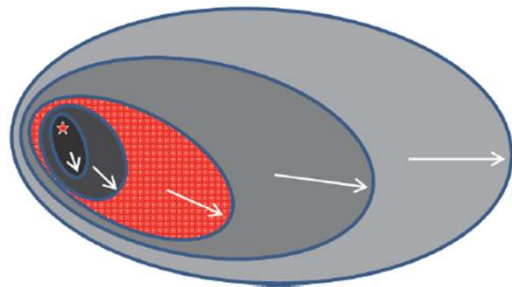




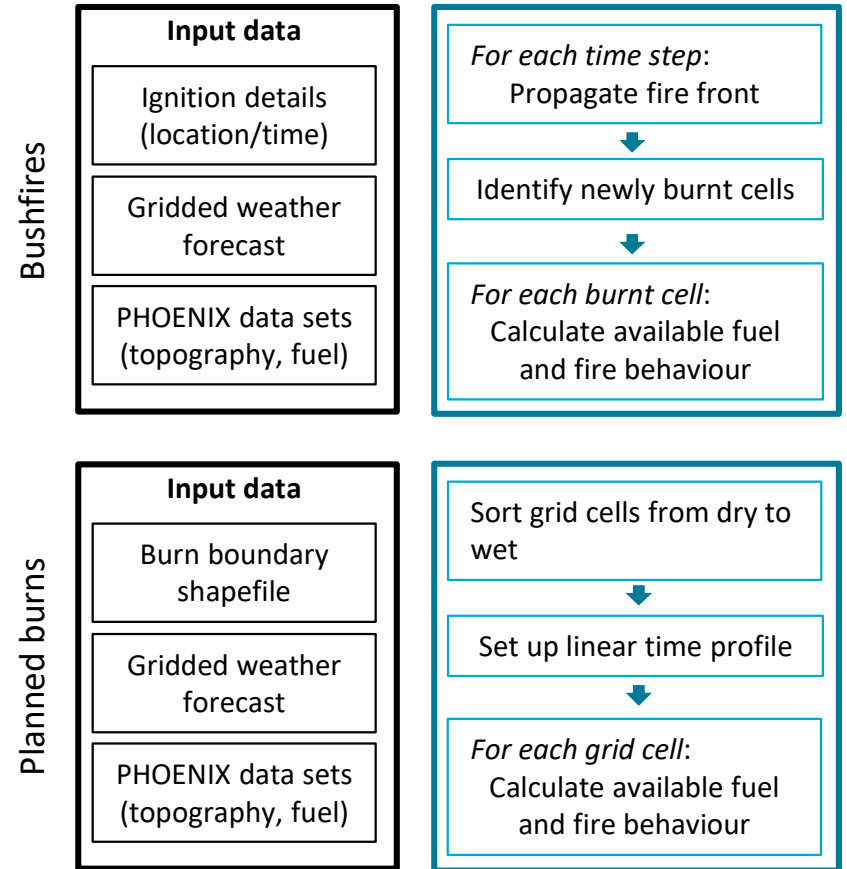
# Prognostic method

In the prognostic method, outputs of fire spread models are used to derive hourly area burnt. The fire spread is forced by Bureau of Meteorology Graphical Forecasting Editor (GFE) data grids and detailed fuel load and land attribute data sets.

Emissions are calculated as per bottom-up method.



*PHOENIX FireFlux bushfire simulator with modifications - at the end of a time step the area burnt is identified as a polygon and the total amount of fuel consumed is calculated*



*Reference:* Walsh S, Duff T and Tolhurst K (2019). Fire activity modelling for use in smoke predictions. In: Cope et al, *Smoke Emission and Transport Modelling*. Research Report 102, The State of Victoria Department of Environment, Land, Water and Planning.



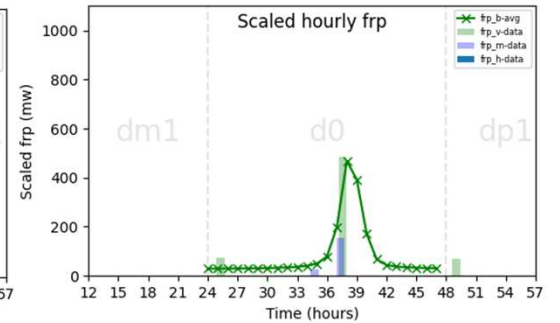
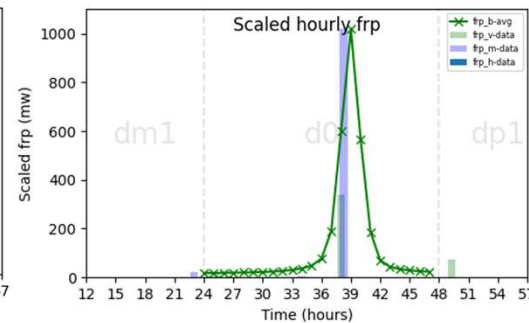
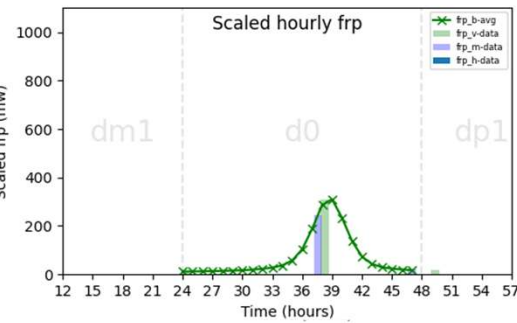
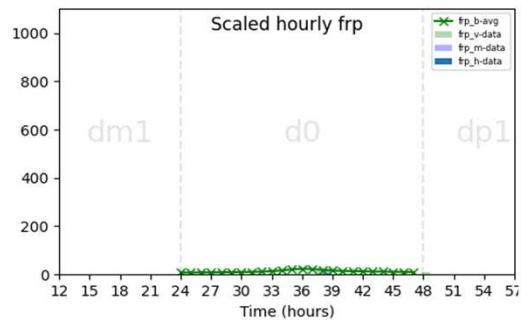
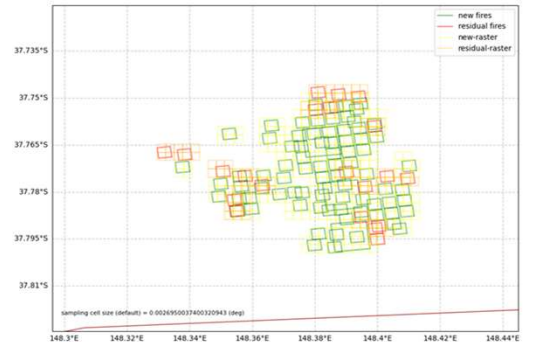
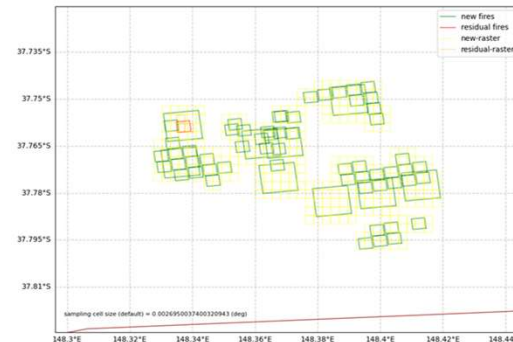
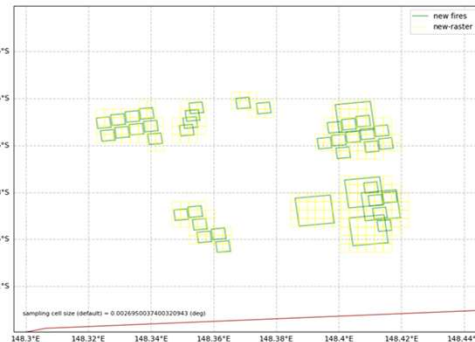
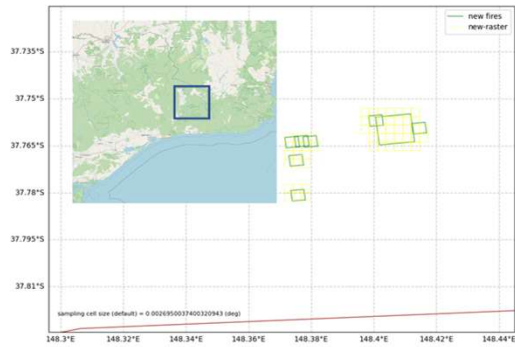
# Example

4<sup>th</sup> April 2017

5<sup>th</sup> April 2017

6<sup>th</sup> April 2017

7<sup>th</sup> April 2017



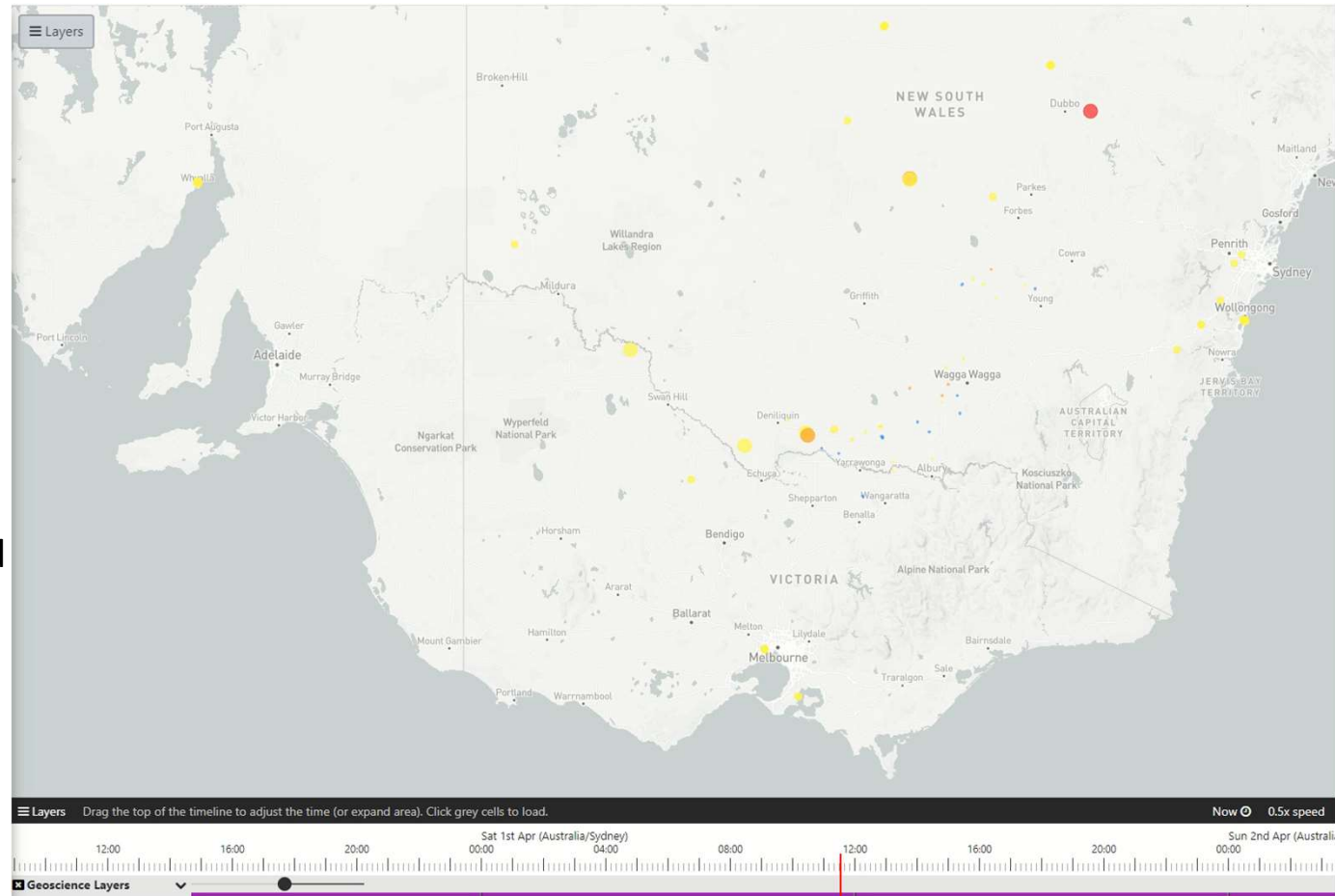


# Hotspot detection- agricultural burning

Significant hotspot activity over central VIC/NSW captured by the MODIS/VIIRS satellite overpass at ~1pm each day. This is primarily due to agricultural burning.

The hotspot activity is significantly lower overnight (as captured by the 1am VIIRS satellite overpass).

This may be due to short-lived fast-moving burns (e.g., agricultural burns) or under-canopy smouldering fires not well captured by MODIS/VIIRS.



Active fire hotspot locations using MODIS and VIIRS satellite observations between 1-5 April 2023





# Emission factors required for both approaches

Top – down approach:

$$\text{Emissions}_i = \alpha \times \int_{t_1}^{t_2} \text{FRP}(t) dt \times \text{EF}_i$$

Smoke composition  
Emission fluxes

Plume rise  
models

Bottom – up approach:

$$\begin{aligned} \text{Emissions}_i &= \text{Area burned} \times \text{Biomass consumed} \times \text{EF}_i \\ &= \text{Area burned} \times \text{Fuel load} \times \text{Burning efficiency} \times \text{EF}_i \end{aligned}$$



# Deriving emission factors



Laboratory experiments in Pyrotron



Field measurements using backpack sampler



Open path FTIR (University of Wollongong)

### Flaming fire

- Fine fuel
- Strong fire plume



### Pyrolysis:

Biomass (solid) + Heat  $\rightarrow$  Pyrolysate (gas) + Char (solid) + Ash (solid)

Oxygen

Oxygen

Glowing combustion – char oxidation  $\rightarrow$   
*Heat + CO<sub>2</sub> + H<sub>2</sub>O + other gases + ash (solid)*

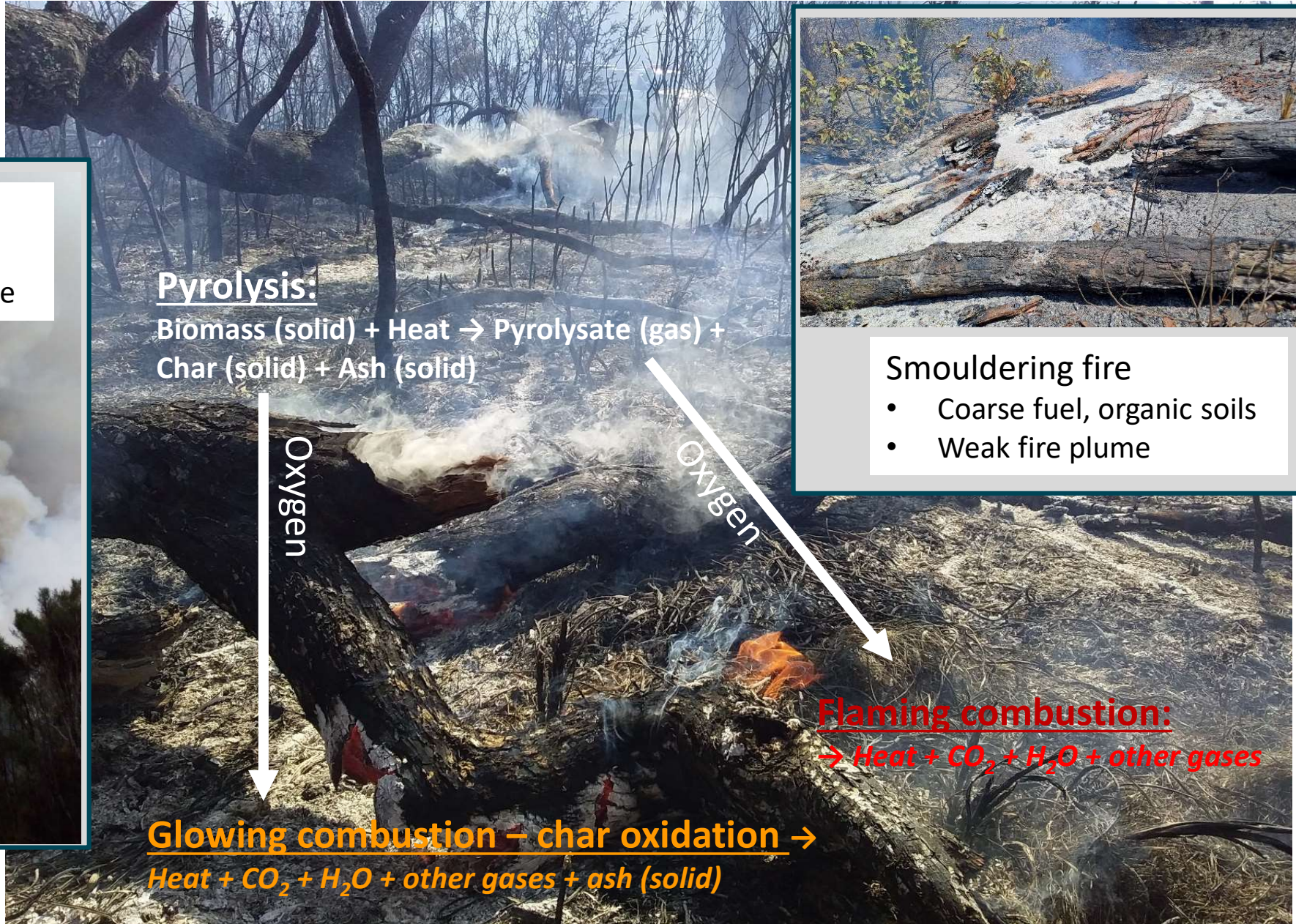


### Smouldering fire

- Coarse fuel, organic soils
- Weak fire plume

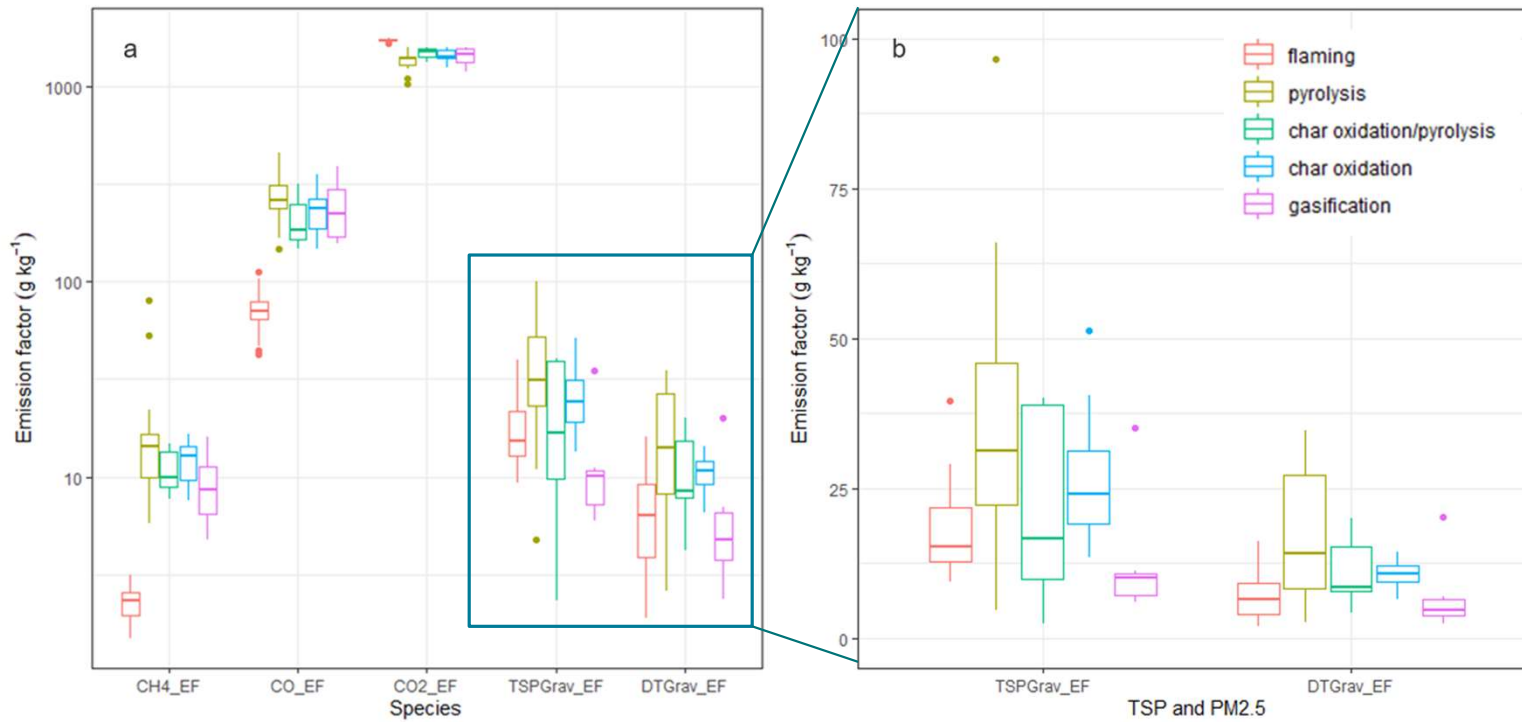
### Flaming combustion:

*$\rightarrow$  Heat + CO<sub>2</sub> + H<sub>2</sub>O + other gases*





# Emissions as a function of combustion process





# Finding an explanatory variable to explain observed variation in particle EF – Combustion efficiency?

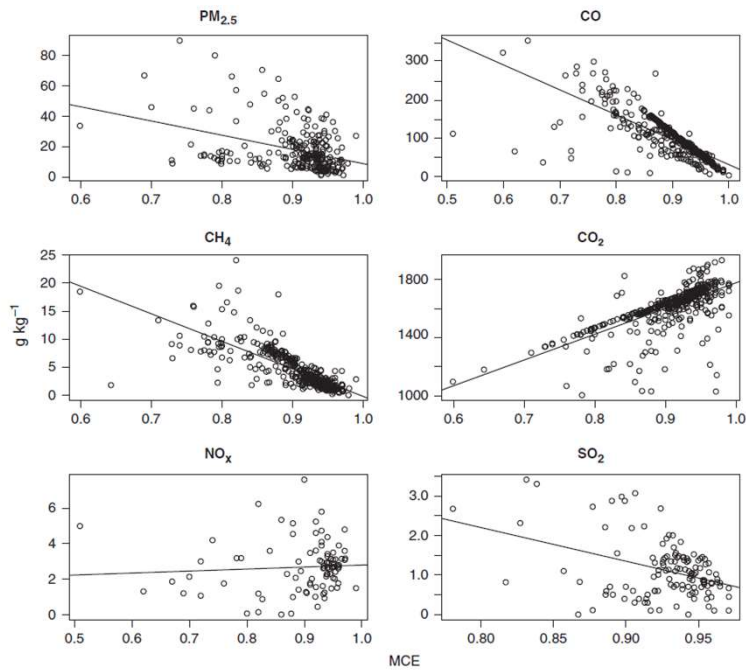
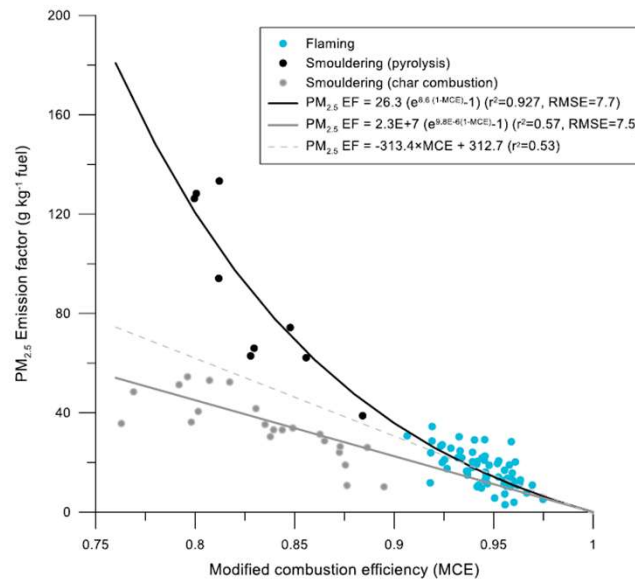
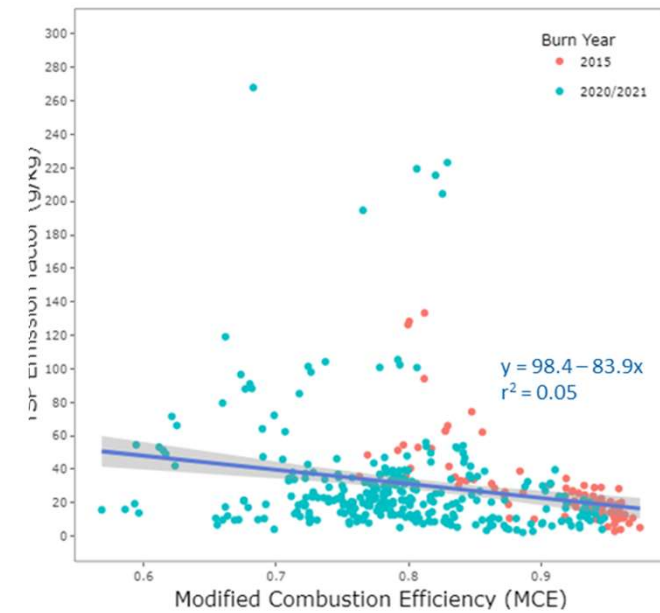


Fig. 2. Correlation plots between modified combustion efficiency and emission factor of major pollutants including PM<sub>2.5</sub>, CO, CH<sub>4</sub>, CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub>.



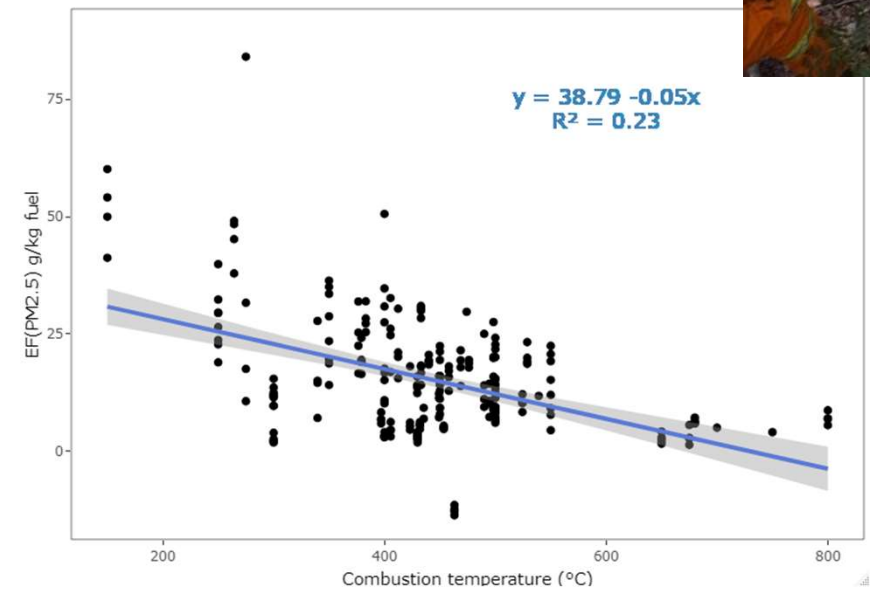
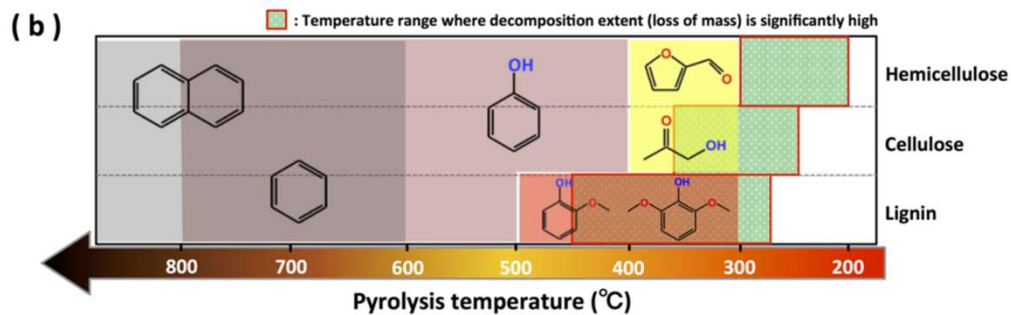
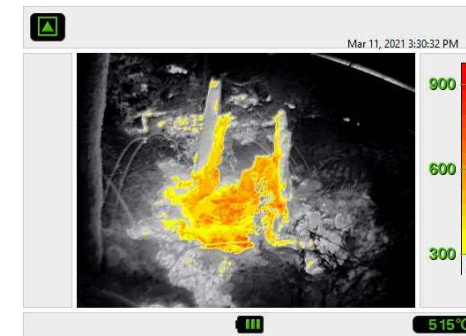
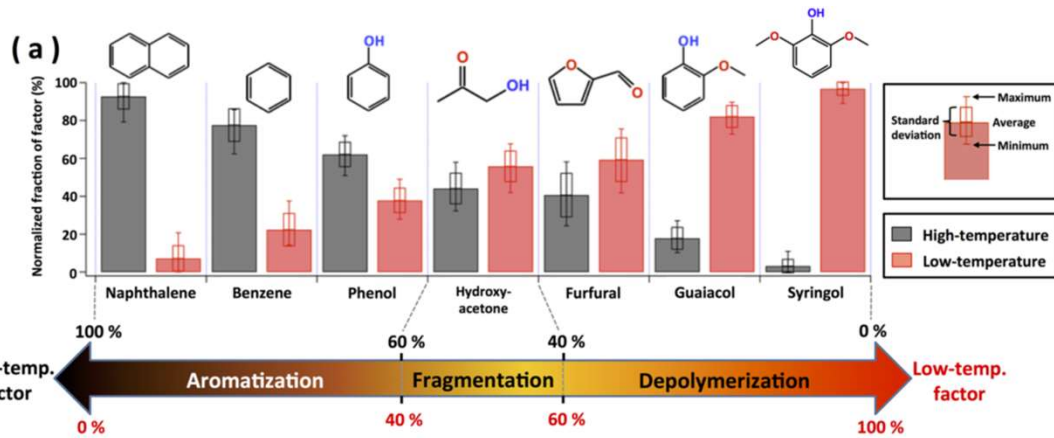
Reisen et al. (2018). Journal of Geophysical Research: Atmospheres, 123, 8301–8314. <https://doi.org/10.1029/2018JD028488>



Prichard et al (2020) International Journal of Wildland Fire, 29, 132–147, <https://doi.org/10.1071/WF19066>



# Finding an explanatory variable to explain observed variation in particle EF – Combustion temperature?



K. Sekimoto et al. (2018) Atmos. Chem. Phys., 18, 9263–9281  
<https://doi.org/10.5194/acp-18-9263-2018>



# Upscaling from individual log to burn area

Develop a distribution of combustion temperatures from smouldering CWD

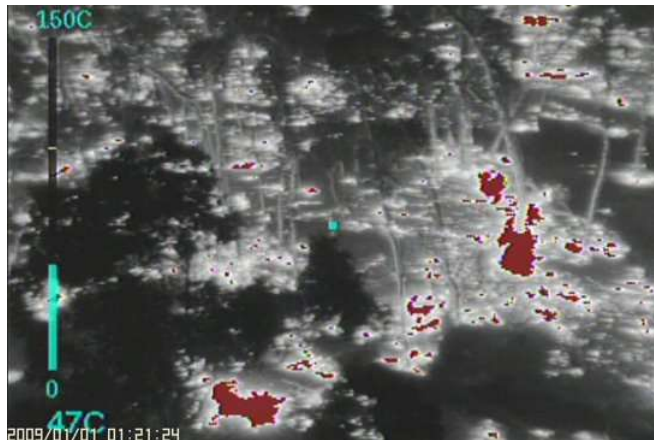
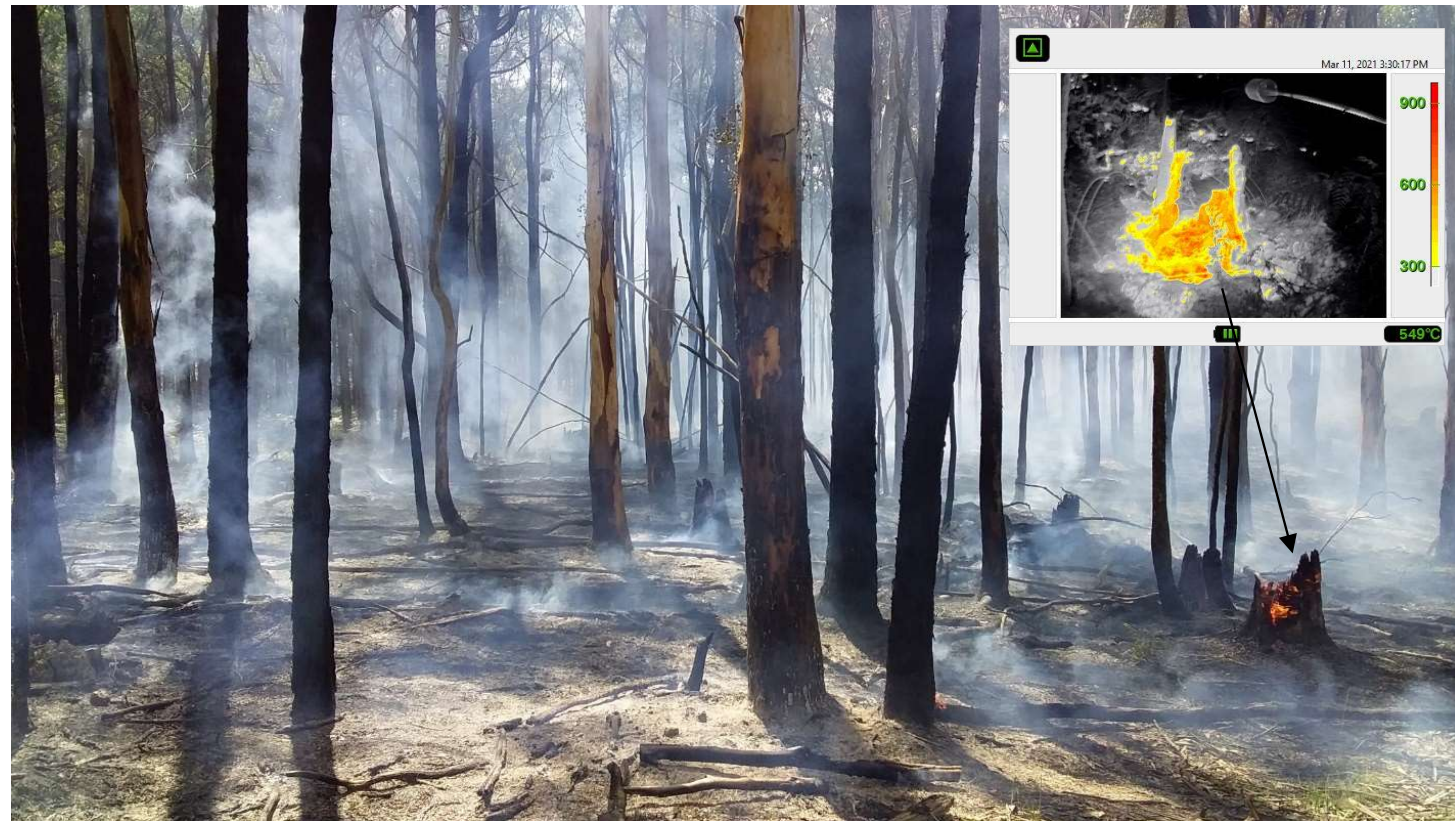
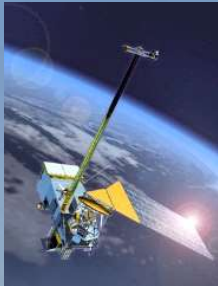


Photo: Aaron van Winden and Will Johnston from DELWP Barwon South West



# Combination of approaches to give us the most robust short-term smoke forecasting



## Top-down approach

Fire Radiative Power  
Satellite observations of AOD/CO



Refinement of emissions  
based on observations and  
inverse modelling



**SMOKE EMISSION FLUXES**



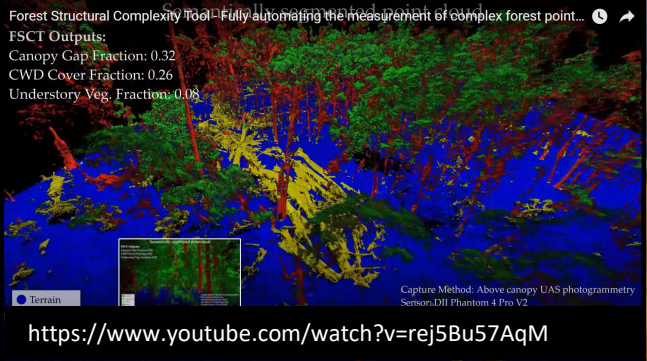
Fuel consumption



Fuel type/Fuel load



## Bottom-up approach



Fuel mapping using optical aerial  
imagery and multispectral LiDAR



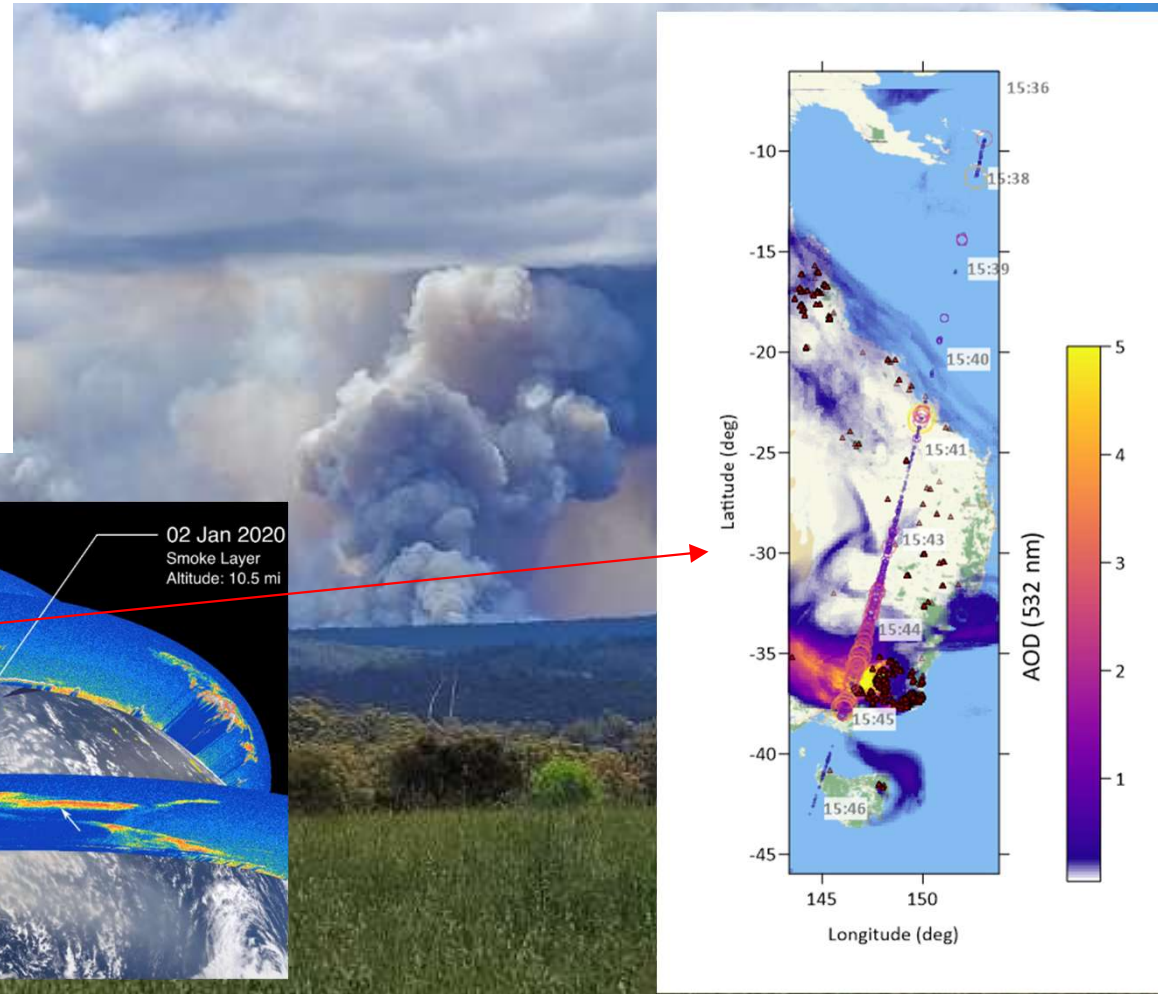




# Derive emissions from satellite AOD or CO observations

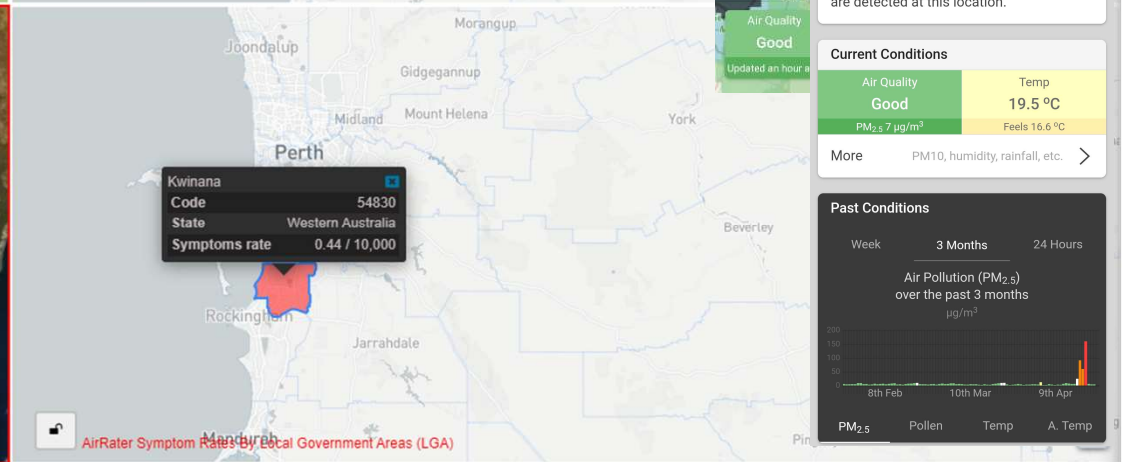
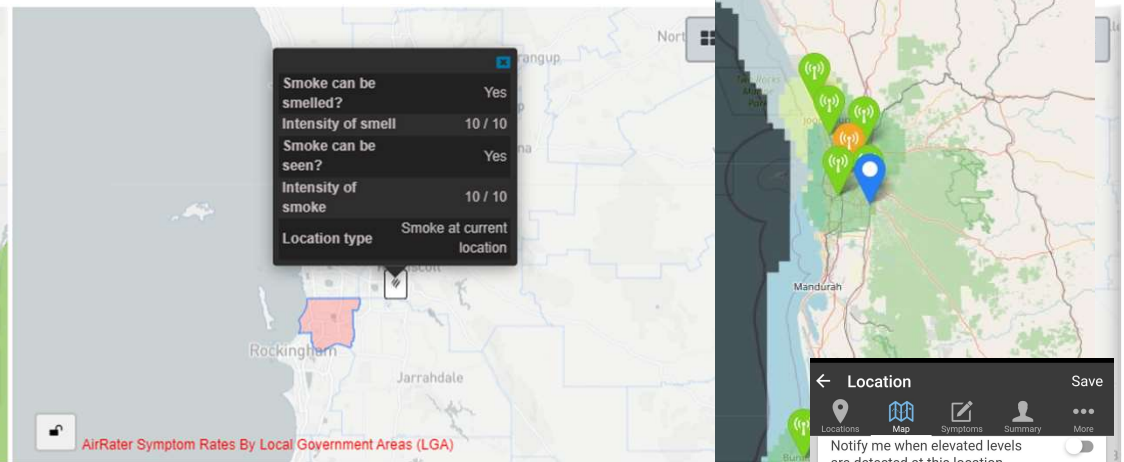
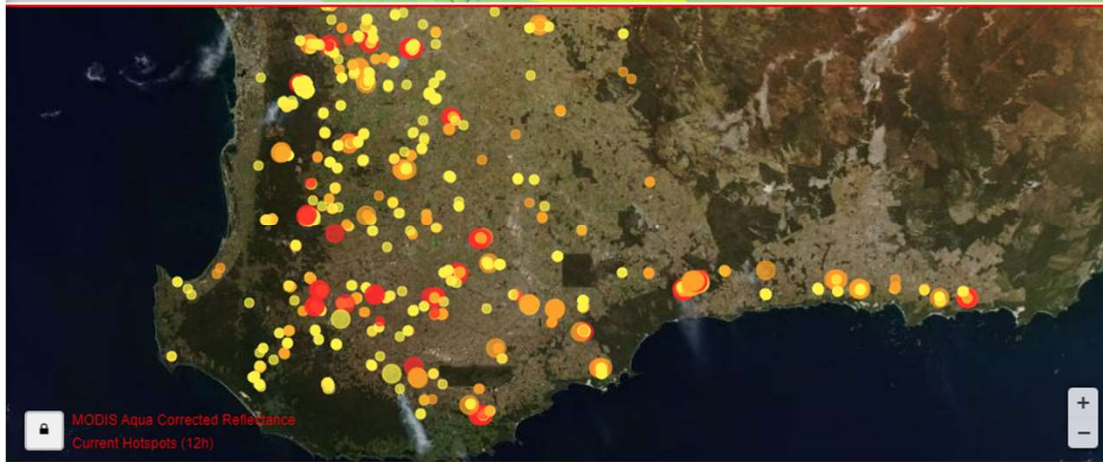
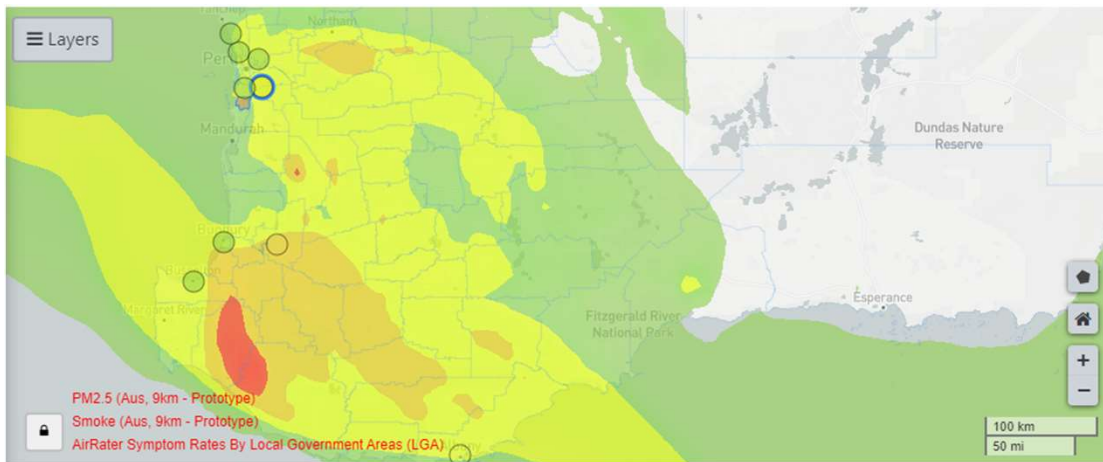
Top – down approach:

1. Derive emissions using FRP, which is related to the rate of biomass combustion
2. Derive particle emissions using satellite AOD observations (MODIS, Himawari)
3. Derive emission rates of trace gases (e.g. CO, NO<sub>2</sub>) using the TROPospheric Monitoring Instrument (TROPOMI) observations.





# From forecast to exposure



Map

Locations | Map | Symptoms | Summary | More

Help | Refresh | Search | Location | Layers

Location

Notify me when elevated levels are detected at this location.

Current Conditions

Air Quality	Temp
Good	19.5 °C
PM2.5 7 µg/m³	Feels 16.6 °C

More: PM10, humidity, rainfall, etc.

Past Conditions

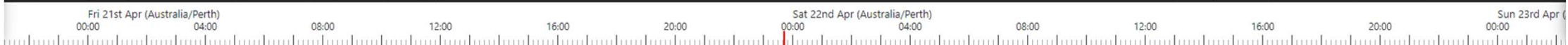
Week | 3 Months | 24 Hours

Air Pollution (PM2.5) over the past 3 months µg/m³

PM2.5 | Pollen | Temp | A. Temp

Layers Drag the top of the timeline to adjust the time (or expand area). Click grey cells to load.

Now 1x speed Play Enlarge Reduce Or shift + mouse wheel





# Thank you

## Environment

Fabienne Reisen  
Principal Research Scientist

+61 3 9239 4435

[fabienne.reisen@csiro.au](mailto:fabienne.reisen@csiro.au)

## Environment

Martin Cope  
Principal Research Scientist

+61 3 9239 4647

[martin.cope@csiro.au](mailto:martin.cope@csiro.au)

Australia's National Science Agency

The screenshot shows the top of a website for 'Air Quality Forecasting' with the CSIRO logo. The main heading is 'National AQFx prototype system' with a sub-heading 'A tool for assessing smoke impacts from bushfires and planned burns'. Below this is a paragraph of text explaining the project's background and a QR code. At the bottom of the screenshot is the URL <https://research.csiro.au/aqfx/>.

**Air Quality Forecasting** CSIRO.AU

Our activities ▾ Who we are News & Publications Portal Login ▾ 🔍

## National AQFx prototype system

A tool for assessing smoke impacts from bushfires and planned burns

The extent of the 2019/2020 bushfires highlighted the urgent need for a national smoke forecasting system to protect the health of Australians. In response, the Australian Government has provided funding to develop a national prototype smoke forecasting system. The project will test potential extensions to the current operational AQEx system. AQFx is run by the Bureau of Meteorology in Victoria for the Department of Environment, Land, Water and Planning (DELWP), and in NSW for the Rural Fire Service (RFS).

The prototype system will be developed through a research collaboration between CSIRO, Bureau of Meteorology, the University of Tasmania, the University of Sydney, the University of Melbourne and DELWP.

<https://research.csiro.au/aqfx/>