The effects of fire-plume dynamics on the lateral and longitudinal spread of long-range spotting

www.cawcr.gov.au

Jeffrey Kepert, William Thurston, Kevin Tory and Robert Fawcett

Tuesday 2 September 2014

bushfire&natural HAZARDSCRC

Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

CSIRO

Motivation

- The lofting and transport of firebrands ignites spot fires downwind from the primary fire

- Spot fires lead to **accelerated** and **unpredictable** fire spread
  - *Accelerated*: Embers cause the fire to jump ahead. Upper-level winds are often faster than near-surface winds,
  - *Unpredictable*: How far will it spot? Upper-level winds are often in a different direction from the near-surface winds

- There is evidence for very long-range spotting in excess of 30 km, e.g. Kilmore East fire during Black Saturday

- A better knowledge of processes involved in spotting will improve our ability to predict fire spread

Modelling methodology

- We use a **two-stage** modelling process to investigate how plume dynamics may affect spotting:

1. Perform very-high-resolution simulations of idealised bushfire plumes in different wind conditions using a large-eddy model (LEM)

2. Use the four-dimensional (3 space, 1 time) velocity fields from the LEM to calculate the trajectories of hundreds of thousands of virtual firebrands assigned a constant fall velocity

UK Met Office Large Eddy Model (LEM)

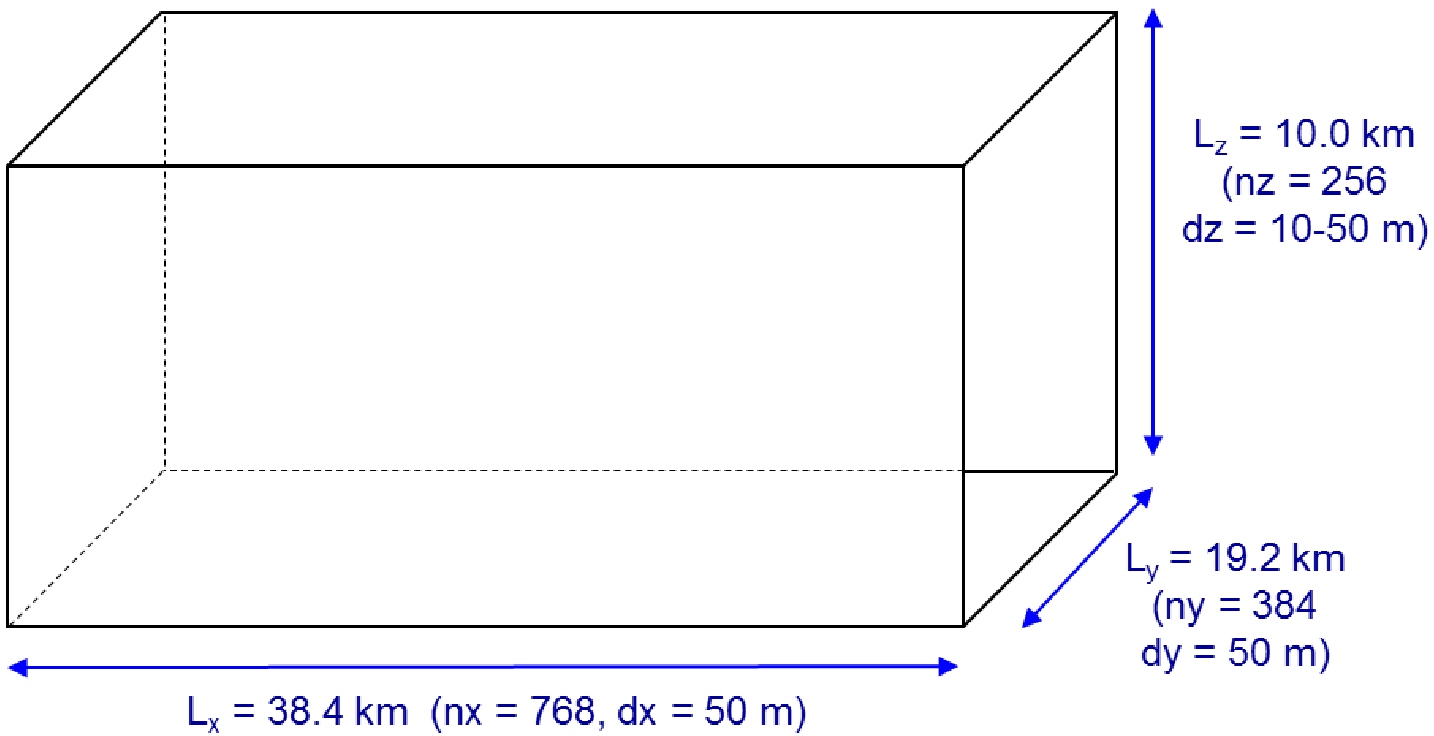
- Think of as a **simplified** numerical weather prediction model, but run at a **very-high resolution** (here grid spacing = 50 m)
  - Able to explicitly resolve plumes, entrainment/detrainment of air

- Historically used for more traditional high-resolution atmospheric applications:
  - Boundary-layer turbulence
  - Clouds and convection

Khairoutdinov and Randall (2006) - Simulated explicitly resolved clouds:

- Recently the ability of the Met Office LEM to model both observed and theoretical plumes has been confirmed

LEM configuration



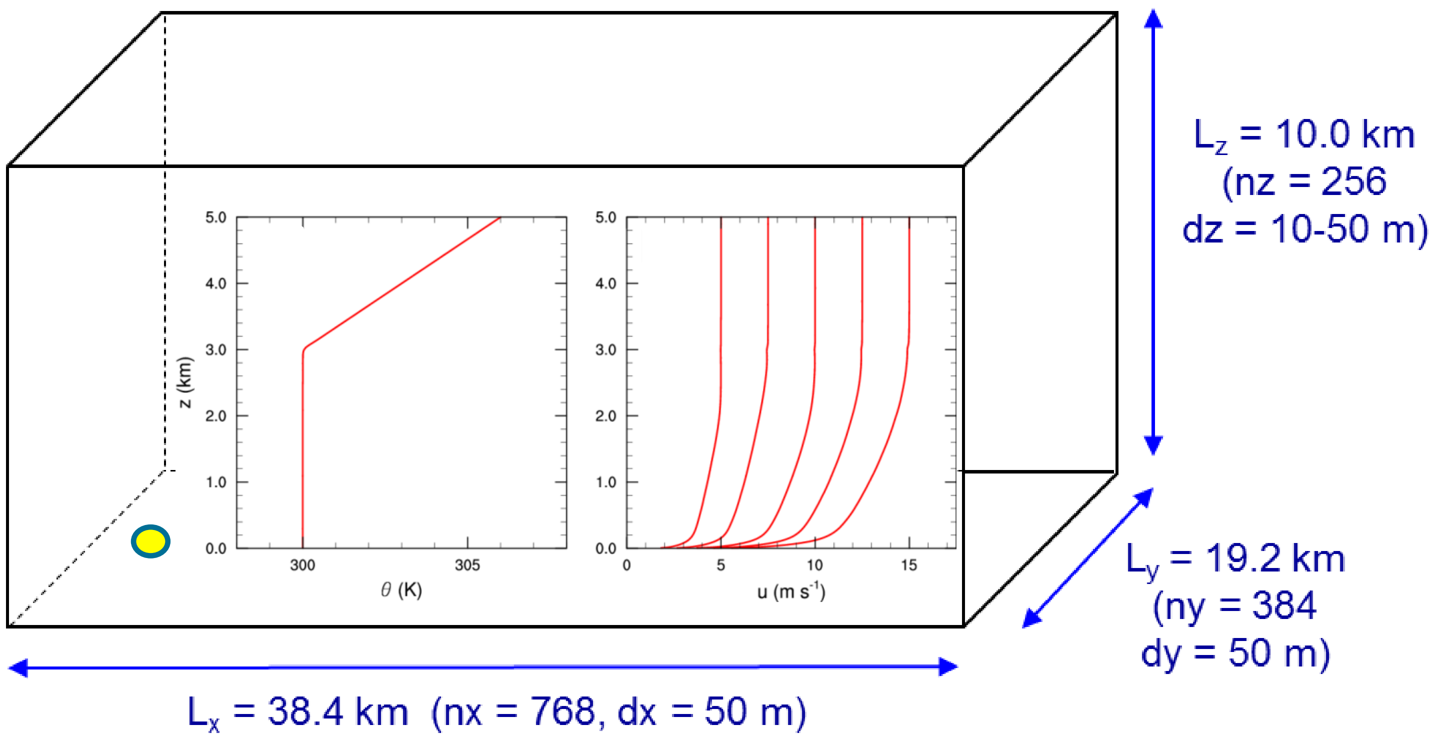
- Idealised setup (no moisture, radiation, Coriolis, topography)
- Periodic lateral boundary conditions
- No-slip lower boundary
- Free-slip upper boundary (+ Newtonian damping layer in upper 2 km)

Plume modelling process

1. Simulate realistic turbulent boundary layers for a range of wind speeds (not previously done in idealised plume studies):
   - Initialise model with horizontally homogeneous potential temperature and wind profiles
   - Apply random perturbations (± 0.2 K) to potential temperature field
   - Run model until turbulence (defined by domain-averaged TKE) has spun up to quasi-steady state

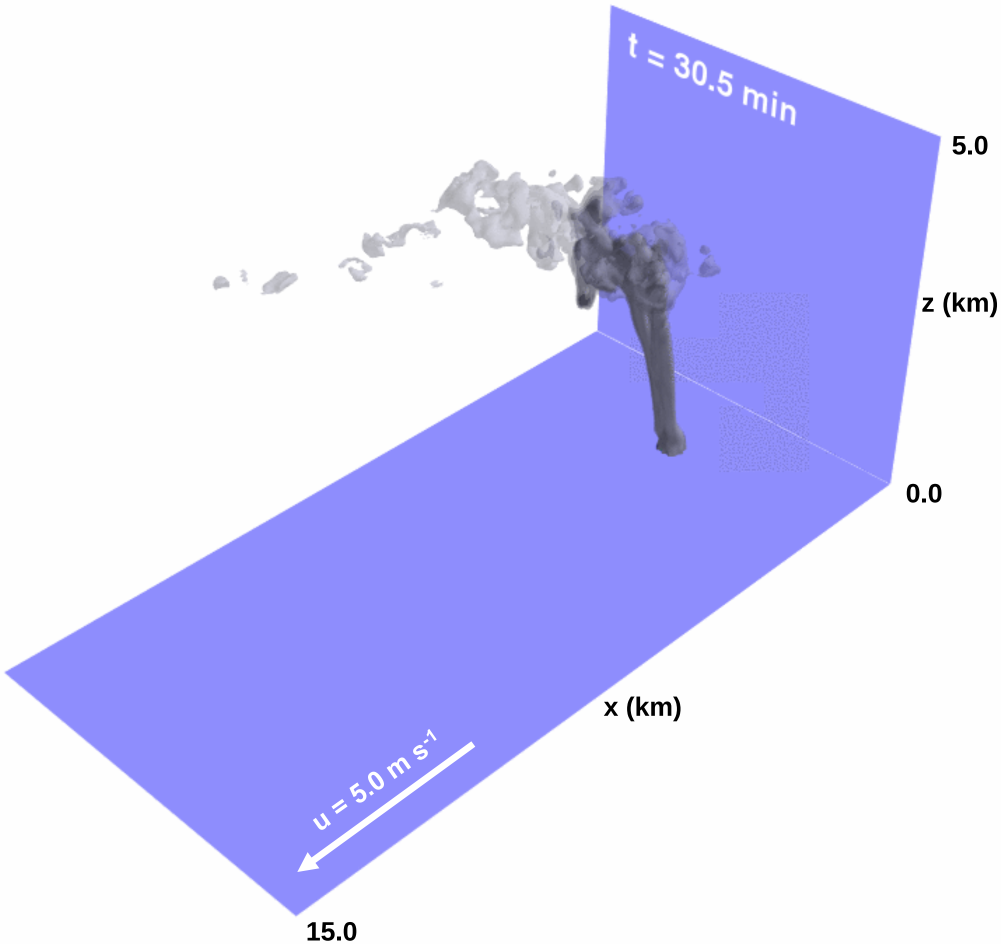
2. Generate a “fire” plume by applying an intense circular surface heat flux anomaly ($Q = 100{,}000\ W\ m^{-2}$, radius = 250 m)
   - No feedback of atmosphere onto fire behaviour
   - No surface spread
   - Allows us to isolate the way plumes respond to wind
   - Passive tracer released for plume visualisation purposes

LEM configuration



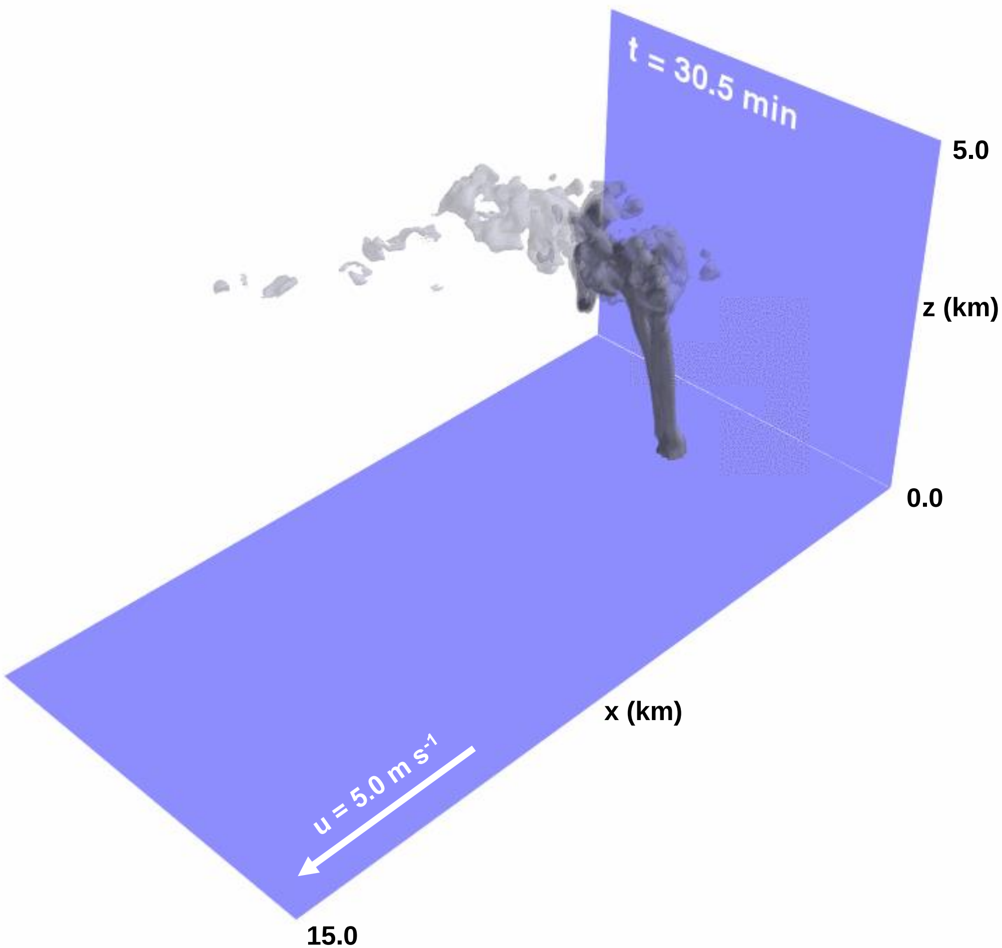
- Potential-temperature profile is well mixed to z = 3 km, stably stratified above
- Five different background wind speeds run, u = 5.0, 7.5, 10.0, 12.5 and 15.0 m s^{-1}

Tracer visualisation – 5 m s^{-1} wind



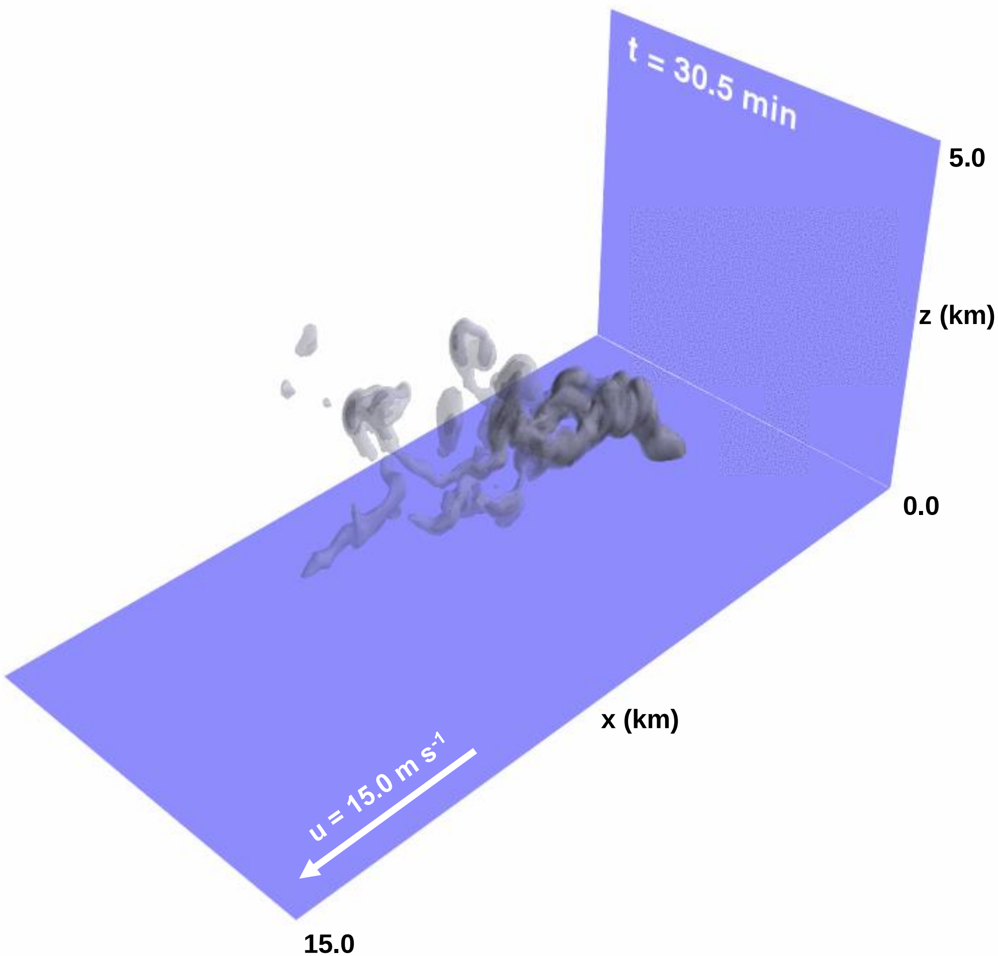
- Lower two-thirds of plume is within boundary layer:
  - Relatively smooth
  - Small instability at top of smooth updraft
  - Consists of a counter-rotating vortex pair
- Upper section of plume above the boundary layer:
  - Plume is much more turbulent

Tracer visualisation – 5 m s^{-1} wind



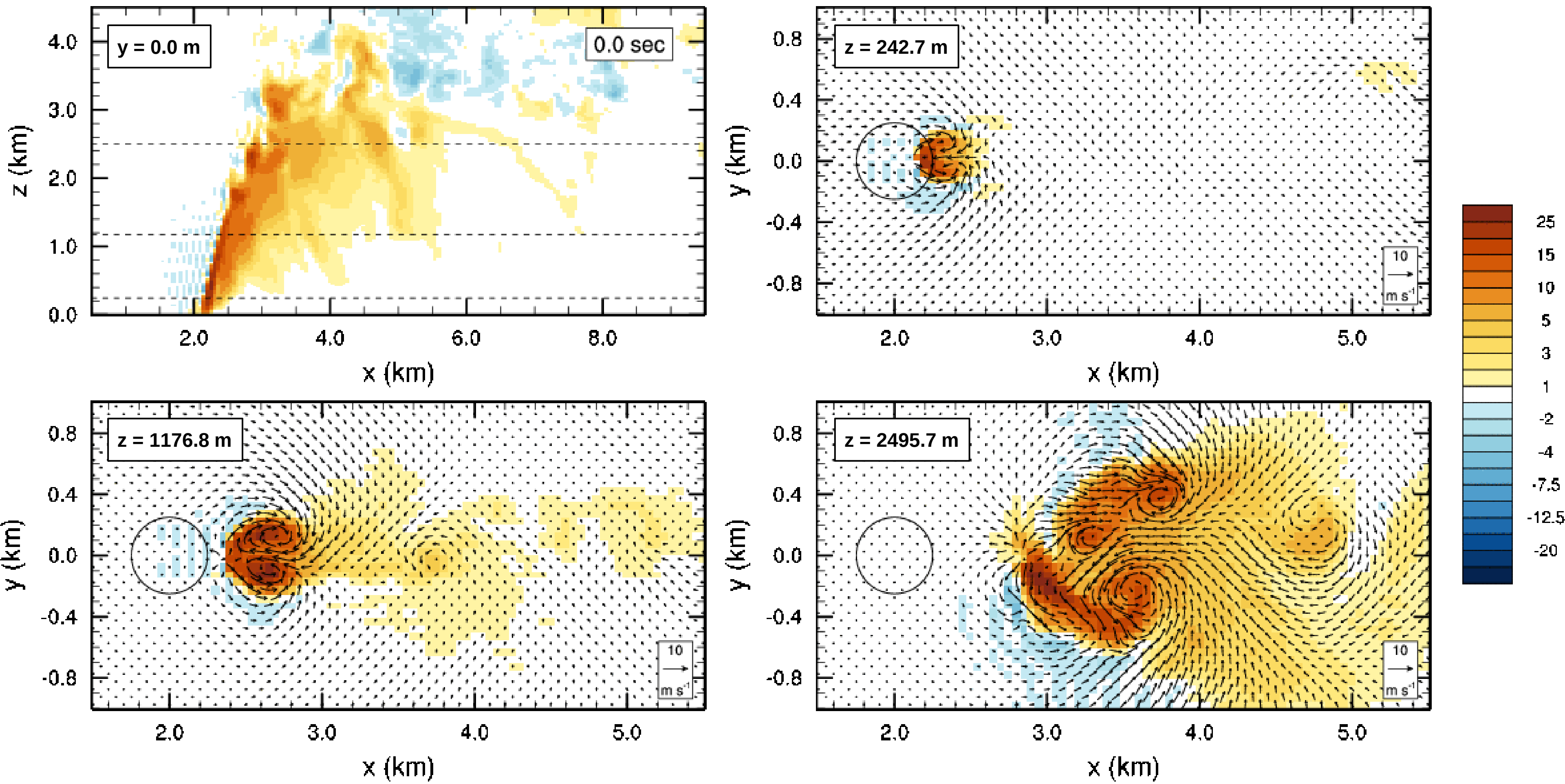
- Lower two-thirds of plume is within boundary layer:
  - Relatively smooth
  - Small instability at top of smooth updraft
  - Consists of a counter-rotating vortex pair
- Upper section of plume above the boundary layer:
  - Plume is much more turbulent
  - Meandering above the boundary layer is more prominent

Tracer visualisation – 15 m s^{-1} wind

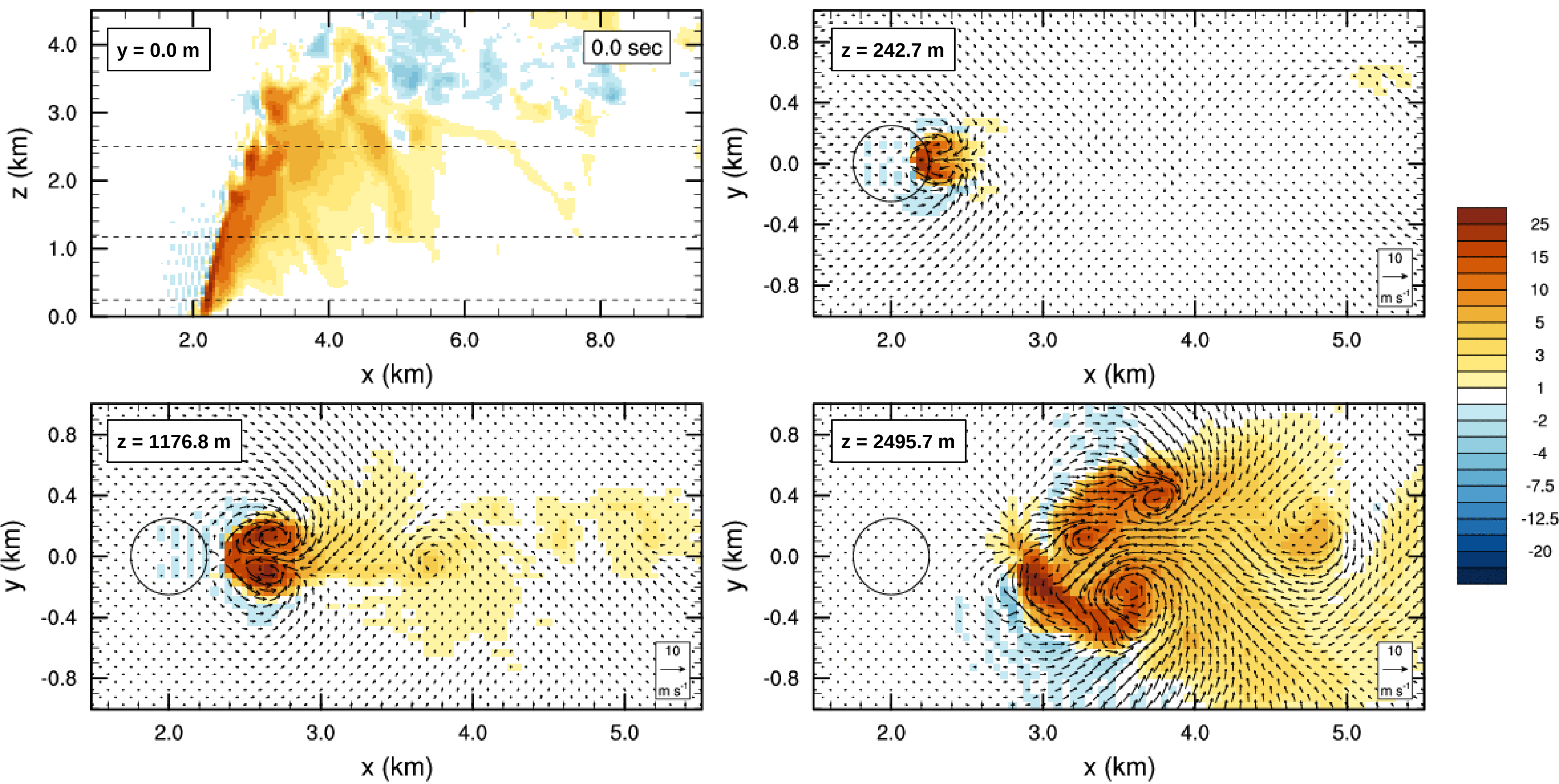


- Plume is turbulent from the surface upwards
- Plume is much more bent over
- Plume exhibits pulsing
- Plume is more dispersed
- Plume meanders from near-surface to top

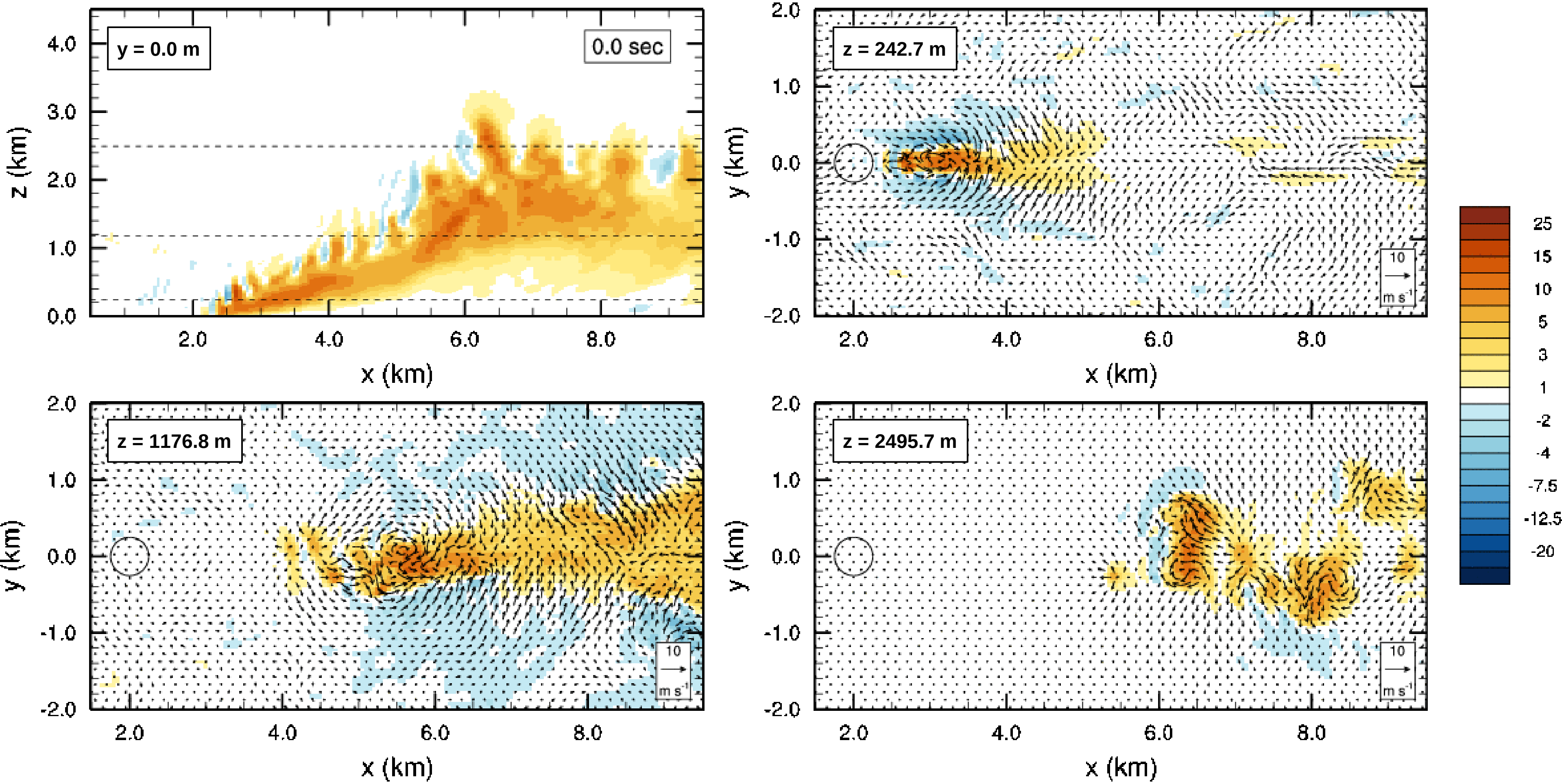
Plume dynamics – 5 m s^{-1} wind



Plume dynamics – 5 m s^{-1} wind



Plume dynamics – 15 m s^{-1} wind



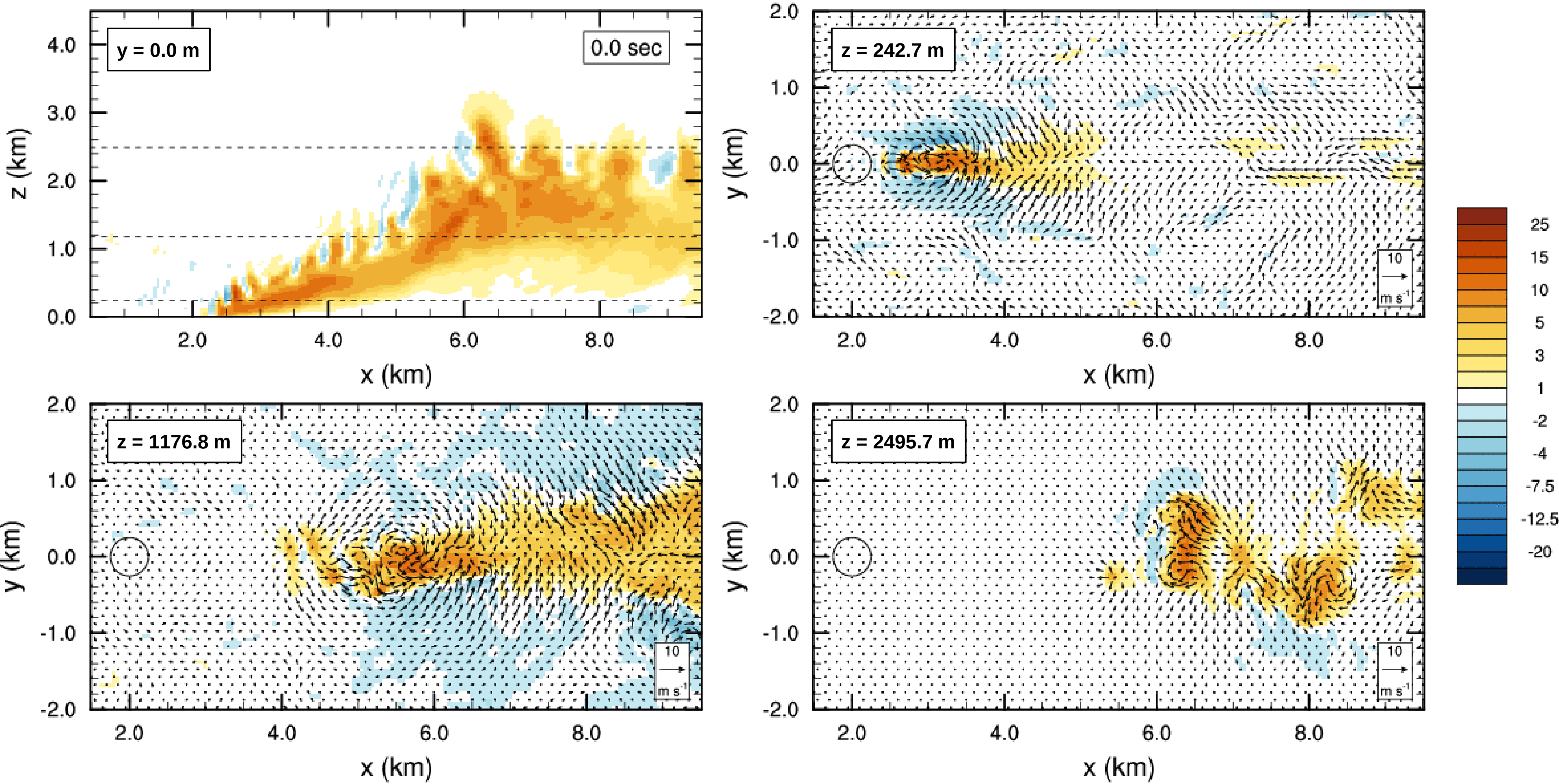
bushfire&natural HAZARDS CRC

Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

CSIRO

Plume dynamics – 15 m s^{-1} wind



bushfire&natural HAZARDSCRC

Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

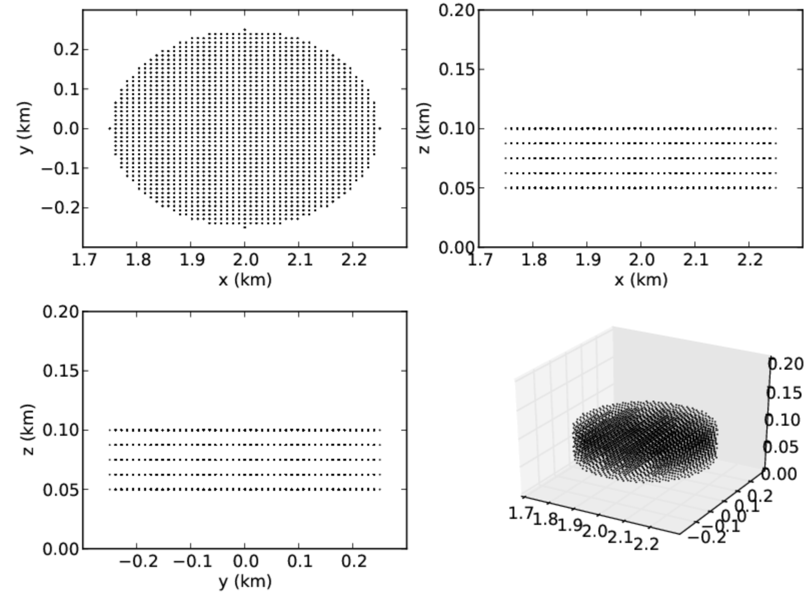
CSIRO

Particle-transport model

- Three-dimensional velocity fields from the LEM are output and stored every 5 seconds
- These are used to drive a simple Lagrangian particle-transport model
- Particles are initialised near the base of the plume and advected by the velocity field plus a constant fall velocity of 6.0 m s^{-1}
  - LEM velocities are linearly interpolated in space and time to each particle's location
- Using a 0.05 s timestep (similar to the LEM plume modelling), the position of each particle at the next timestep is calculated using the 2nd order Runge-Kutta method

Particle initialisation

- Particles are released in a cylindrical "blob" of radius 250 m, located between z = 50 and z = 100 m.
- Equal (*x*,*y*,*z*) spacings of approximately 10 m between particles result in 8265 particles per release
- One release is performed every 5 s for 15 minutes, resulting in almost 1.5 million particles being tracked per plume
- About one third of these travel more than 1 km downwind of their launch – the threshold we use here for calculating statistics of firebrand transport



bushfire&natural HAZARDSCRC

Australian Government
Bureau of Meteorology

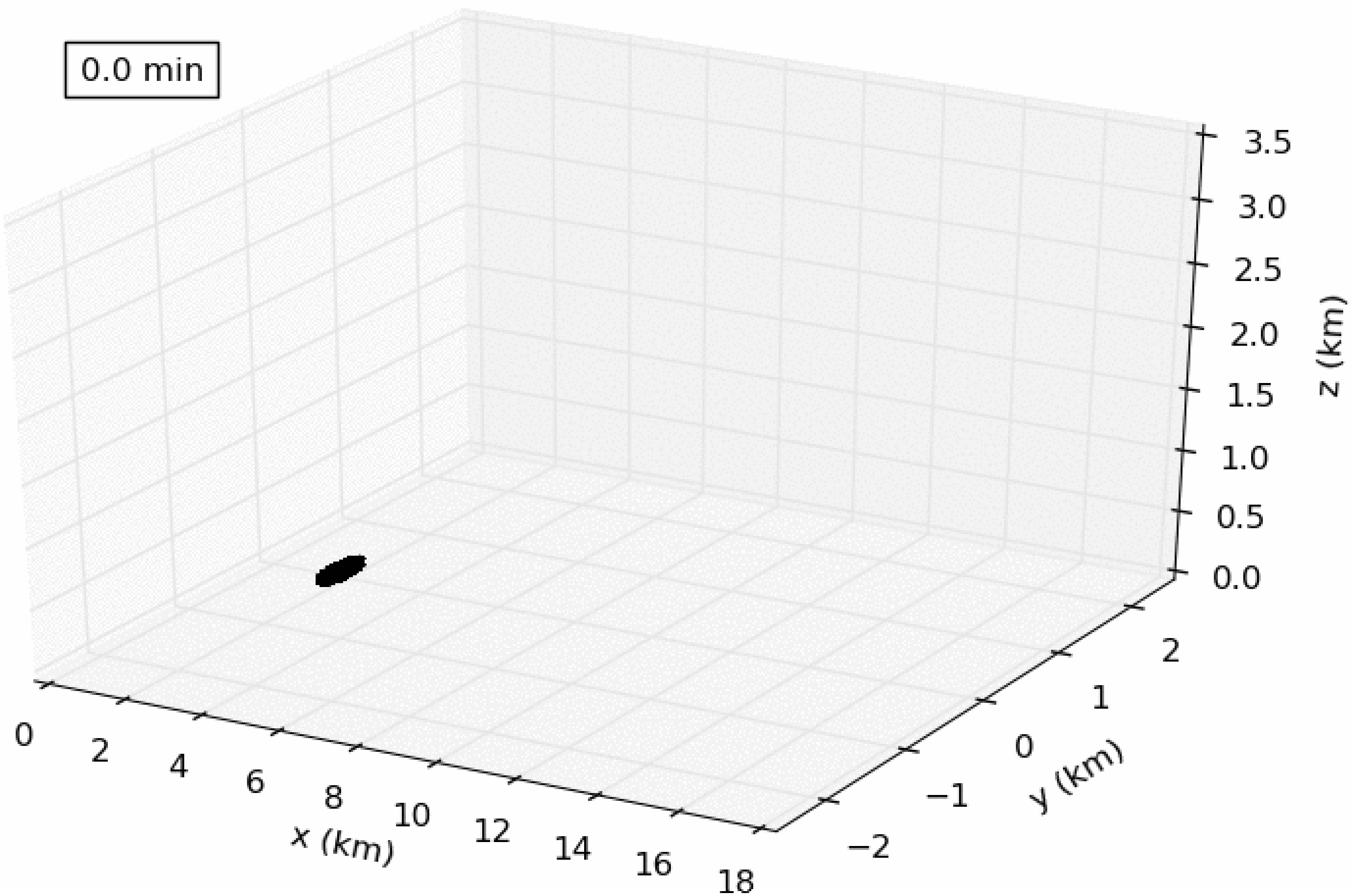
The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

CSIRO

Firebrand transport – 5 m s^{-1} wind

8265 particles released every 5 s for 15 min = 1,487,700 total

Only every 100th particle is shown here

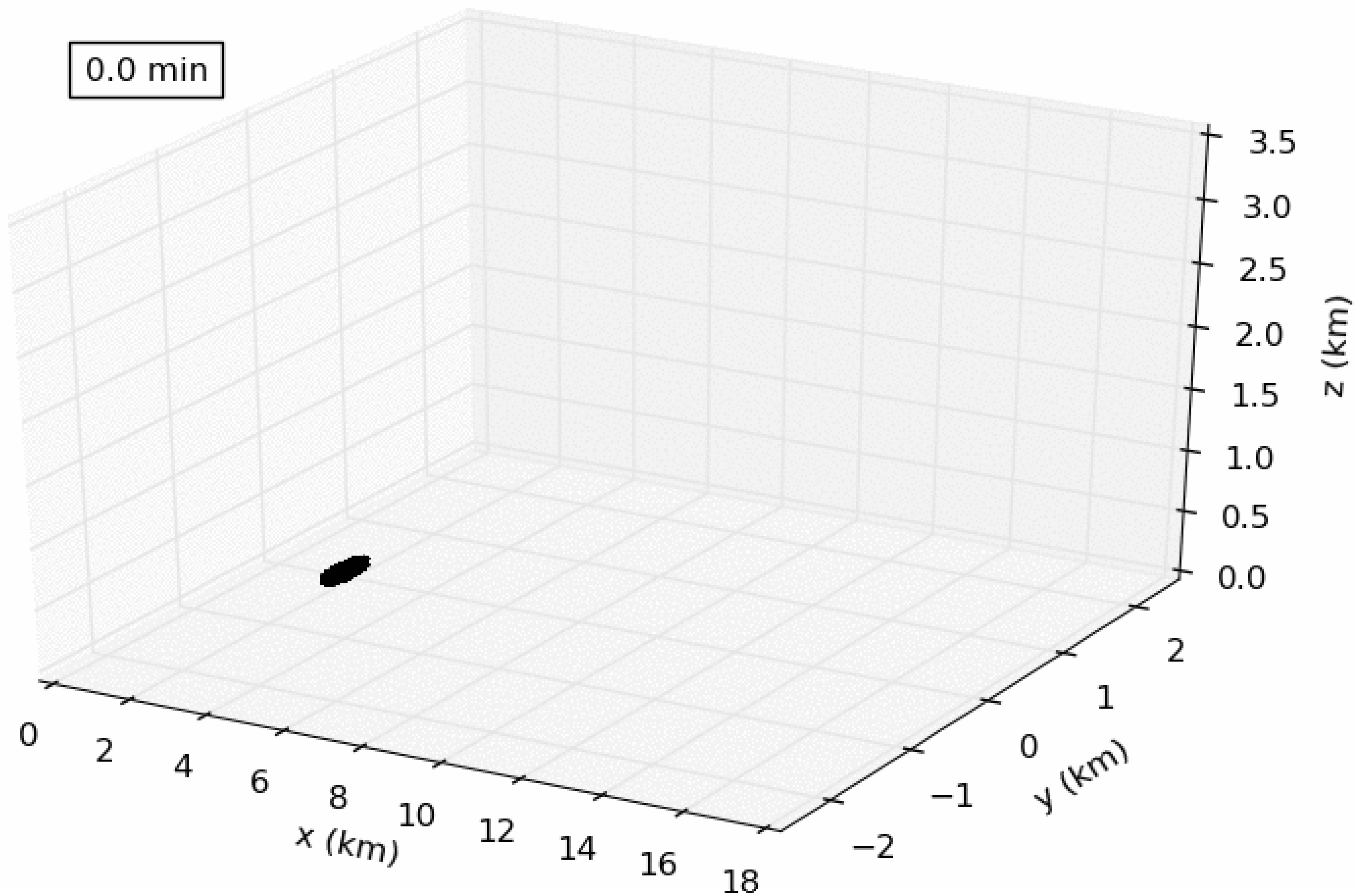


Firebrand transport – 5 m s^{-1} wind

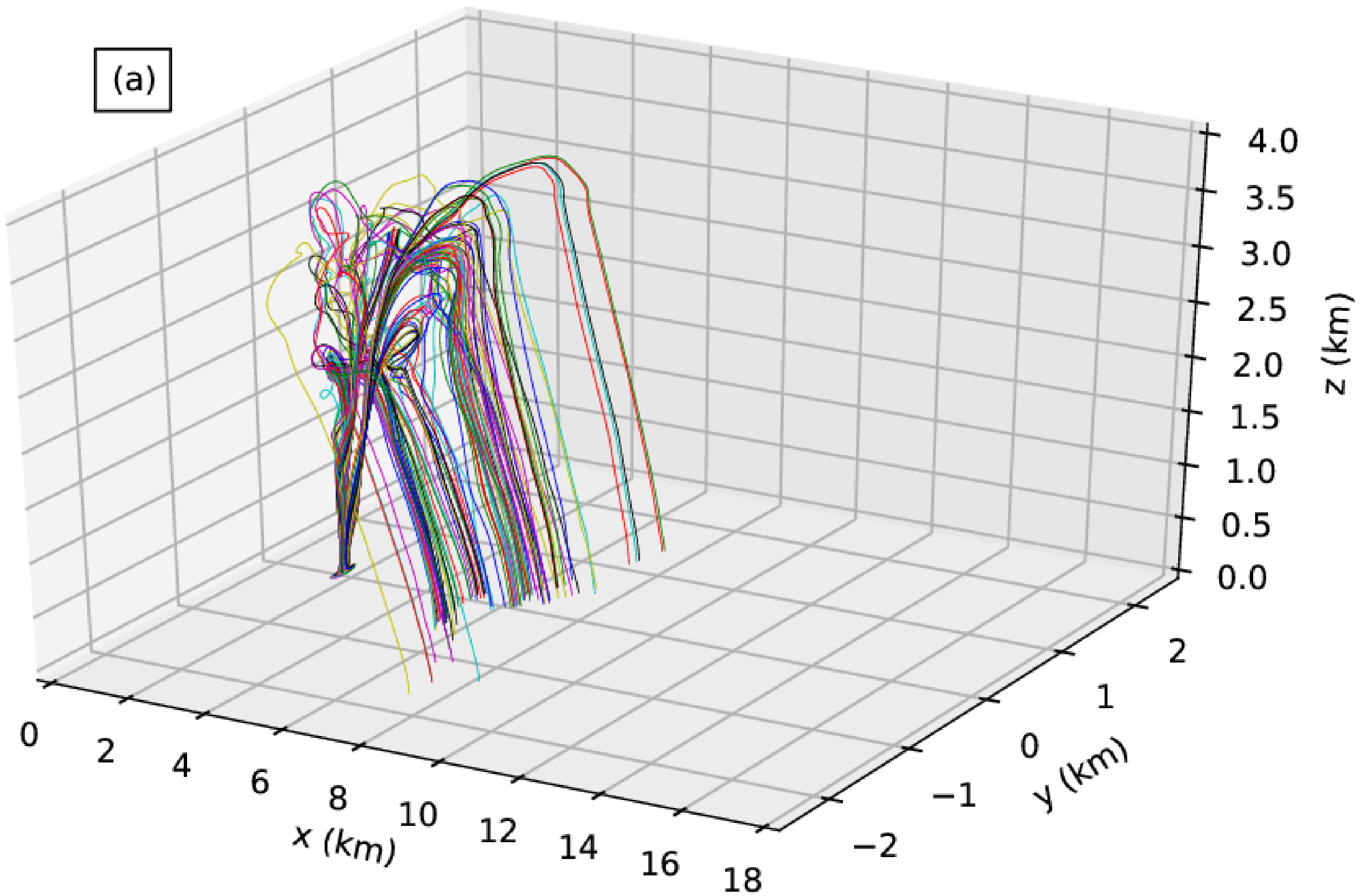
8265 particles released every 5 s for 15 min = 1,487,700 total

Only every 100^{th} particle is shown here

471,004 (31.7 %) travel > 1 km



100 random trajectories – 5 m s^{-1} wind

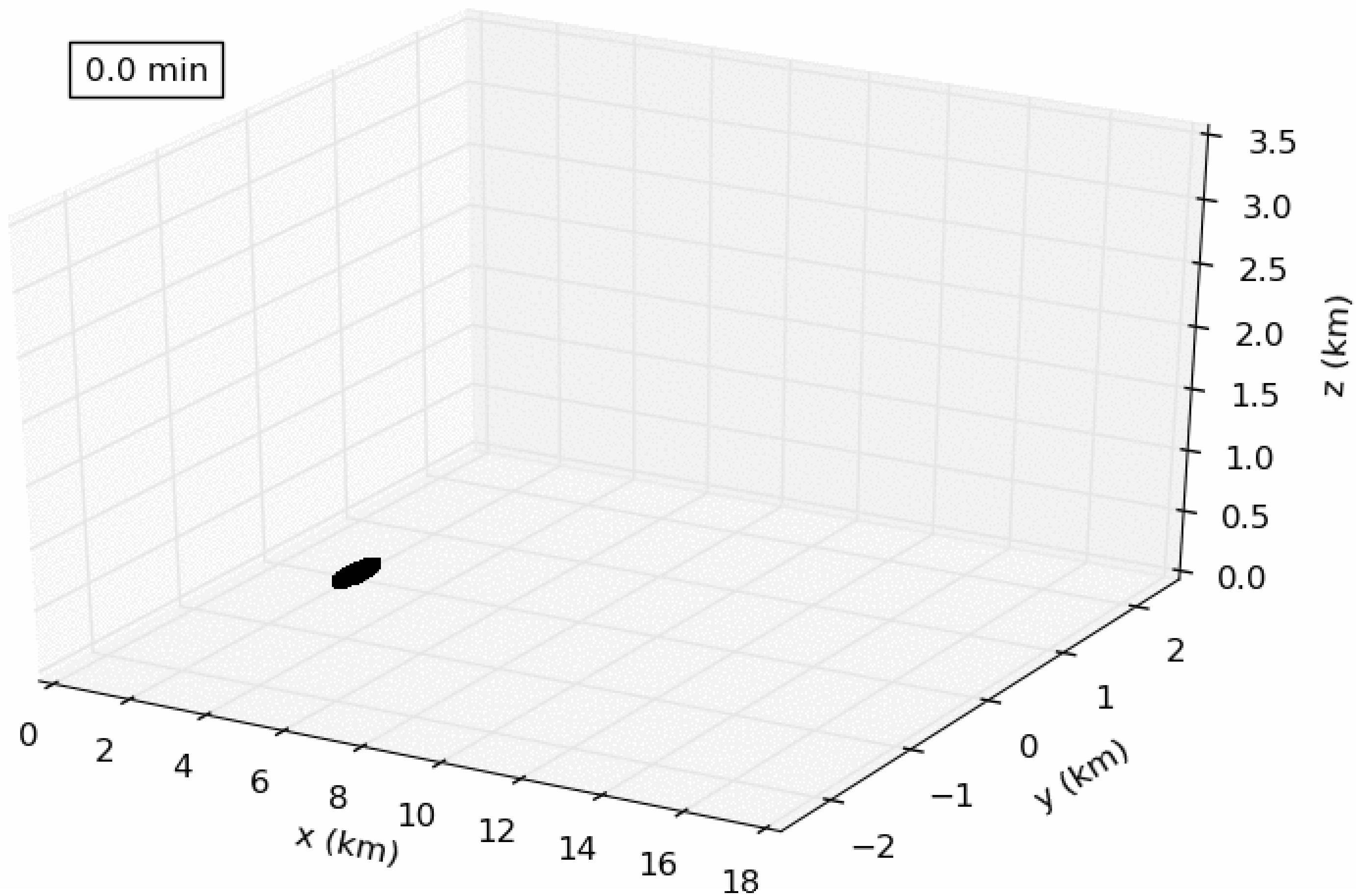


Firebrand transport – 15 m s^{-1} wind

8265 particles released every 5 s for 15 min = 1,487,700 total

Only every 100th particle is shown here

478,058 (32.1 %) travel > 1 km

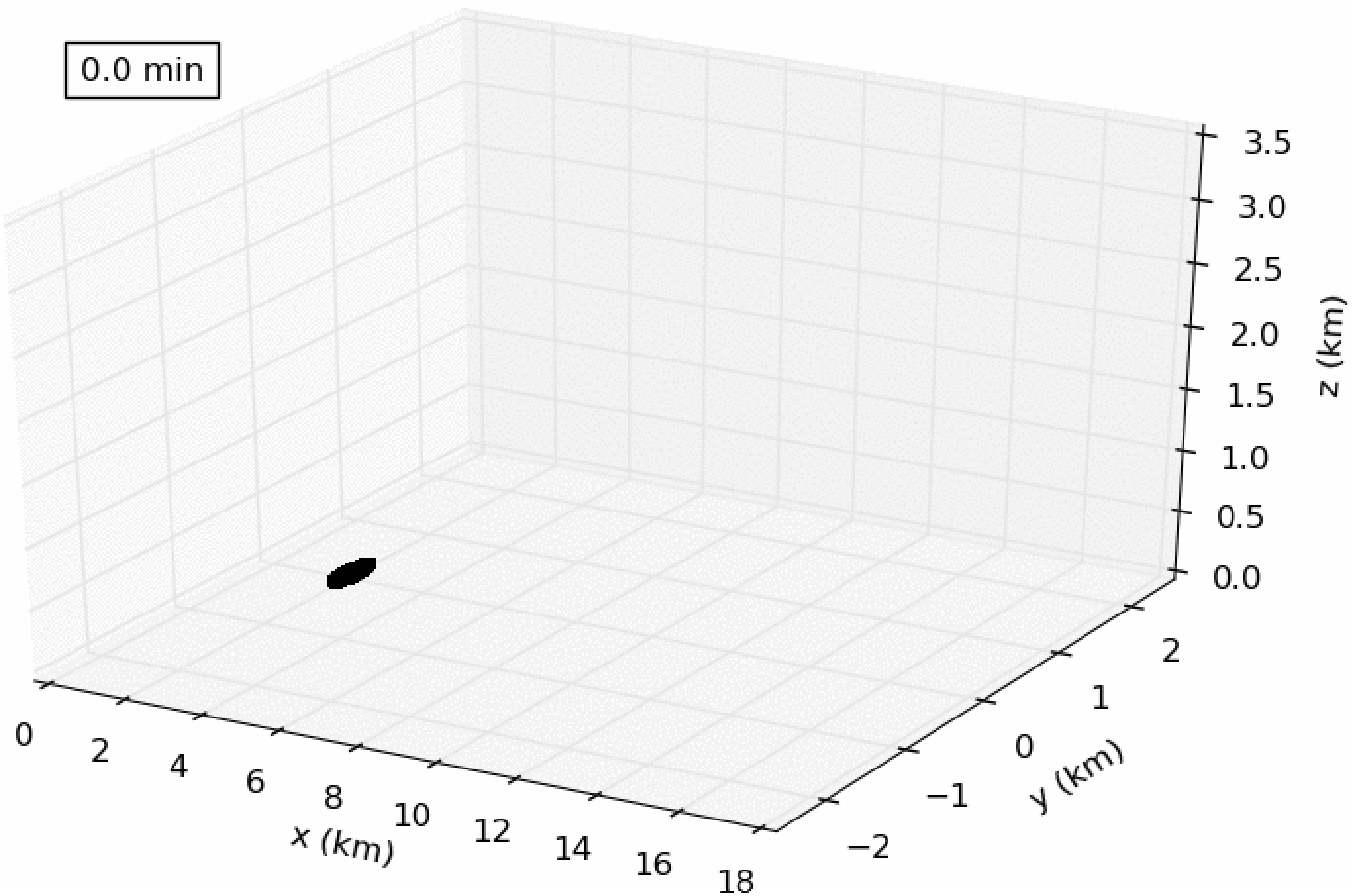


Firebrand transport – 15 m s^{-1} wind

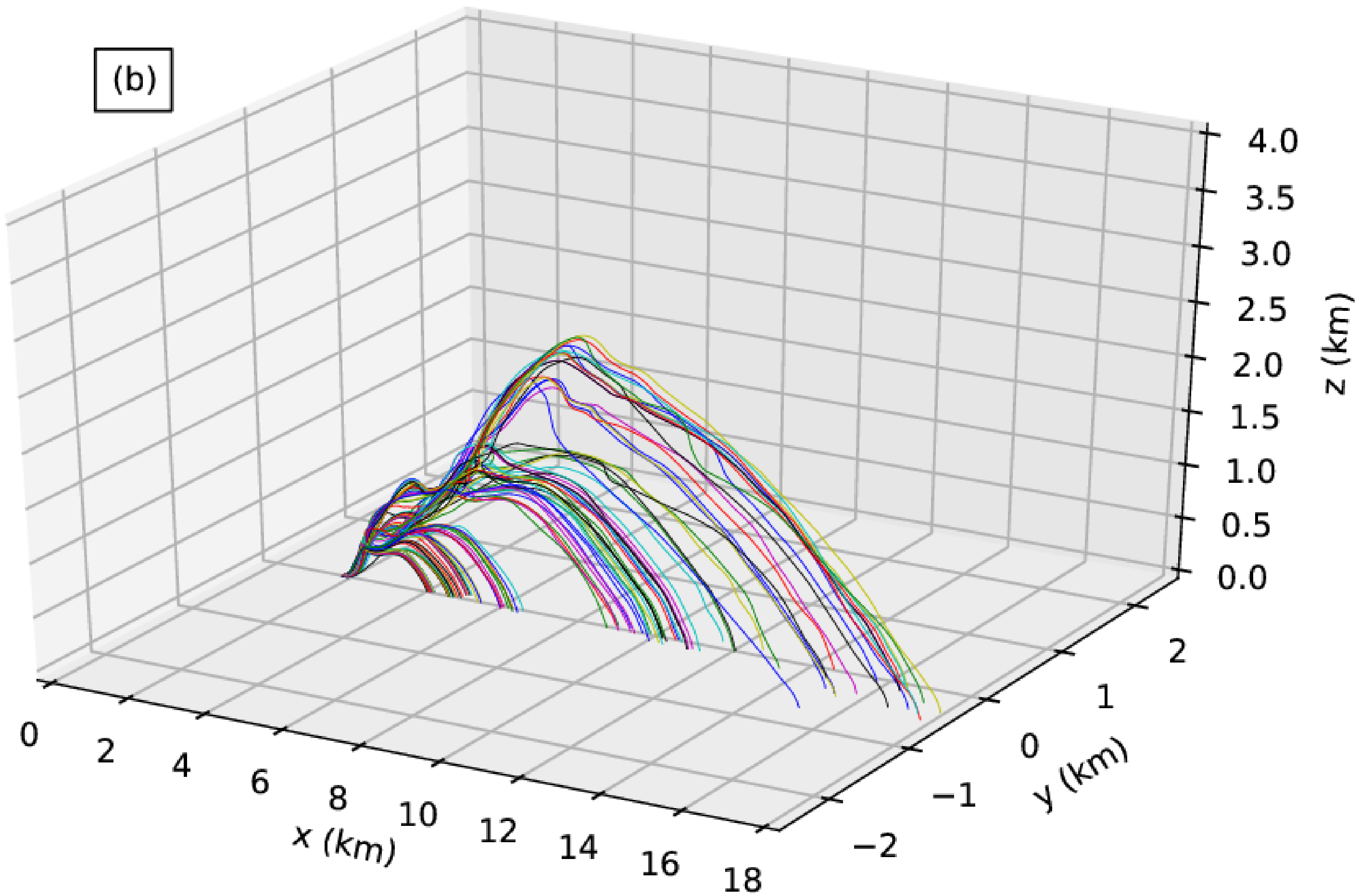
8265 particles released every 5 s for 15 min = 1,487,700 total

Only every 100th particle is shown here

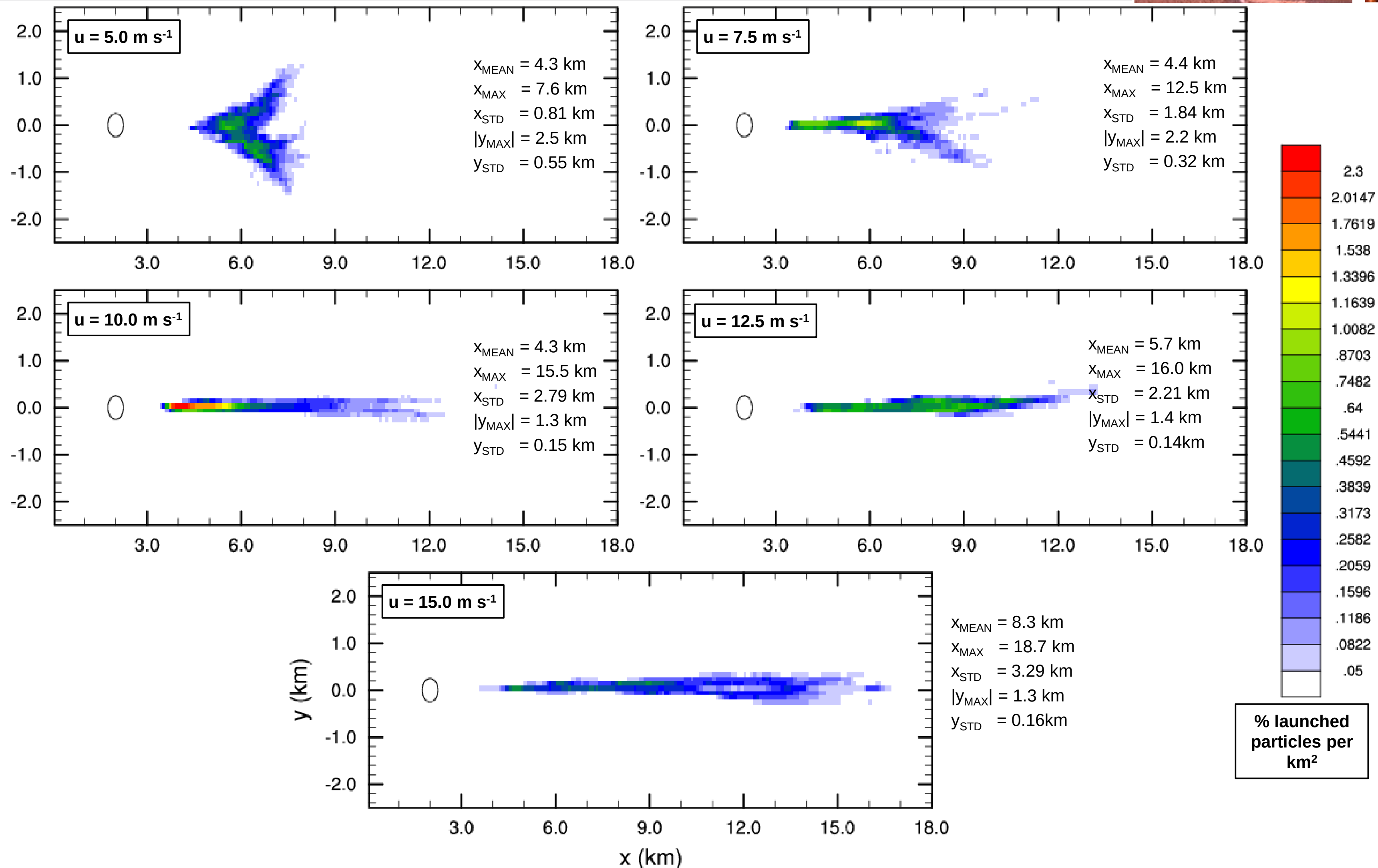
478,058 (32.1 %) travel > 1 km



100 random trajectories – 5 m s^{-1} wind



Two-dimensional landing distributions



bushfire&natural HAZARDS CRC

Australian Government
Bureau of Meteorology

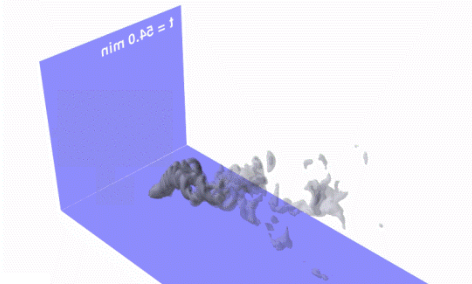
The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

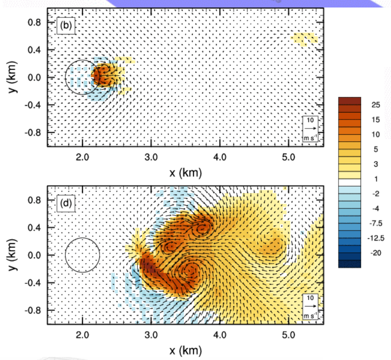
CSIRO

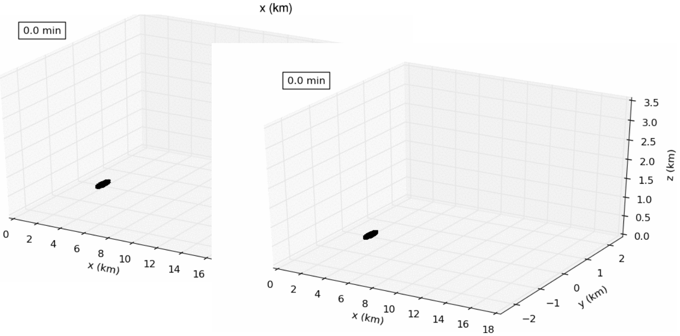
Future work

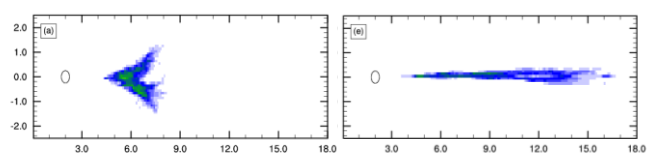
- The results presented have been extended by releasing particles over 30 minutes to capture more of the "slow" meandering variability of the plume
- Trajectory calculations are also being carried out for a range of firebrand fall velocities
- Analysis will be extended to consider the flight time of firebrands
- Trajectories calculated using the four-dimensionally varying velocity fields will be compared to time-mean and theoretical plume fields
- This work forms the building blocks of parameterizing spotting **distance** and **spread**.

Summary









- Large-eddy simulations of bushfire plumes
- Plume vortical structures and turbulent puffing identified, depending on background wind conditions
- Trajectories calculated for simple firebrands
- Trajectories heavily dependent on plume structure
  - Weak winds -> plume vortices -> lateral spread
  - Strong winds -> turbulent plume -> longitudinal spread
- Two-dimensional landing-position distributions constructed
- Potential for spotting parameterization development

bushfire&natural HAZARDSCRC

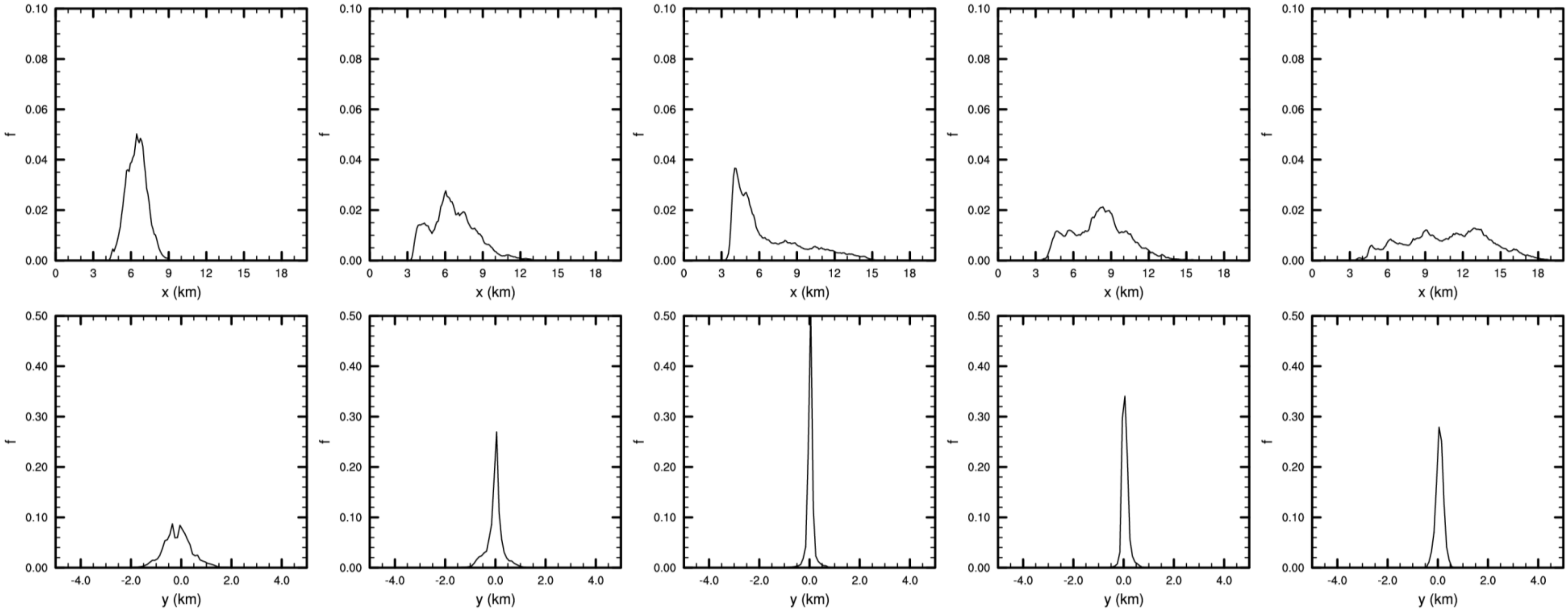
Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

CSIRO

One-dimensional landing distributions

u = 5.0 m s^{-1} | **u = 7.5 m s^{-1}** | **u = 10.0 m s^{-1}** | **u = 12.5 m s^{-1}** | **u = 15.0 m s^{-1}**



u = 5.0 m s^{-1}

x_{MEAN} = 4.3 km
x_{MAX} = 7.6 km
x_{STD} = 0.81 km
$|y_{MAX}|$ = 2.5 km
y_{STD} = 0.55 km

u = 7.5 m s^{-1}

x_{MEAN} = 4.4 km
x_{MAX} = 12.5 km
x_{STD} = 1.84 km
$|y_{MAX}|$ = 2.2 km
y_{STD} = 0.32 km

u = 10.0 m s^{-1}

x_{MEAN} = 4.3 km
x_{MAX} = 15.5 km
x_{STD} = 2.79 km
$|y_{MAX}|$ = 1.3 km
y_{STD} = 0.15 km

u = 12.5 m s^{-1}

x_{MEAN} =5.7 km
x_{MAX} = 16.0 km
x_{STD} = 2.21 km
$|y_{MAX}|$ = 1.4 km
y_{STD} = 0.14km

u = 15.0 m s^{-1}

x_{MEAN} =8.3 km
x_{MAX} = 18.7 km
x_{STD} = 3.29 km
$|y_{MAX}|$ = 1.3 km
y_{STD} = 0.16km