Understanding complex fire behaviour
Modelling lofting phenomena and wind variability

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High Impact Weather team
23rd October 2012

Thanks to Robert Fawcett, Jeff Kepert, Kevin Tory, Susan Rennie

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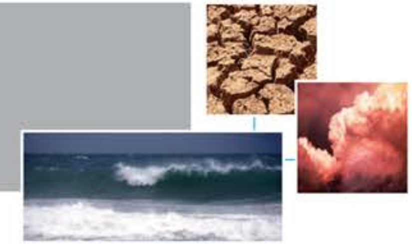
Introduction



"Understanding Complex Fire Behaviour: Modelling investigation of lofting phenomena and wind direction variability"

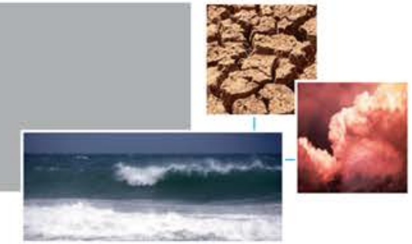
(i) Updraft phenomena

- (i) Spot fires lead to unpredictable and accelerated fire spread
- (ii) Spotting caused by lofting of firebrands into ambient wind
- (iii) Anecdotal evidence of tens of kilometres (e.g. Kilmore East)

(ii) Wind direction variability

- (i) Broad fire fronts propagate faster than narrow fire fronts
- (ii) High wind direction variability contributes to fire front broadening, hence fire spread rates

Structure of talk

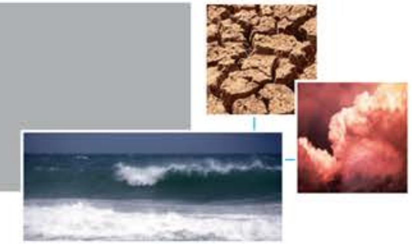


(I) High resolution ACCESS case study of Black Saturday

- Observed and modelled boundary-layer rolls
- Contribution of boundary-layer rolls to updrafts and direction variability

(II) Idealised fire plume modelling with UK Met Office large eddy model

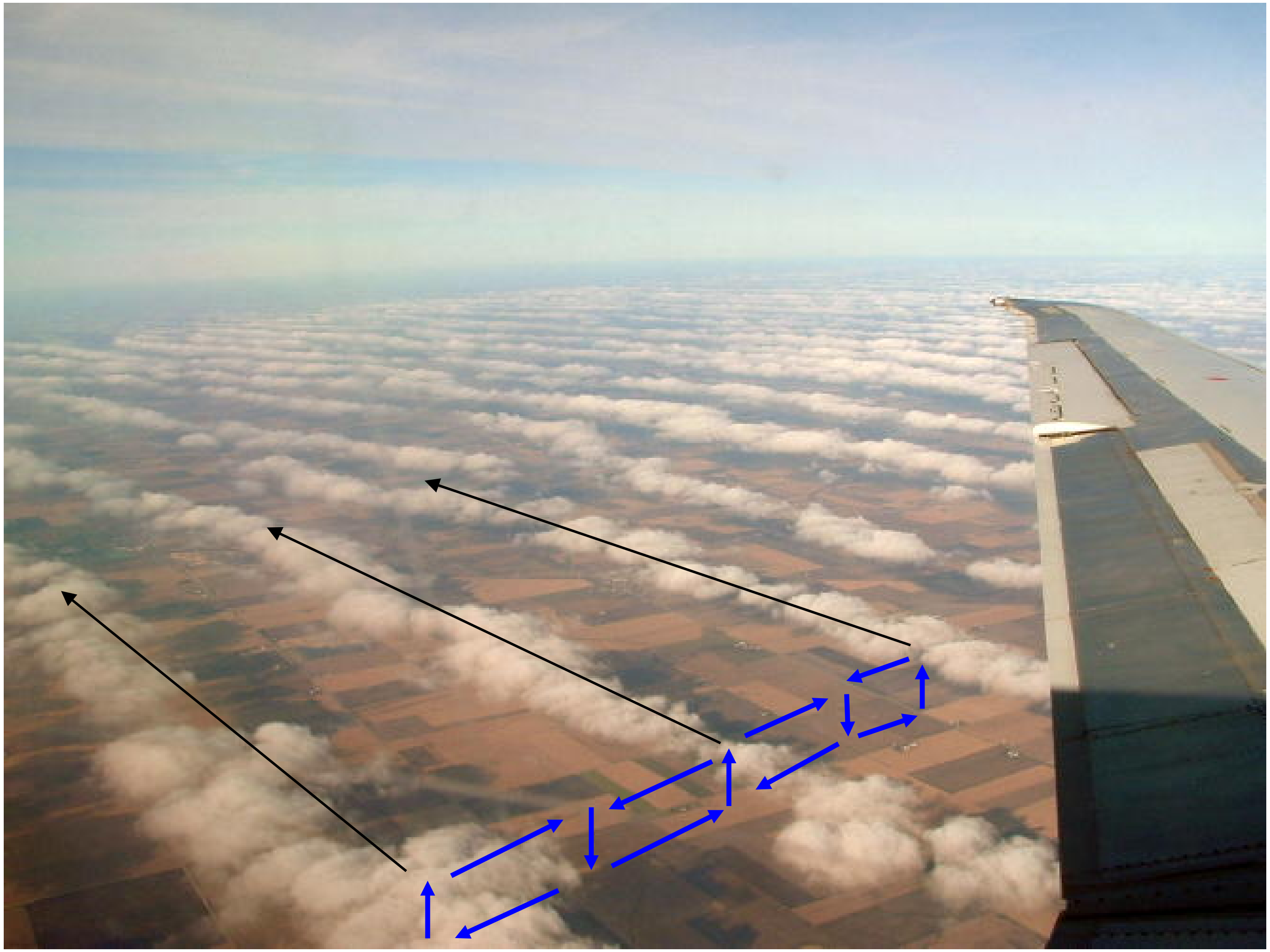
- Structure of fire plumes under varying wind regimes
- Updraft strengths and potential for firebrand lofting



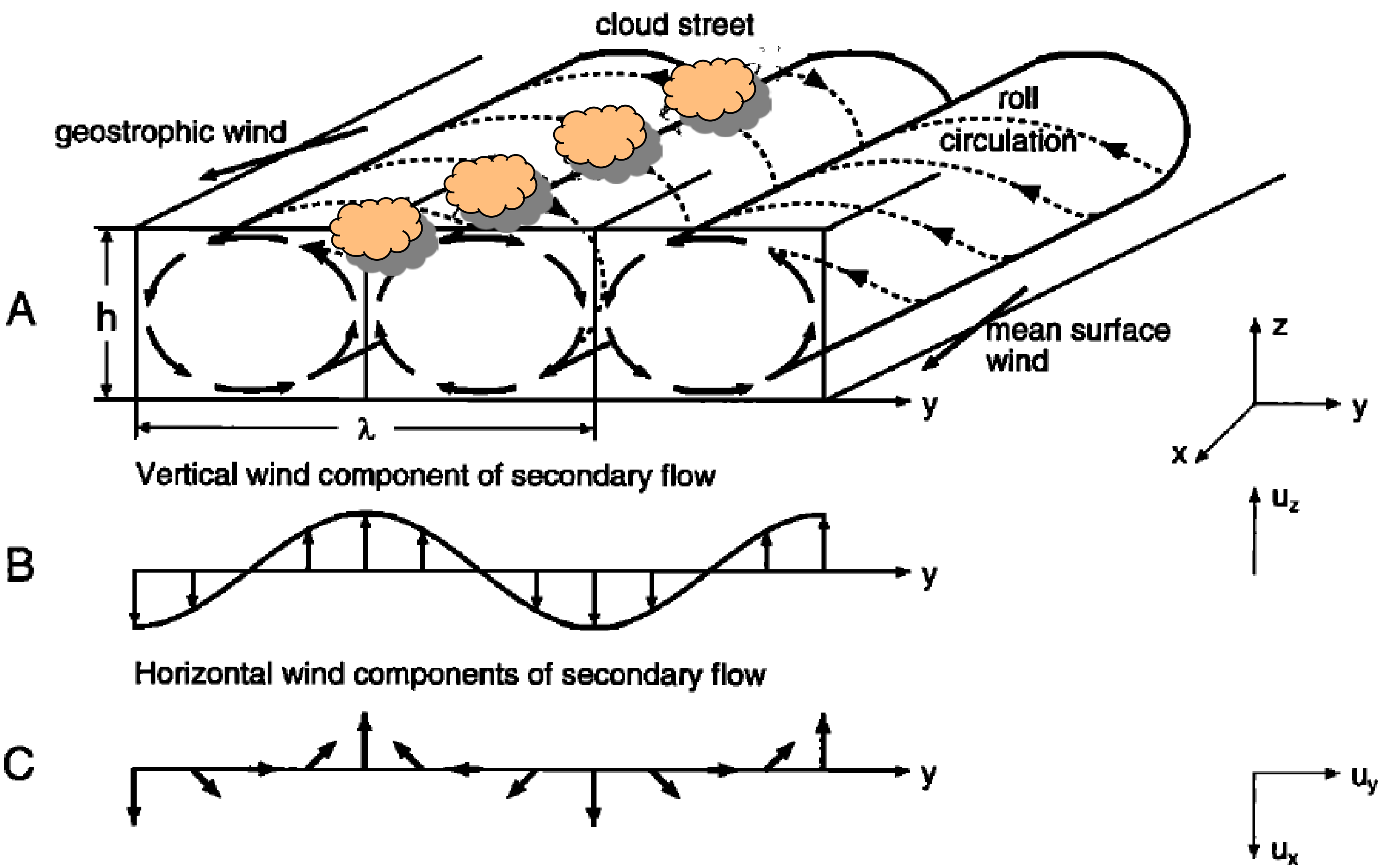
Part I:

High resolution ACCESS case study of Black Saturday boundary layer rolls

What are boundary-layer rolls?



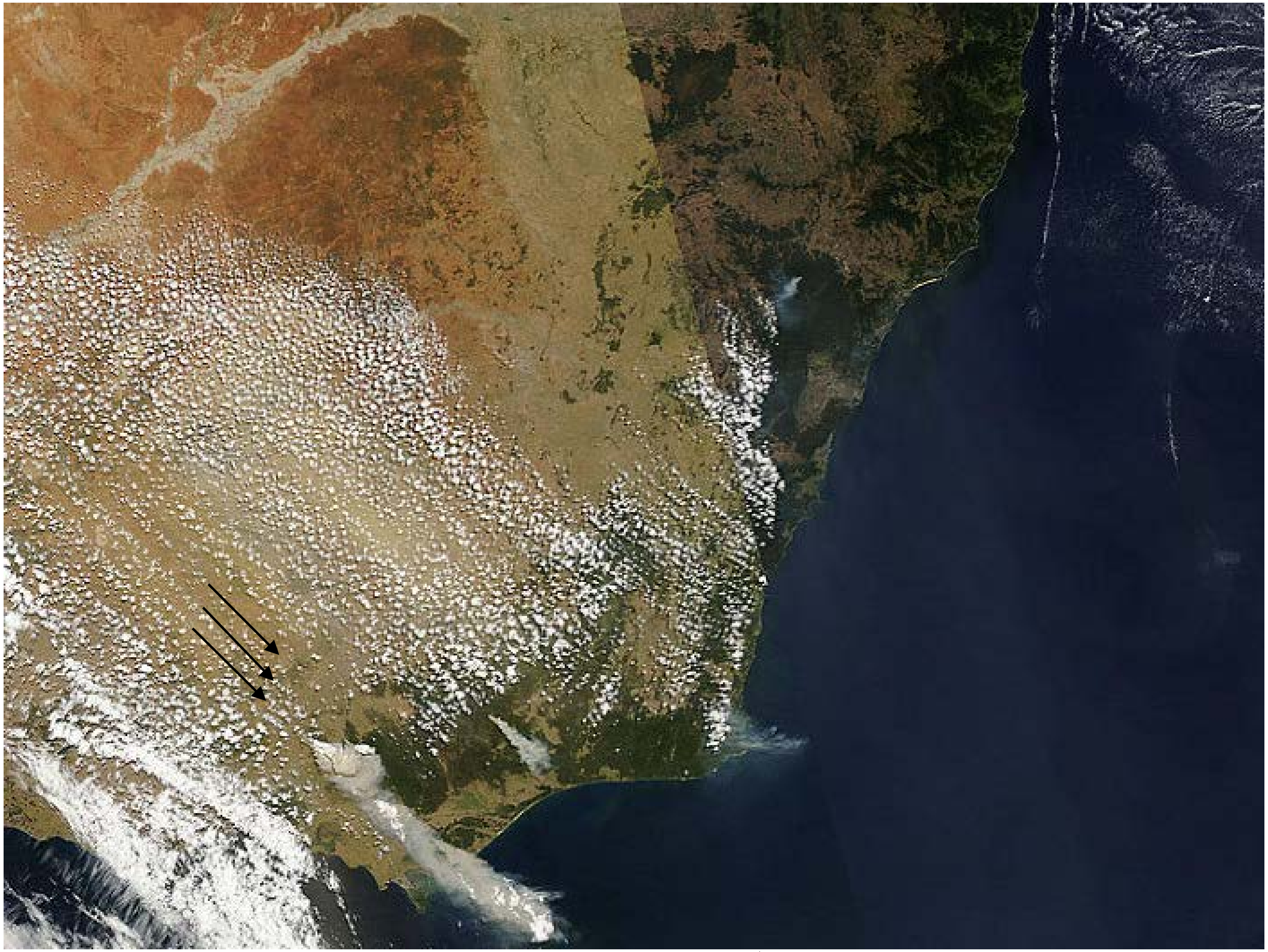
Boundary-layer rolls: Schematic diagram



- h = 1–5 km
- λ ~ 3h

(Alpers & Brümmer, 1994)

Black Saturday - MODIS Aqua 04:50 UTC



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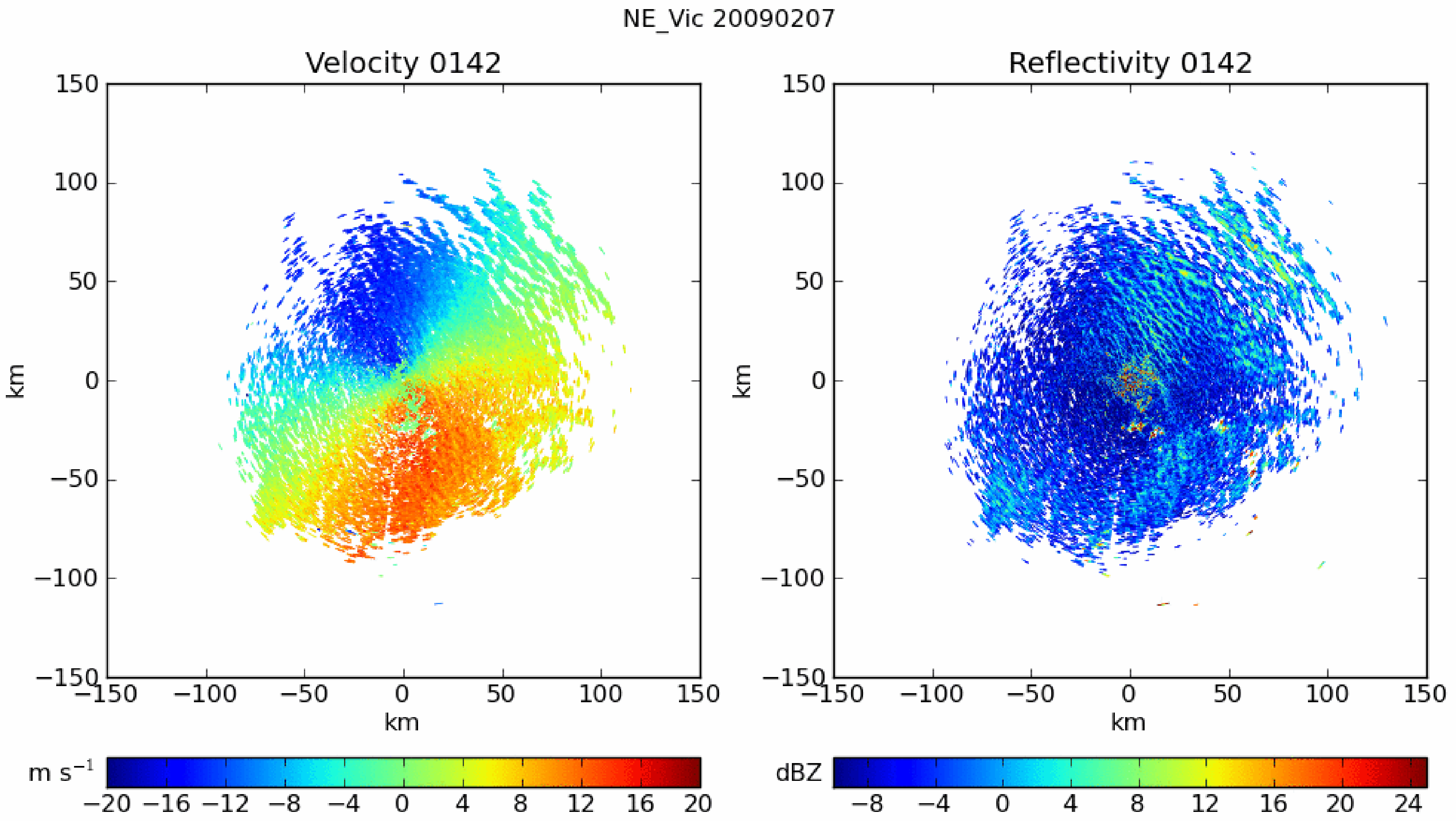
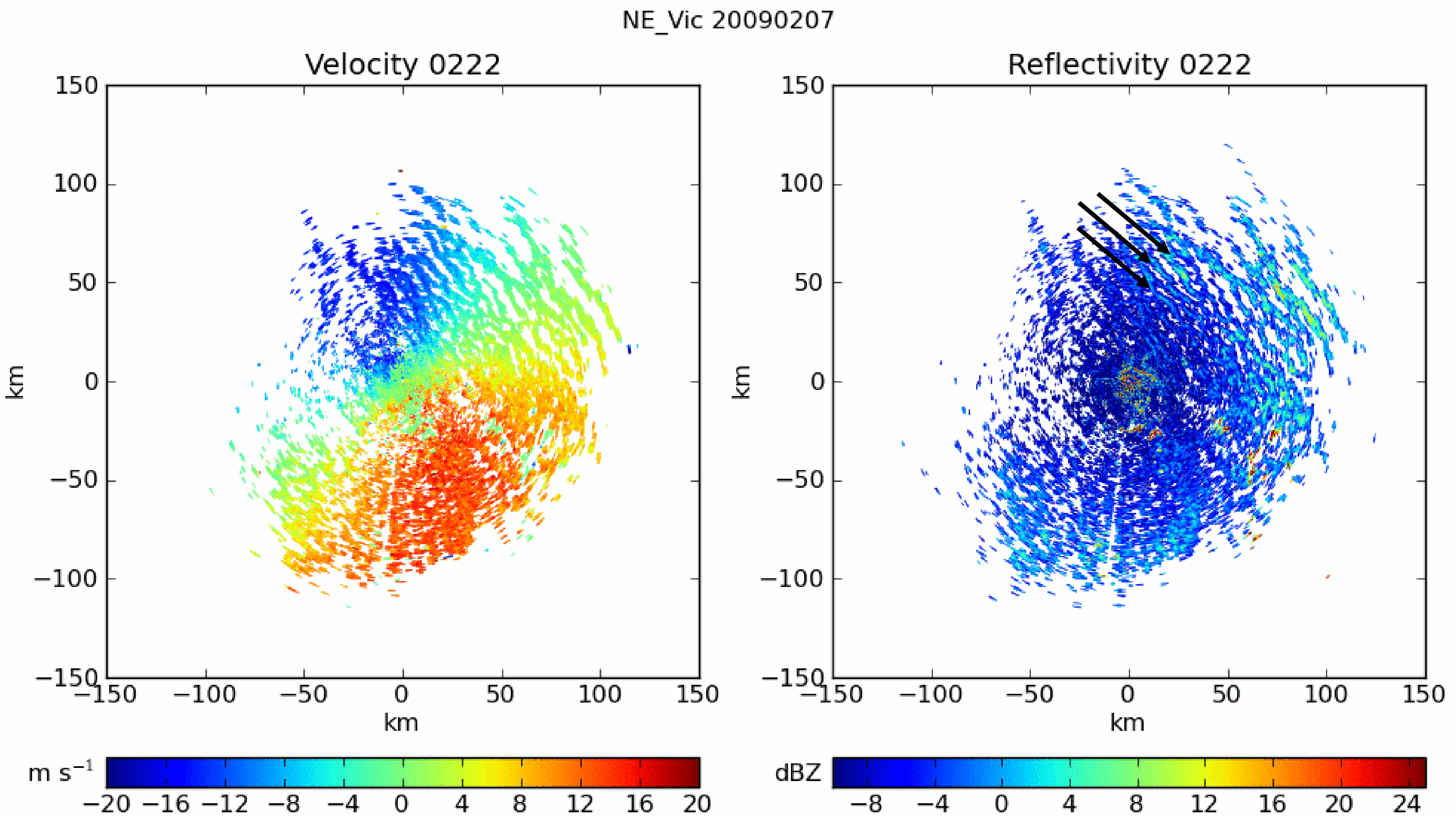
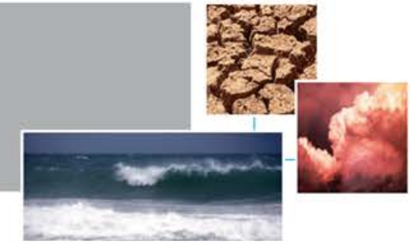
Yarrawonga radar – 01:42 UTC

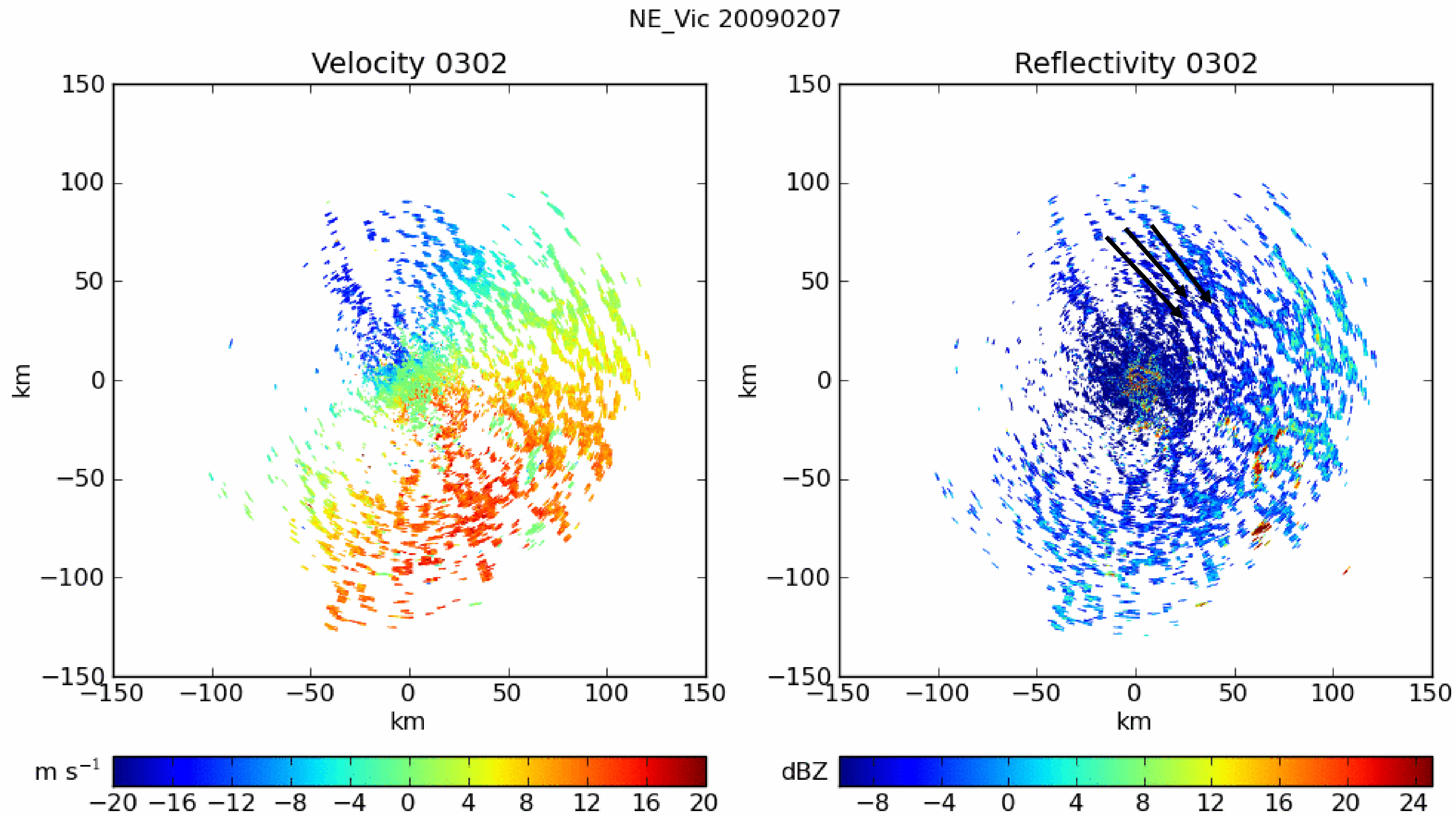


Yarrawonga radar – 02:22 UTC



Yarrawonga radar – 03:02 UTC





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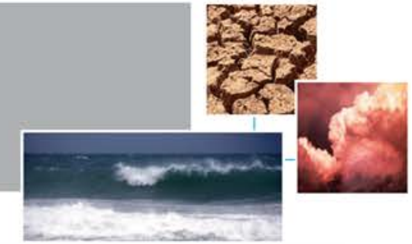
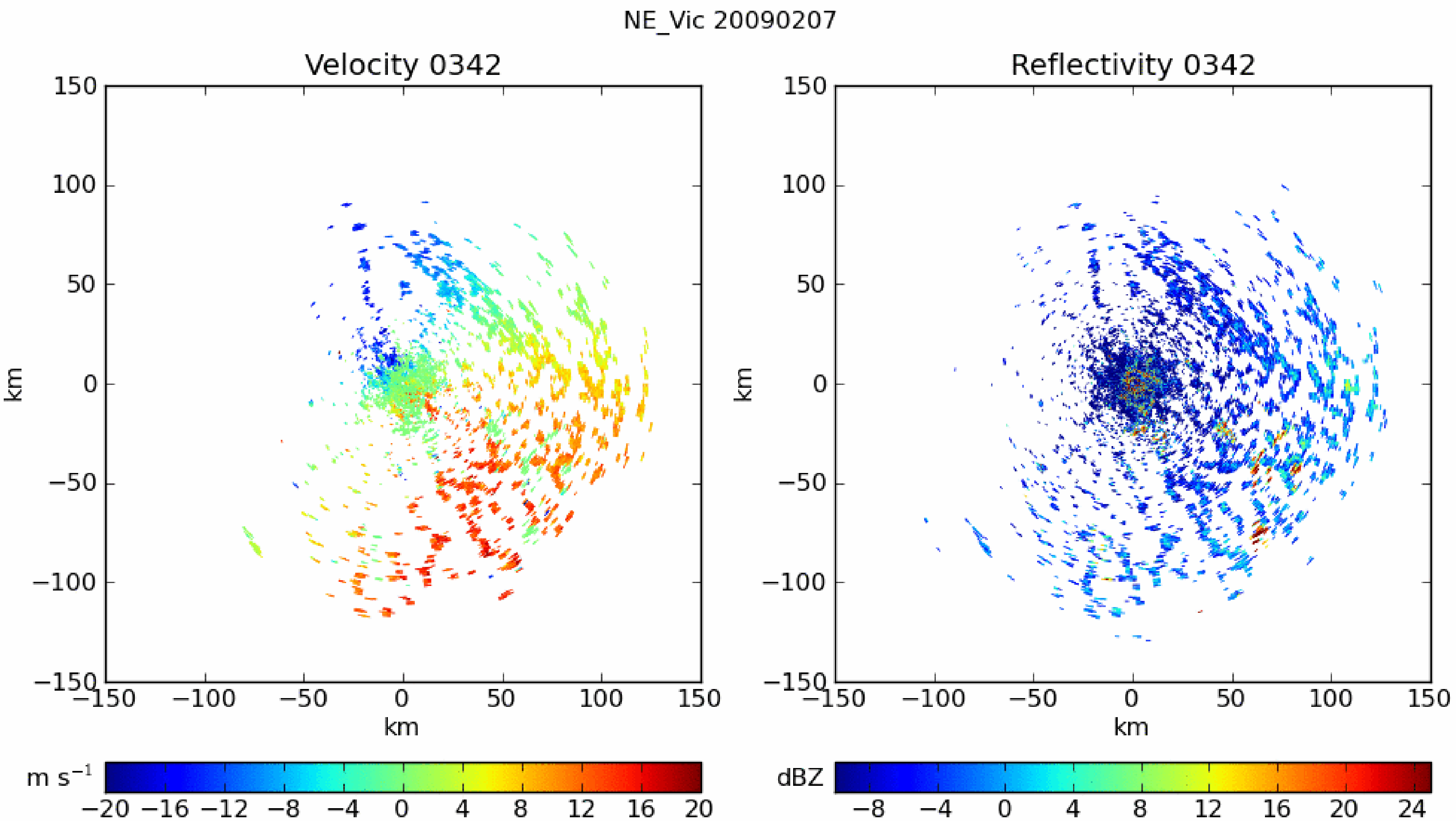
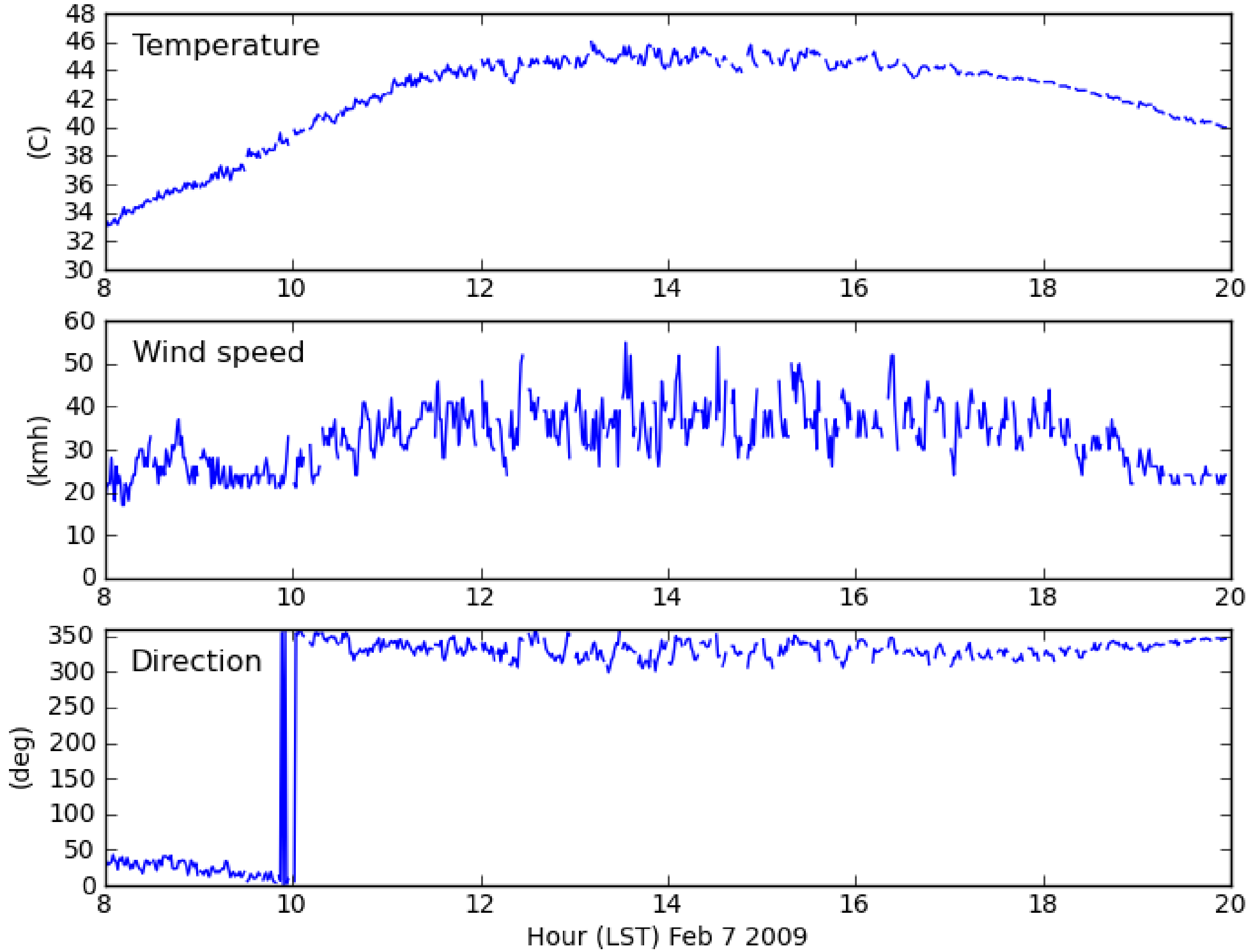
Yarrawonga radar – 03:42 UTC





Yarrawonga automatic weather station



dT ~ 2 °C

du ~ 20 km/h

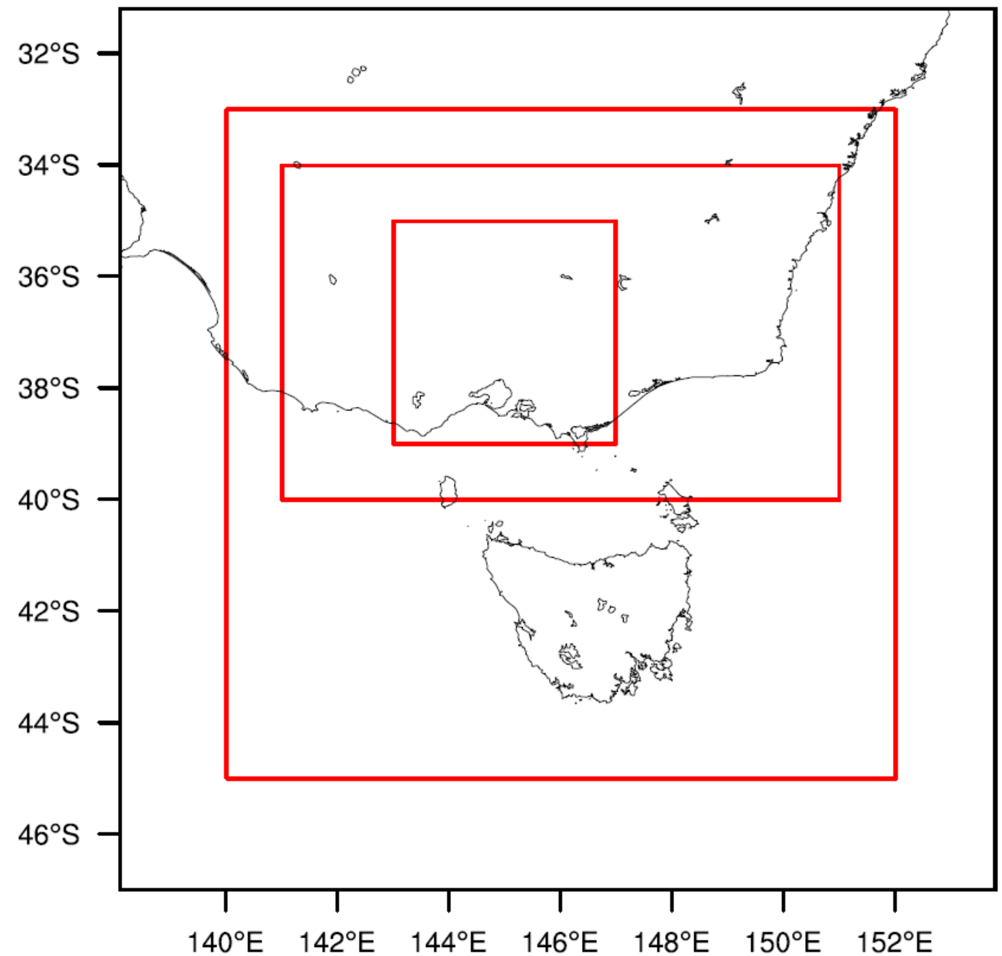
dθ ~ 60 °

Model setup

- High resolution ACCESS simulation of Black Saturday

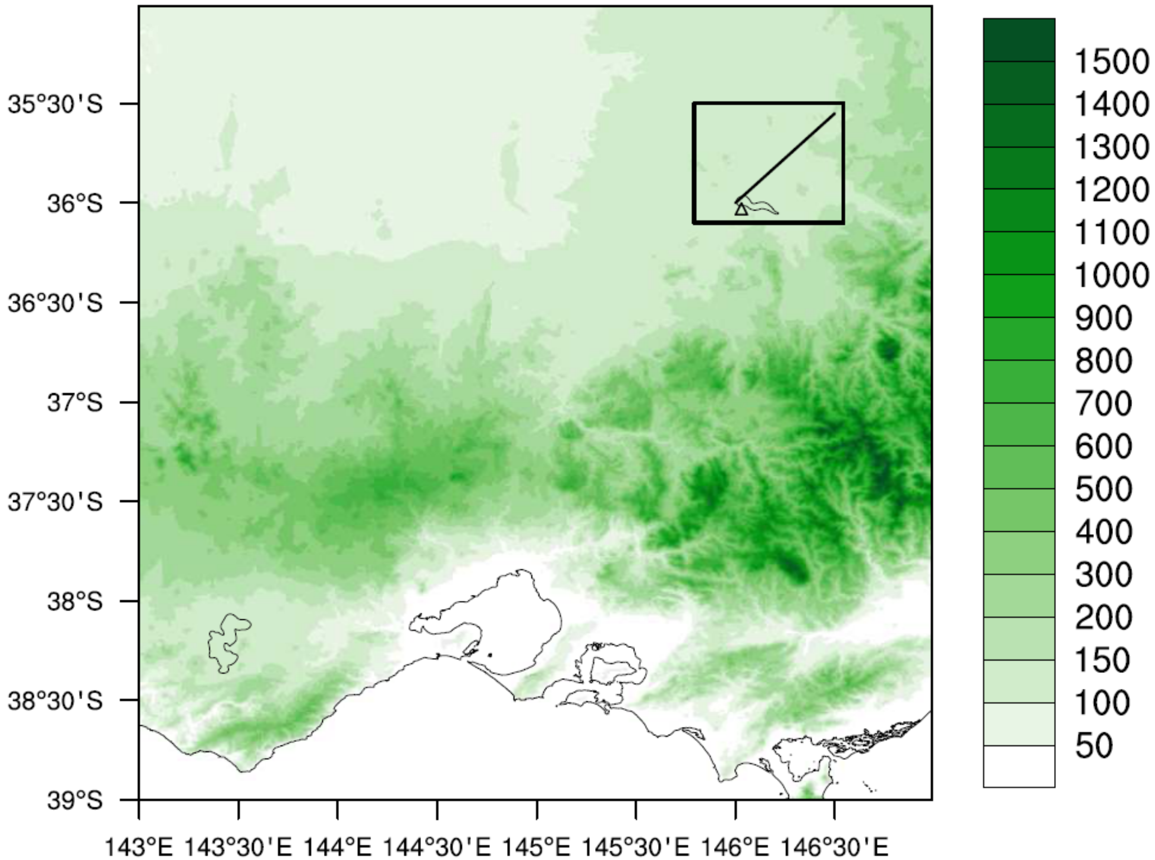
- Nested from coarse global model run down to high resolution regional 0.004° (~ 400 m) run

- Model validation against available observations is excellent



Area of study

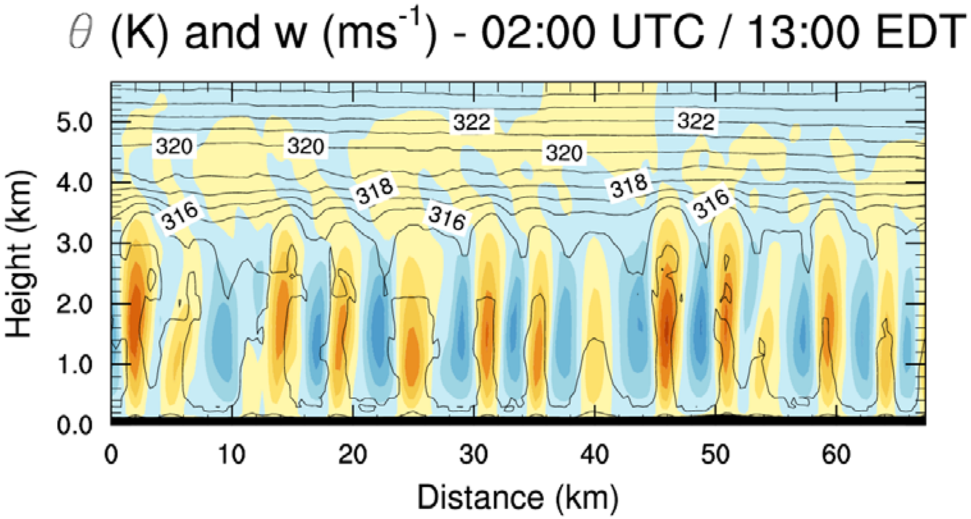
ACCESS model terrain height (m) - 0.004° domain

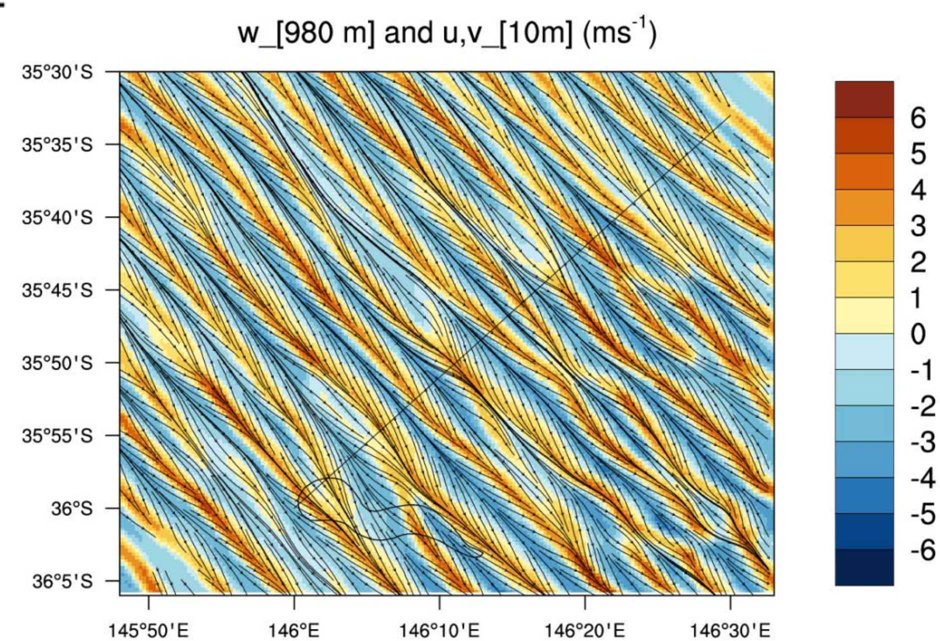


Small sub-region of 0.004° domain approximately 50 x 50 km

- Flat
- Yarrawonga Radar
- Yarrawonga AWS

Vertical cross-section & horizontal slice





Well-mixed boundary layer to ~ 3km

Structure of rolls evident

Evenly-spaced updrafts/downdrafts

Peak ~4 m/s and ~ 5.5 km spaced

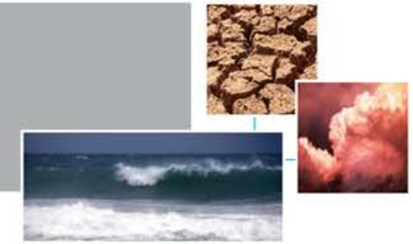
Peak updraft at z ~ 1.5 km

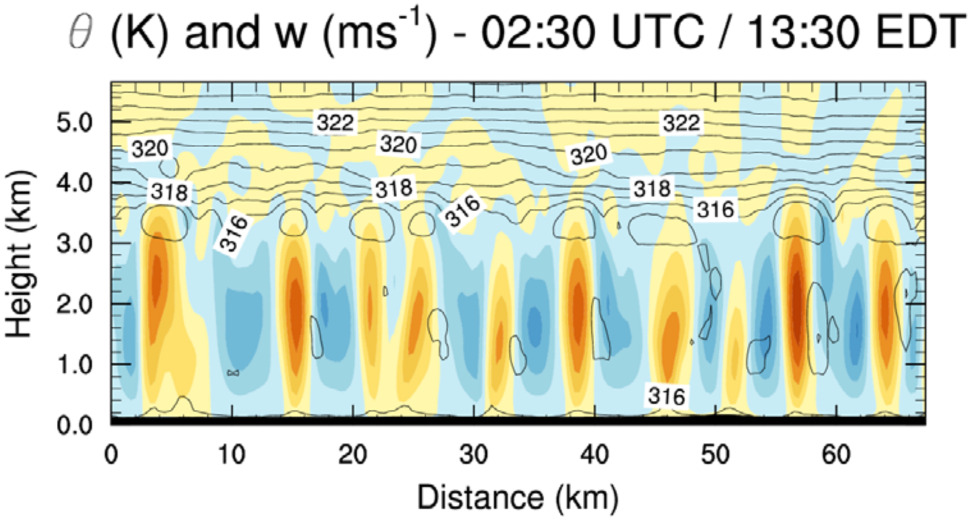
Warm updrafts/cool downdrafts

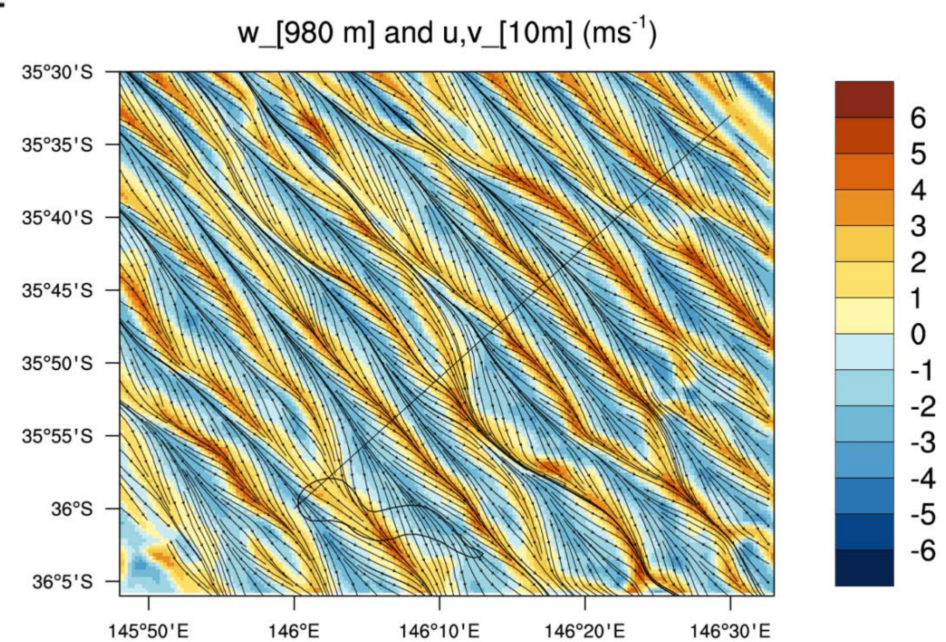
Regular pattern of alternating convergence divergence beneath up/downdrafts

Causes variations of > 40° over few km

Vertical cross-section & horizontal slice







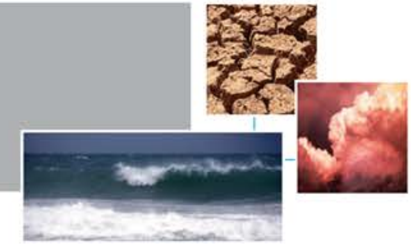
Updrafts/downdrafts relatively even

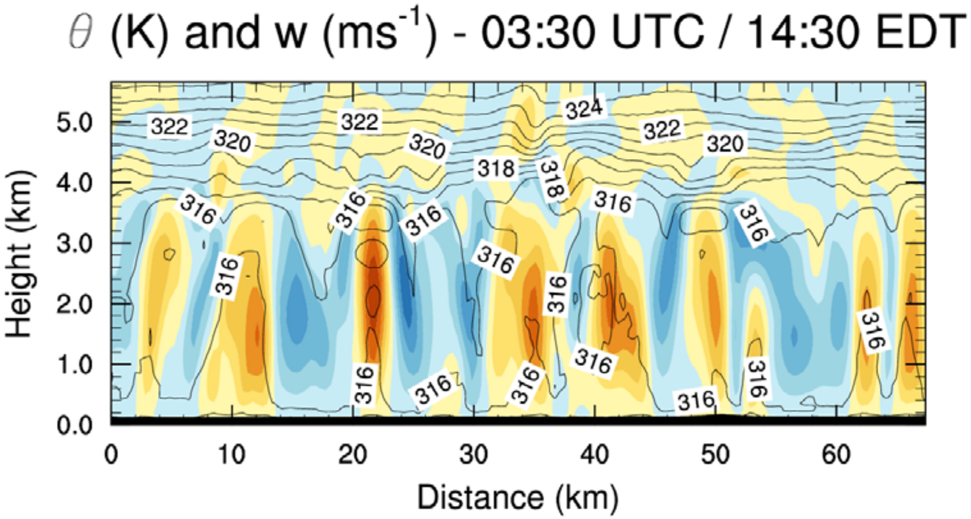
Mixed-layer depth increases to 3.5 km

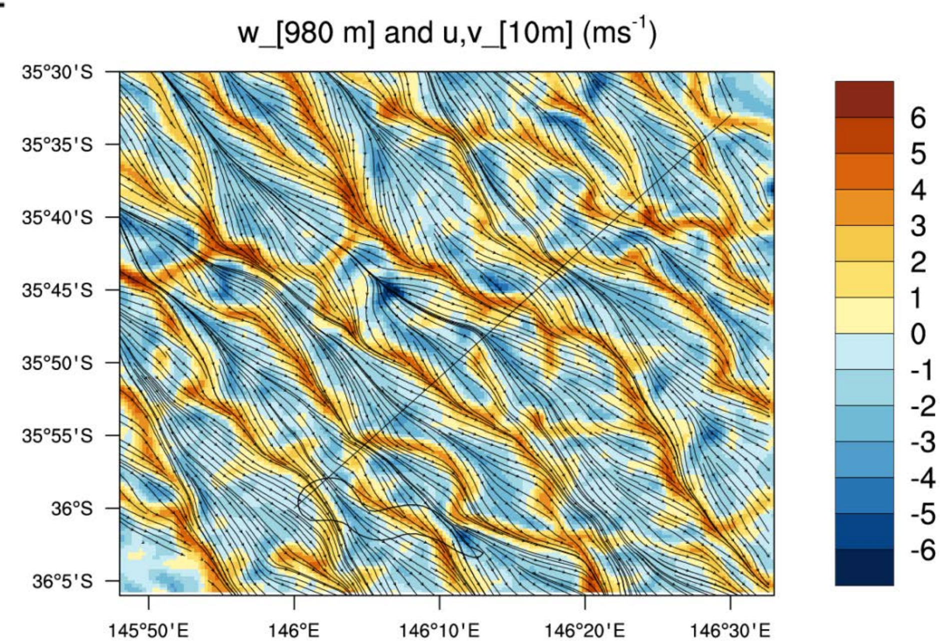
Peak ~6 m/s and ~ 6.5 km spaced

Peak updraft at z ~ 2 km

Vertical cross-section & horizontal slice







Updrafts/downdrafts less regular

Mixed-layer depth increased to 4 km

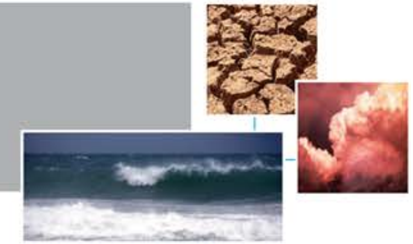
Peak >6 m/s and ~ 13 km spaced

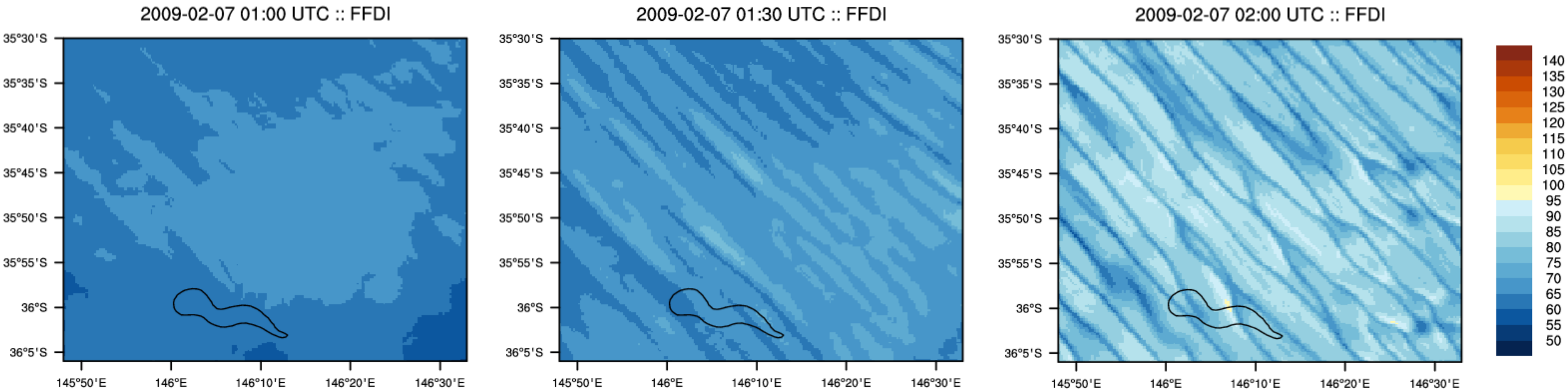
Peak updraft increased to z ~ 2.5 km

Regular pattern of alternating convergence divergence starts to be broken by downdrafts which are felt at the surface

Causes variations of > 60° over few km

Impact on FFDI





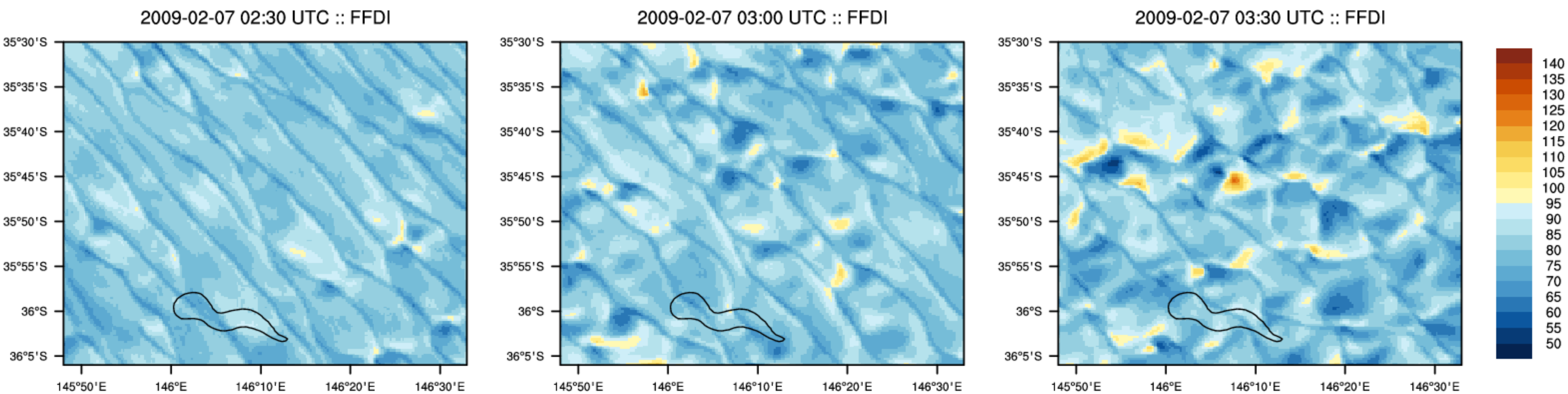
Initially a largely homogeneous FFDI field ~ 60, increases with heating

Development of rolls leads to spatial patterns in FFDI over a few km, consistent with roll structure

Thin patches of depressed FFDI superimposed onto constant background field

Reduces FFDI from 90 to 70

Impact on FFDI

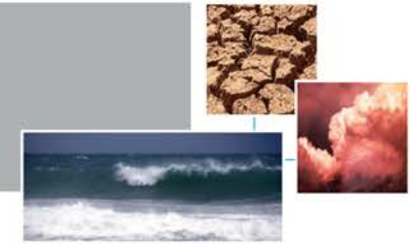


As rolls become less regular the variations in FFDI do too.

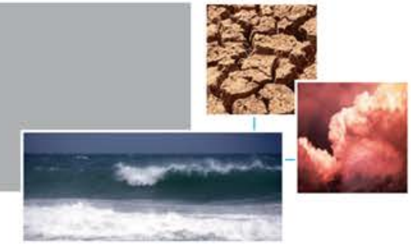
Strips of low FFDI are augmented by patches of low FFDI and then by patches of elevated FFDI – more serious implications.

Increases local FFDI from 60 to 120 locally

Summary – Part I: Boundary layer rolls



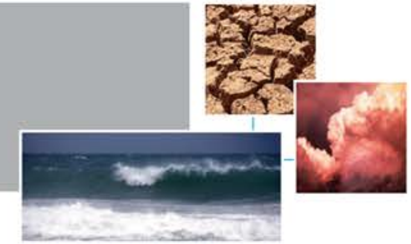
- Boundary layer rolls are linear convective circulations
- They contribute to temperature, wind speed and direction fluctuations at the surface
- They contain updraft velocities in excess of the fall velocities of common firebrands
- They are responsible for substantial spatial and temporal variations in instantaneous FFDI
- Numerical weather prediction models run in high resolution ‘research’ mode are capable of reproducing these features



Part II:

Idealised fire plume modelling

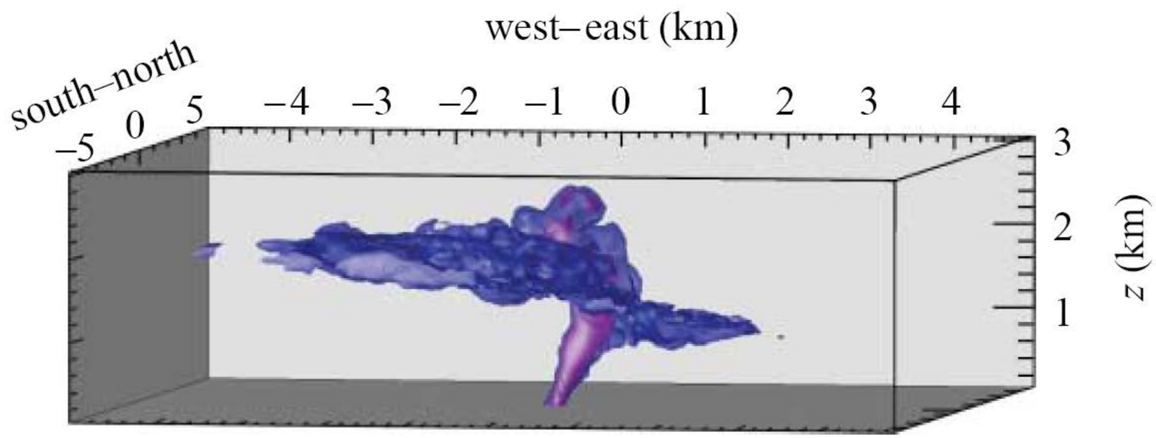
The UKMO Large Eddy Model (LEM)



- *Very* high resolution atmospheric model (dx < 100 m)
- Resolves large scale eddies in turbulent atmospheric boundary layer
- Simple “idealised” setups, typically with horizontally homogeneous
- Previous successful uses:
  - Boundary-layer turbulence
  - Land surface-atmosphere interaction
  - Mid-latitude shallow cumulus clouds
  - Tropical deep convection cumulonimbus clouds
  - Buncefield oil depot fire

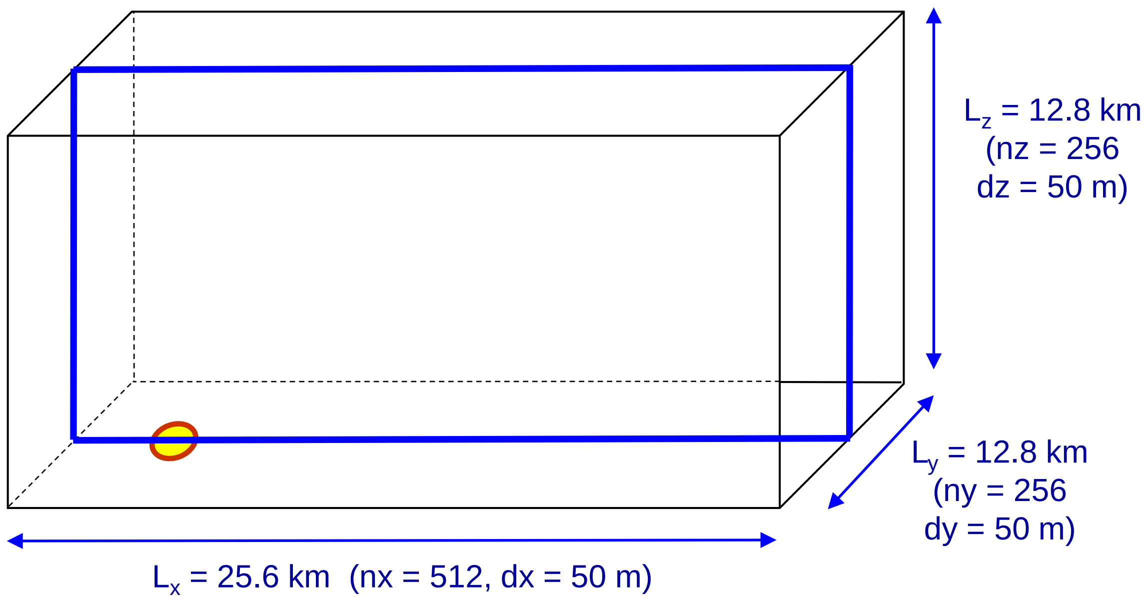
Buncefield oil depot fire

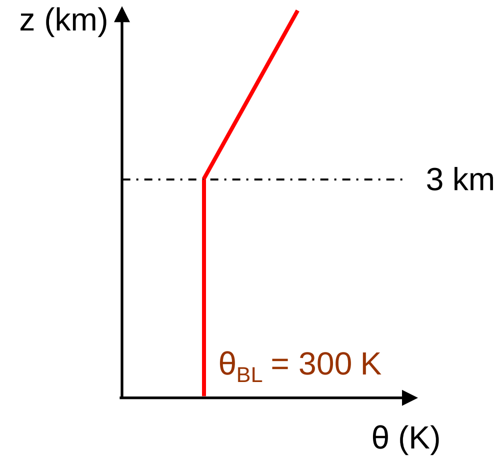
- Hertfordshire UK, 11th December 2005
- Largest fire in Europe since the Second World War
- Burned for 4 days

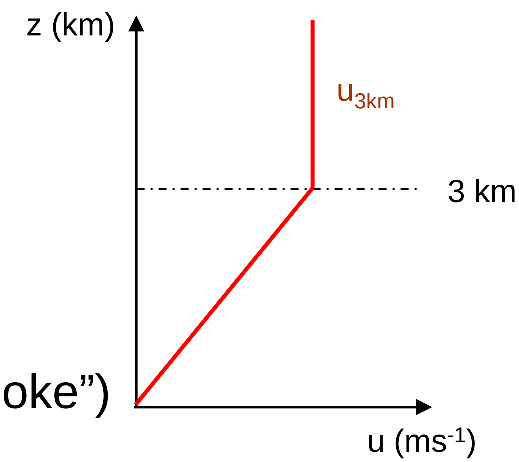


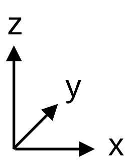
- UKMO LEM successfully used to replicate plume behaviour (Devenish et al., 2009, *Proc. Roy. Soc. A*).

LEM configuration



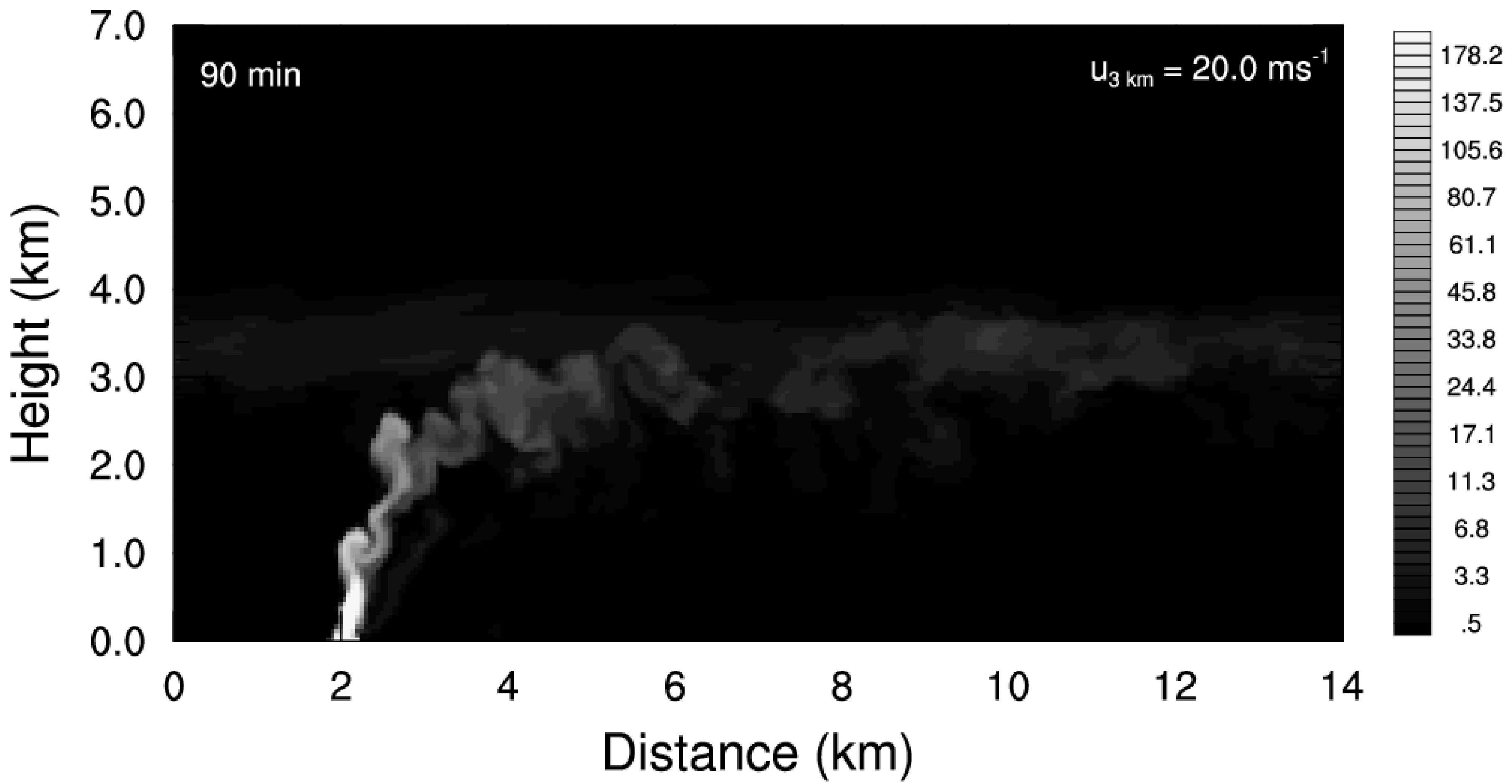




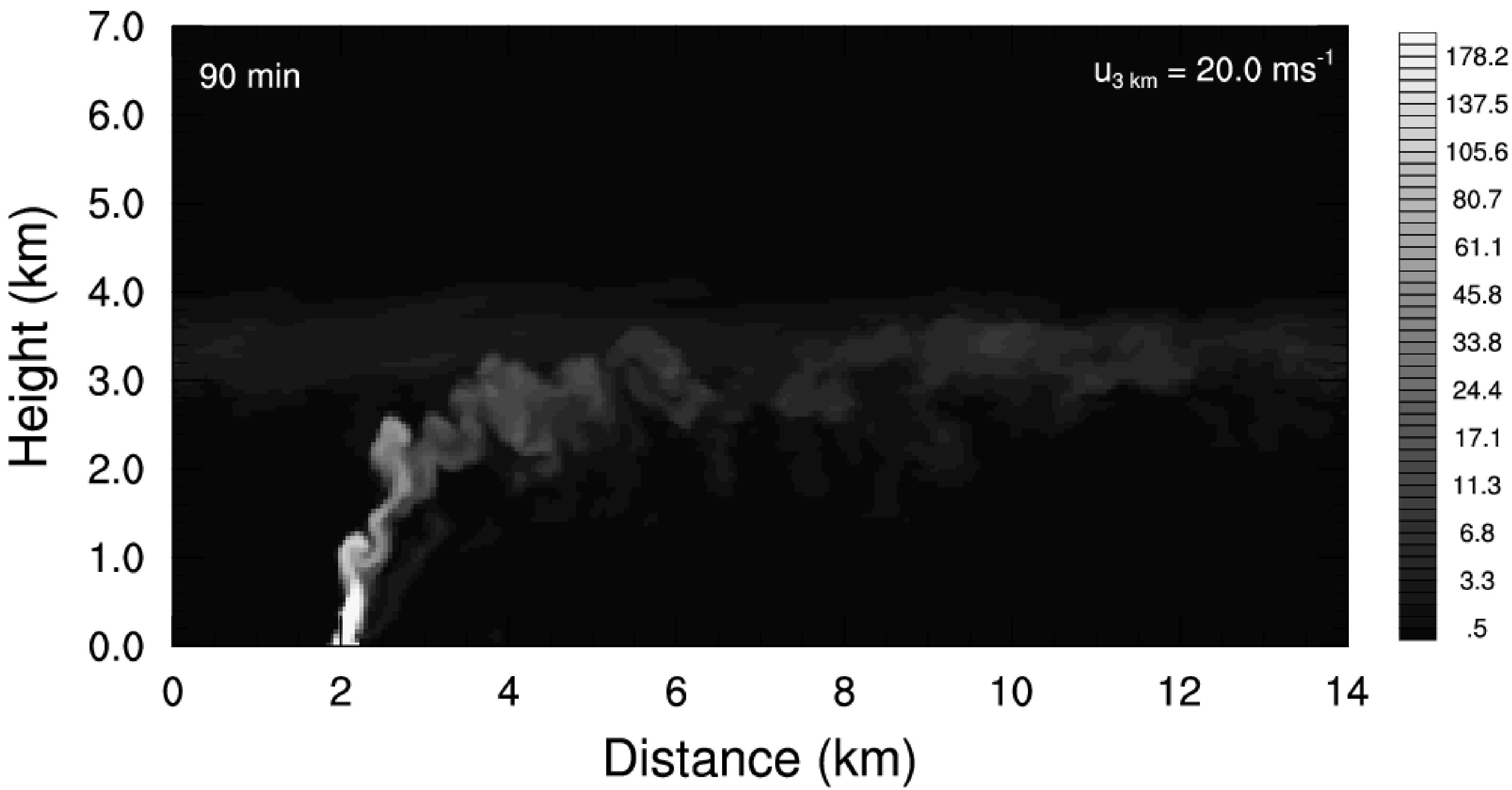


t	= 3 h
u_{3km}	= 2.0, 3.0, 5.0, 7.5, 10.0, 12.5, 15.0, 17.5, 20.0 m s^{-1}
Q_{FIRE}	= 100,000 W m^{-2} (+ passive tracer "smoke")
r_{FIRE}	= 200 m

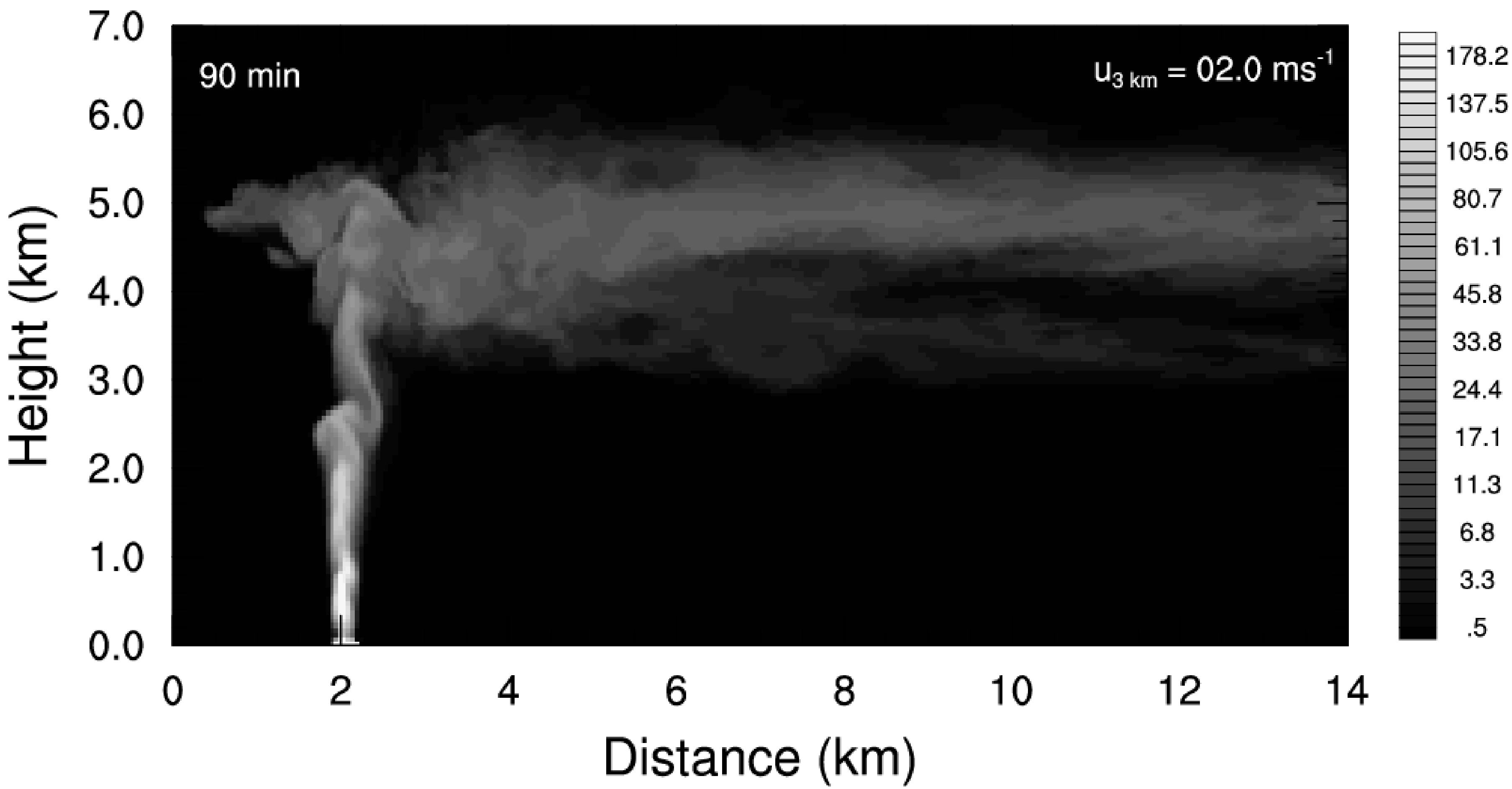
Plume video – strong background wind



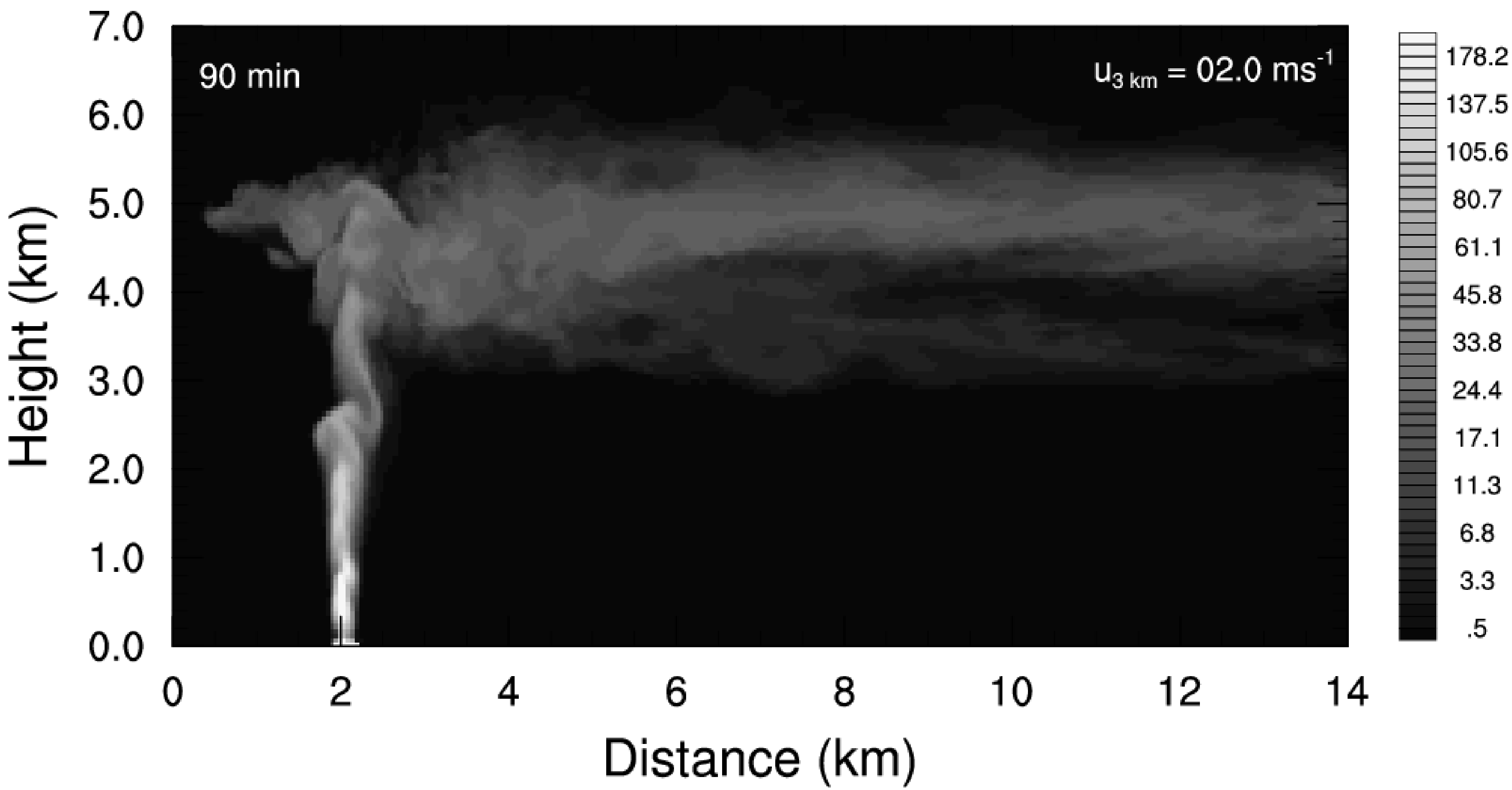
Plume video – strong background wind



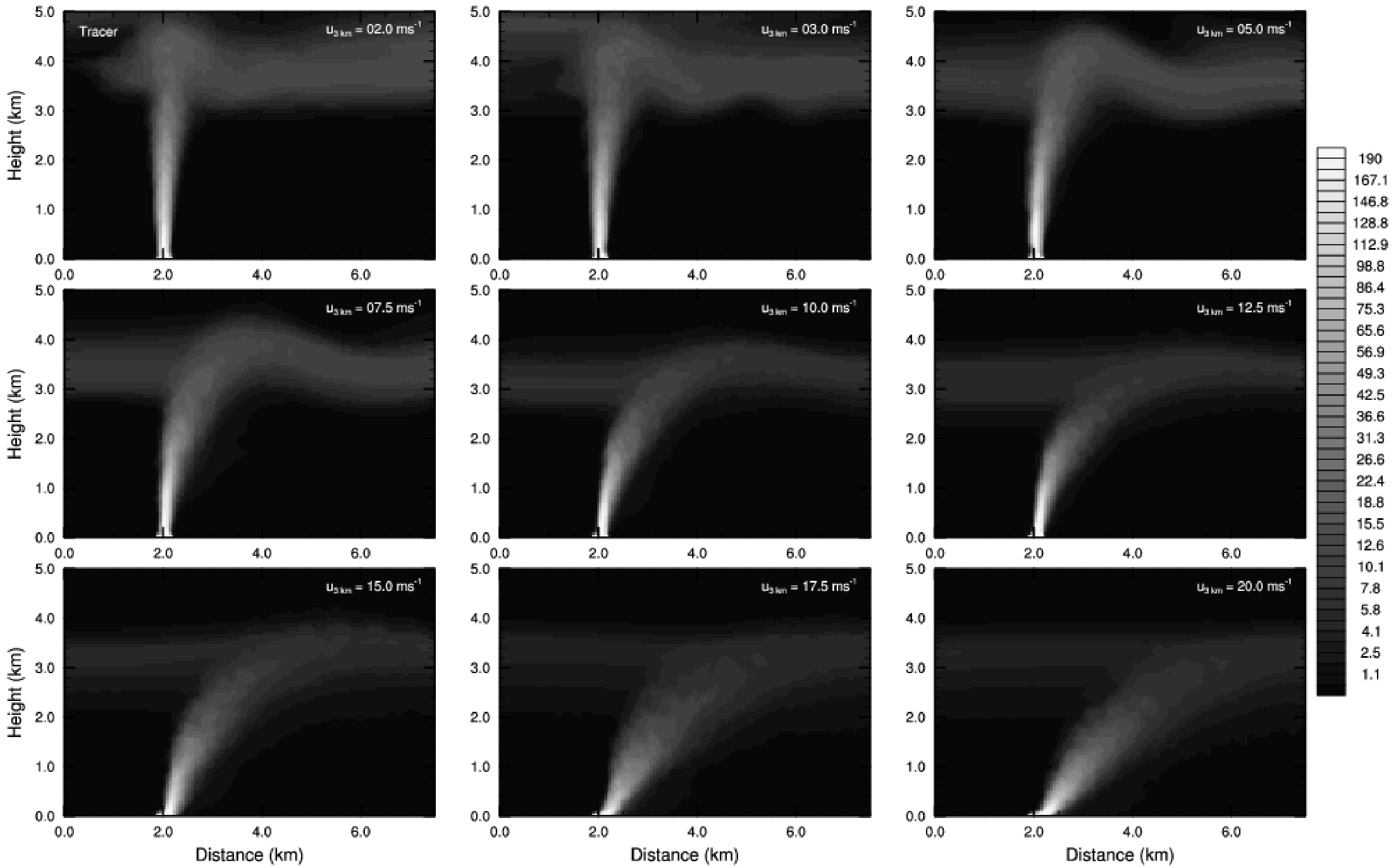
Plume video – weak background wind



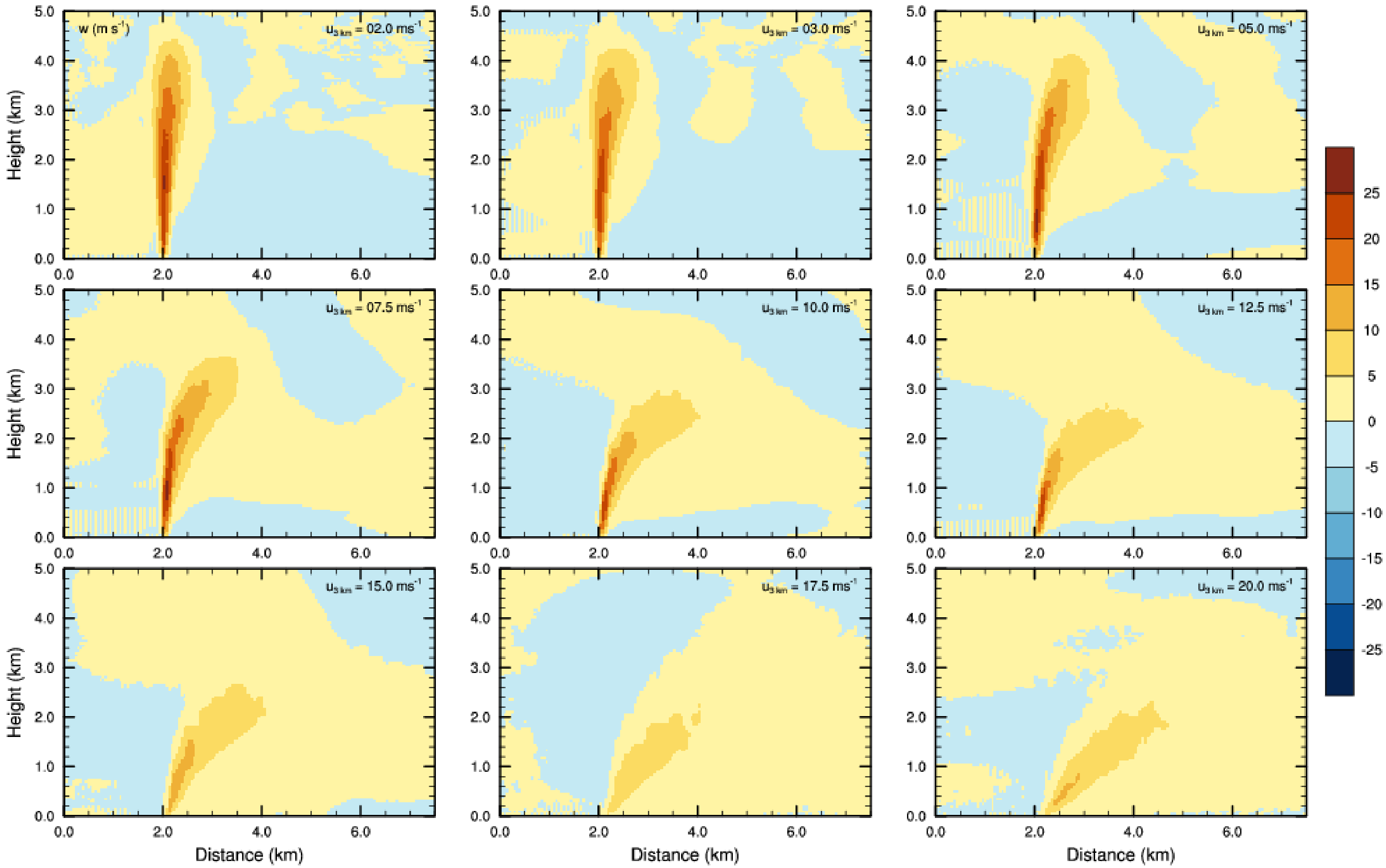
Plume video – weak background wind



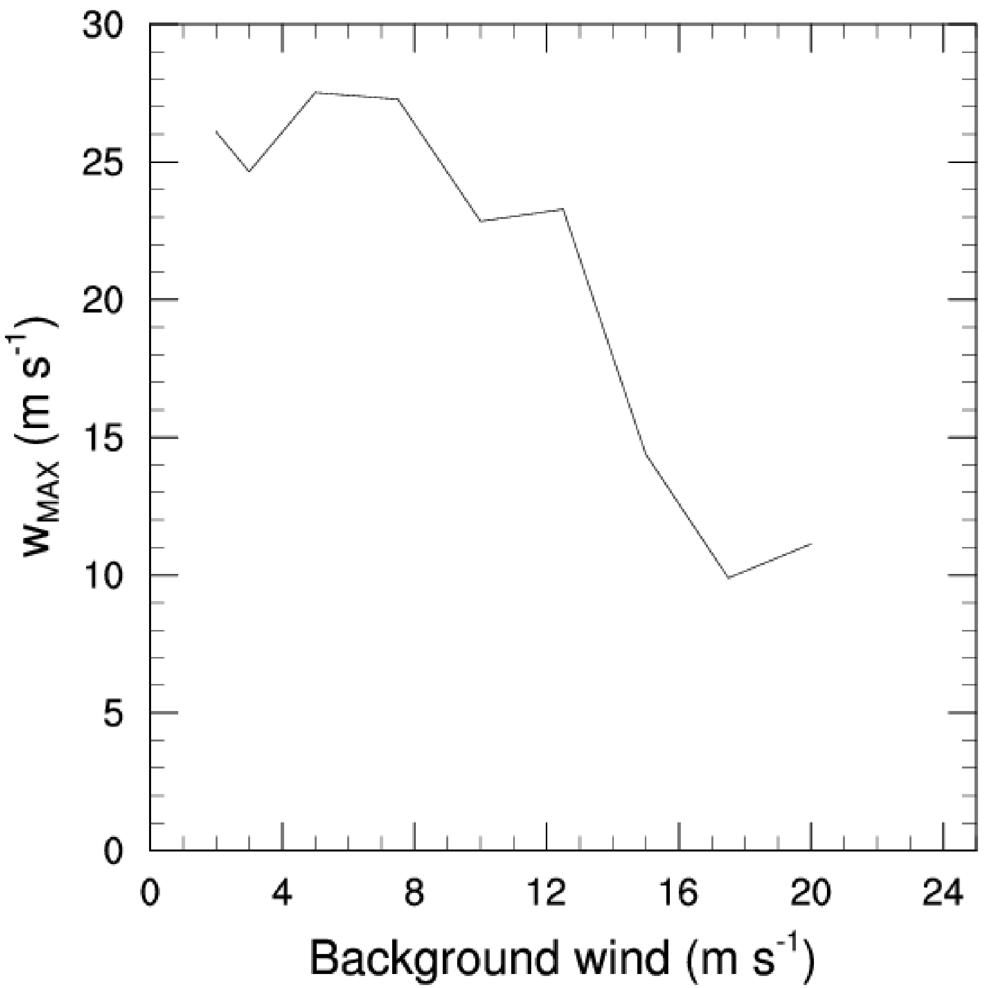
One-hour mean "smoke" position



One-hour mean updraft strength (m s^{-1})



One-hour max updraft strength (m s⁻¹)



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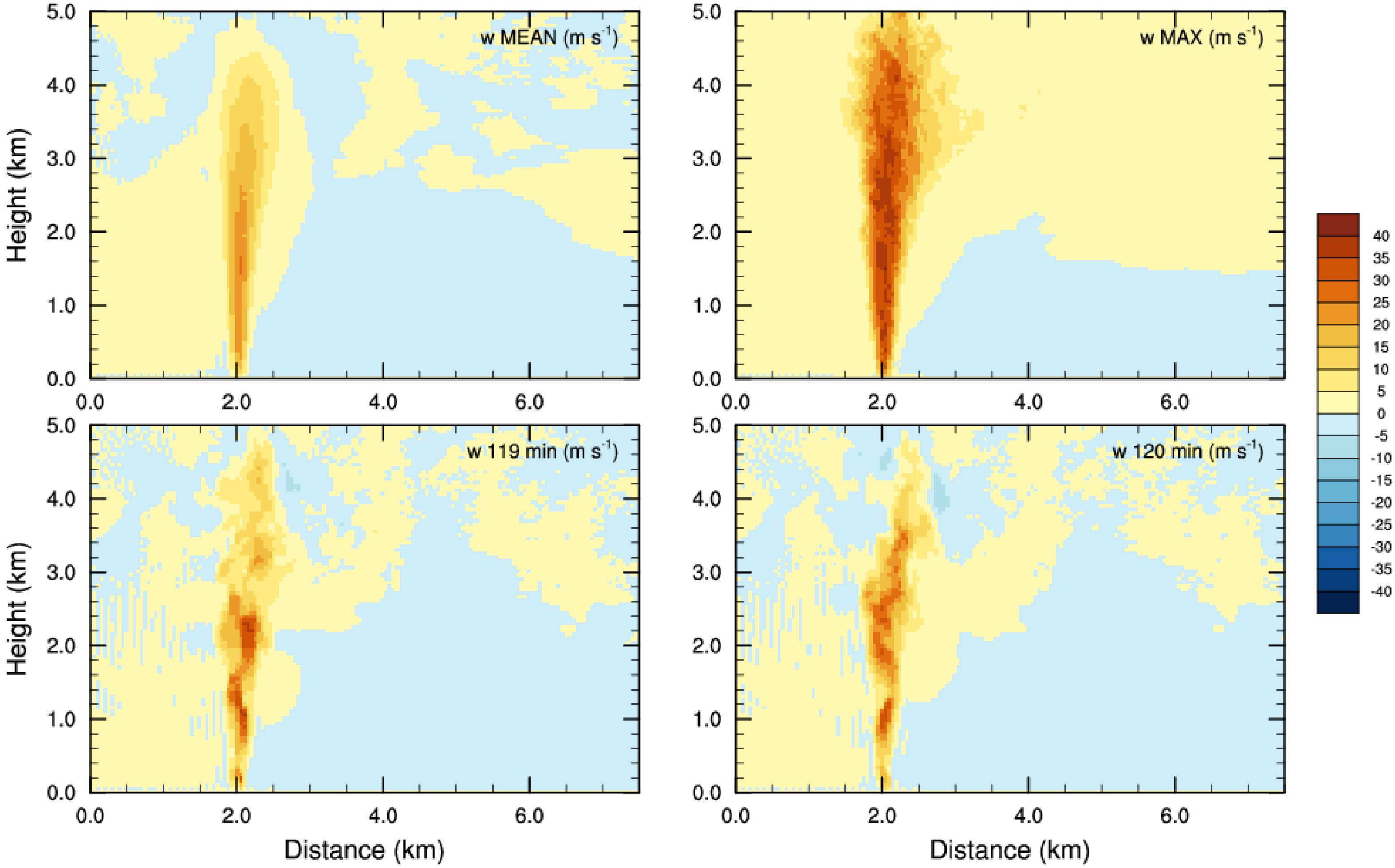
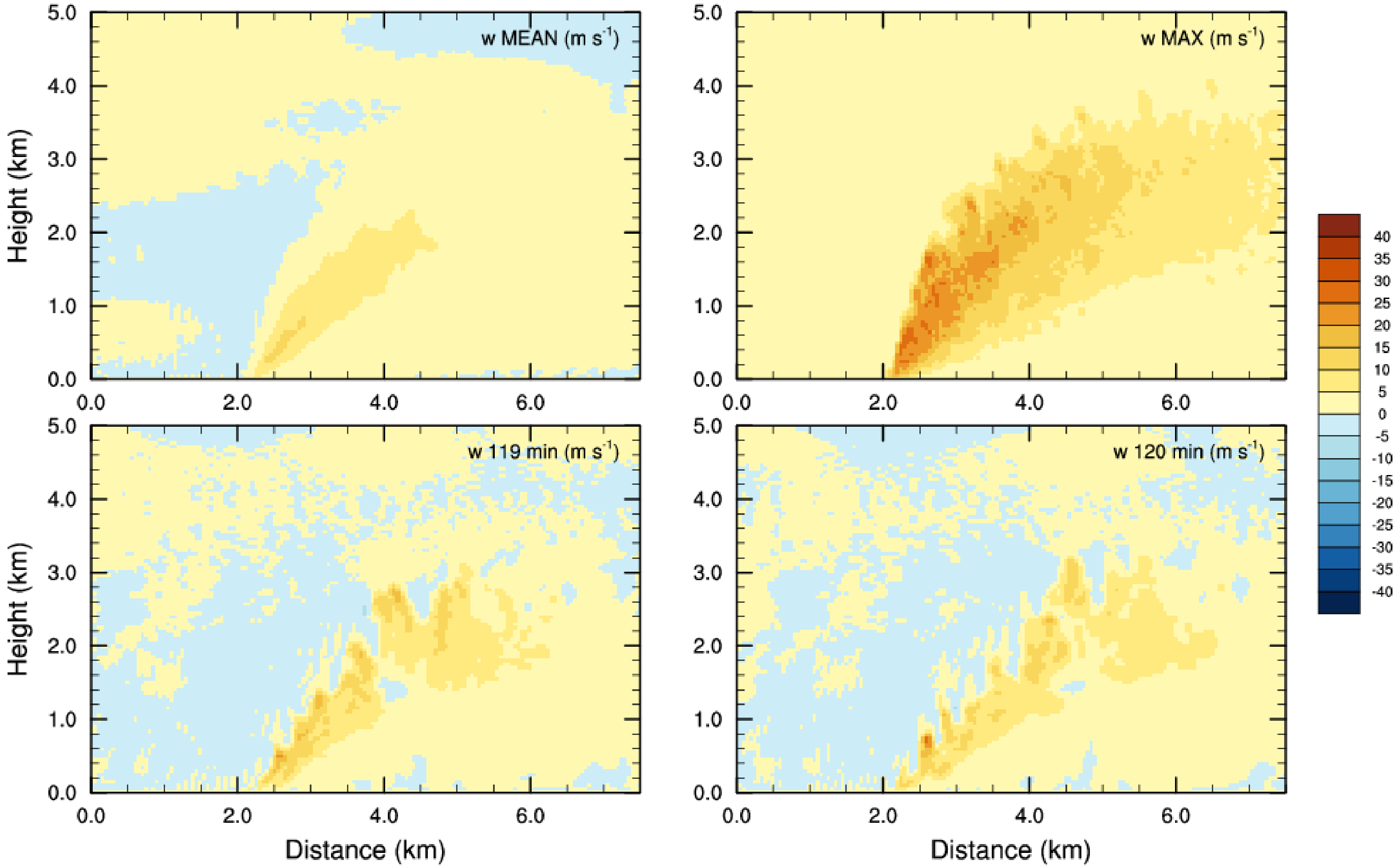
Updraft stats – 2.0 m s^{-1} background wind



Updraft stats – 20.0 m s^{-1} background wind



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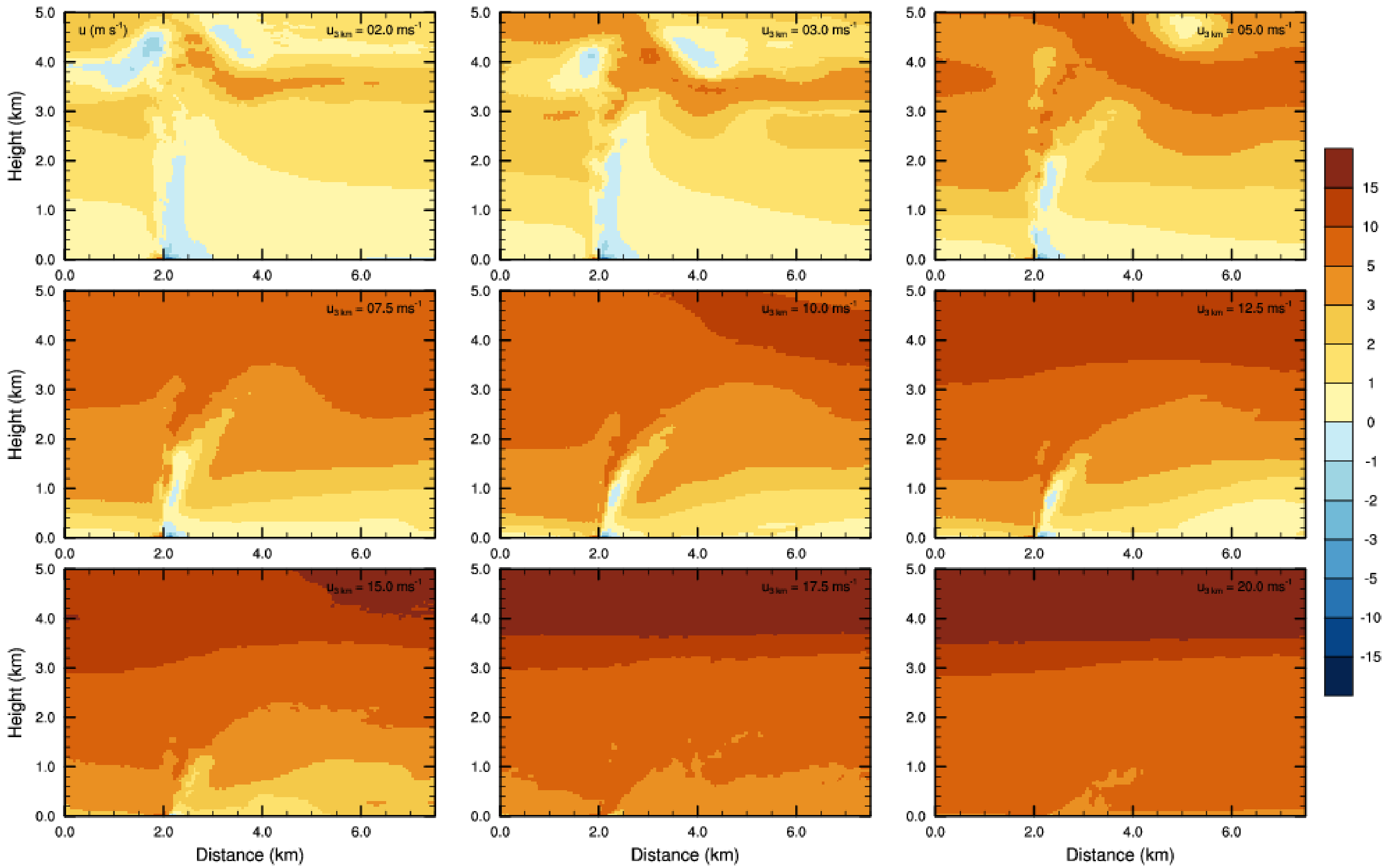
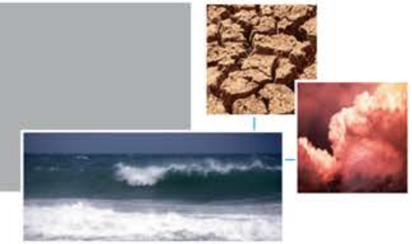
One-hour mean inflow strength (m s^{-1})



Summary – Part II: Plume modelling

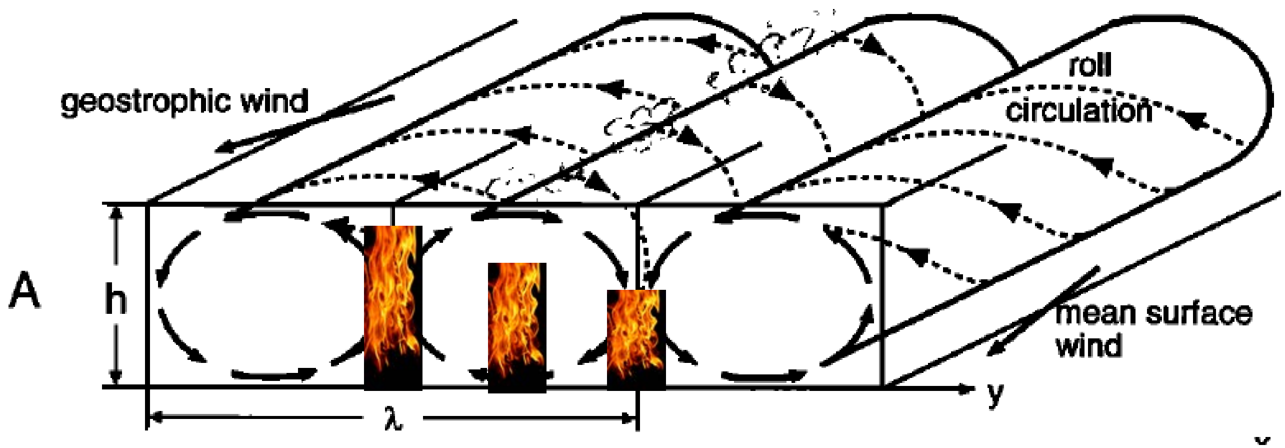


- The UK Met Office large eddy model (LEM) has been used to simulate simplified fire plumes
- The response of plumes to a range of background winds has been tested
- Plumes become bent over and have weaker updrafts under strong winds
- Plumes create near-surface inflows under weak background winds

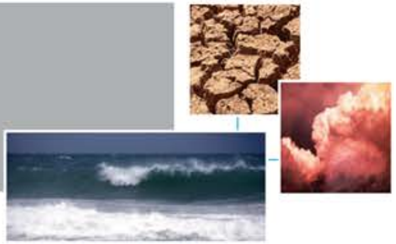
Future work

- Perform particle transport calculations on plume modelling output to assess potential for lofting and spotting

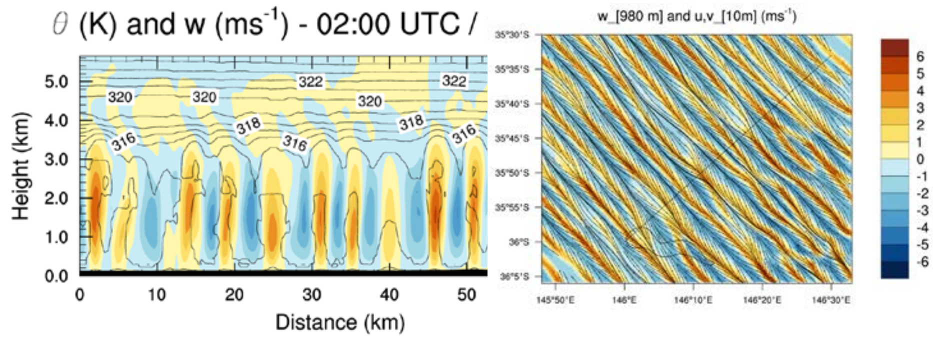
- Investigate interaction between plume and boundary layer rolls and the consequent effects on updrafts and spotting

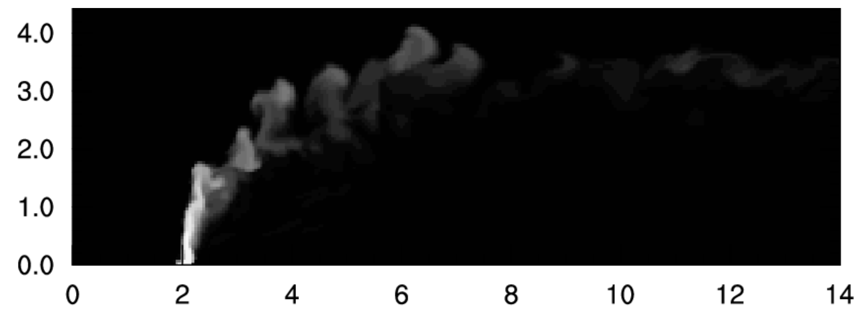


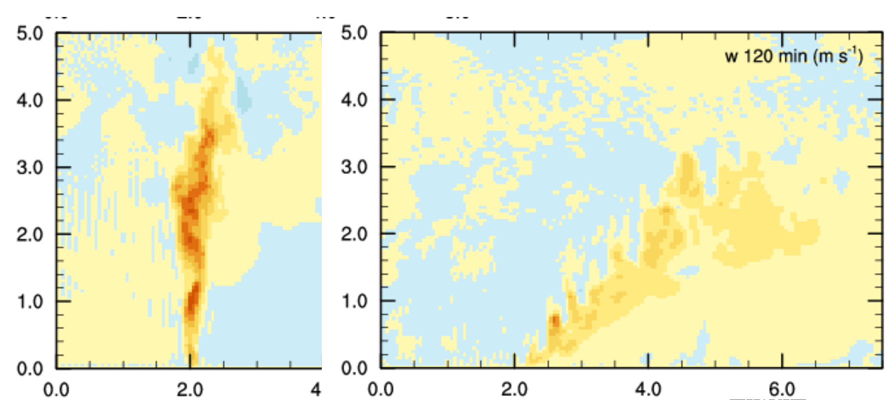
Conclusions



- High resolution numerical weather prediction is capable of reproducing boundary-layer rolls
- These have potential impacts on updrafts and surface wind variability, hence fire spread
- Idealised large eddy modelling of fire plumes reveals a range of plume behaviour in response to wind
- Future work will assess the interaction between plumes and boundary-layer rolls







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