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Large-eddy simulations of pyro-convection and its sensitivity to environmental conditions

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AFAC & BNHCRC Conference, Adelaide, 1 September 2015

Motivation

- Pyro-convection is responsible for the ***lofting*** of embers downwind of fires
    - ***Unpredictable*** and ***accelerated*** fire spread

- With a sufficient source of moisture, ***moist*** pyro-convection (Cu/Cb) may occur
    - Enhanced ***plume updrafts***
    - Variable and intense ***near-surface winds***
    - PyroCb ***lightning***
    - (Stratospheric aerosol injection)

- The importance of the environment and moisture source remains unclear:
    - Cunningham & Reeder (2009) – moisture from fire required
    - Trentmann et al. (2006) – environmental moisture is sufficient

How do changes in the environment modify the behavior of pyro-convection?

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

Plume modelling methodology

- Spin up convective boundary layer under atmospheric profiles representative of high fire danger days
  - Initialise model with horizontally homogeneous potential temperature and moisture profiles (zero wind today)
  - Apply random perturbations ($\pm$ 0.2 K) to potential temperature field
  - Impose uniform 50 W m^{-2} sensible heat flux
  - Run model until turbulence (defined by domain-averaged TKE) has spun up to quasi-steady state

- Generate a “fire” plume by applying an intense circular surface heat flux anomaly (radius = 250 m)
  - No moisture source
  - No feedback of atmosphere onto fire behaviour
  - No surface spread
  - Allows us to isolate the way plumes respond to different environments

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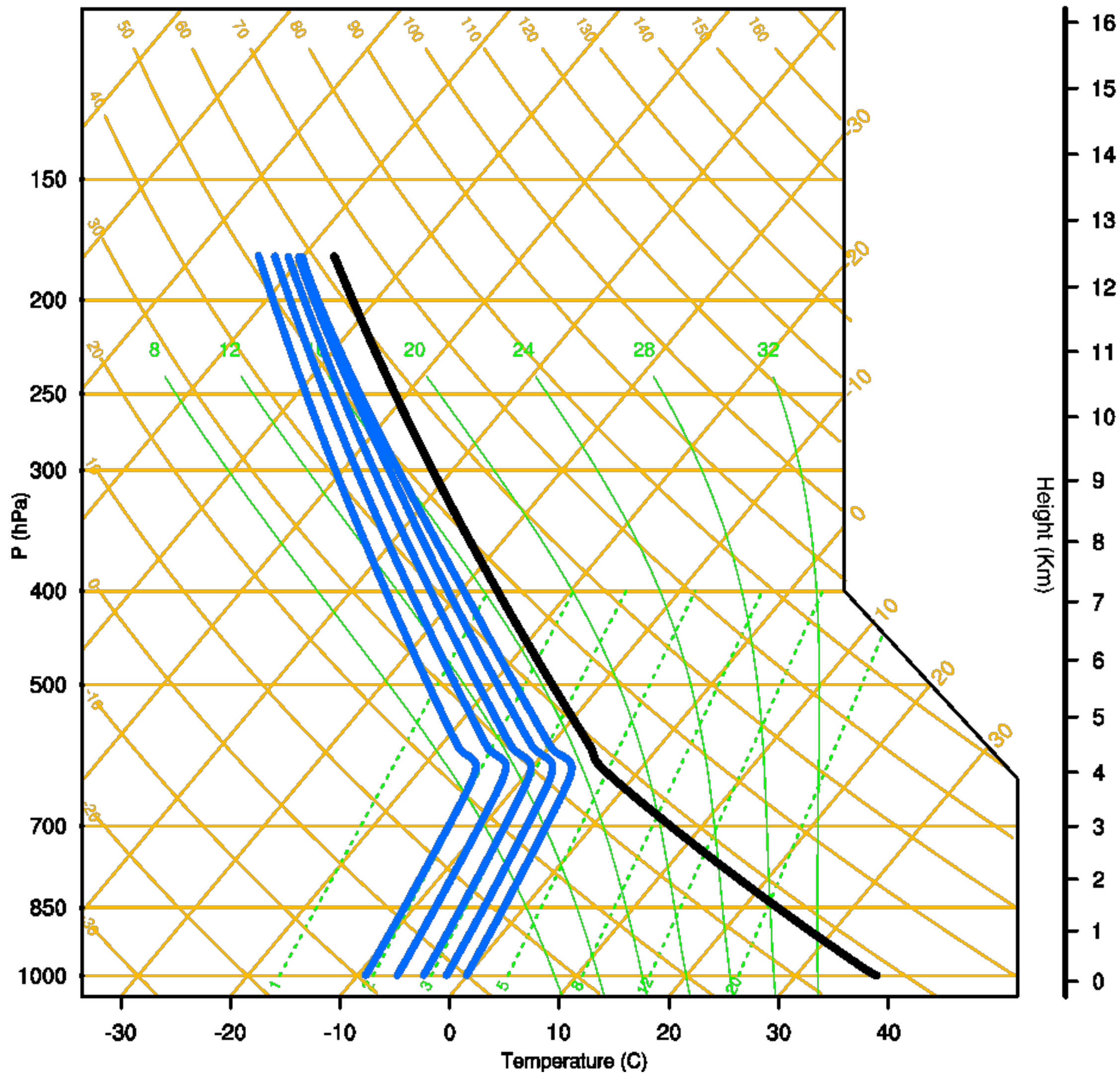
Modelling strategy

- Five different atmospheres
  - Identical temperature profiles
  - 4-km deep, warm boundary layer
  - Boundary-layer specific humidity q_{bl} = 2.0, 2.5, 3.0, 3.5 and 4.0 g kg^{-1}
- Four fire intensities
  - Q = 5, 10, 20, 30 kW m^{-2}
  - Smoothly increased for 5 min
  - Held at peak for 60 min
  - Smoothly decreased for 5 min
- 20 simulations in total



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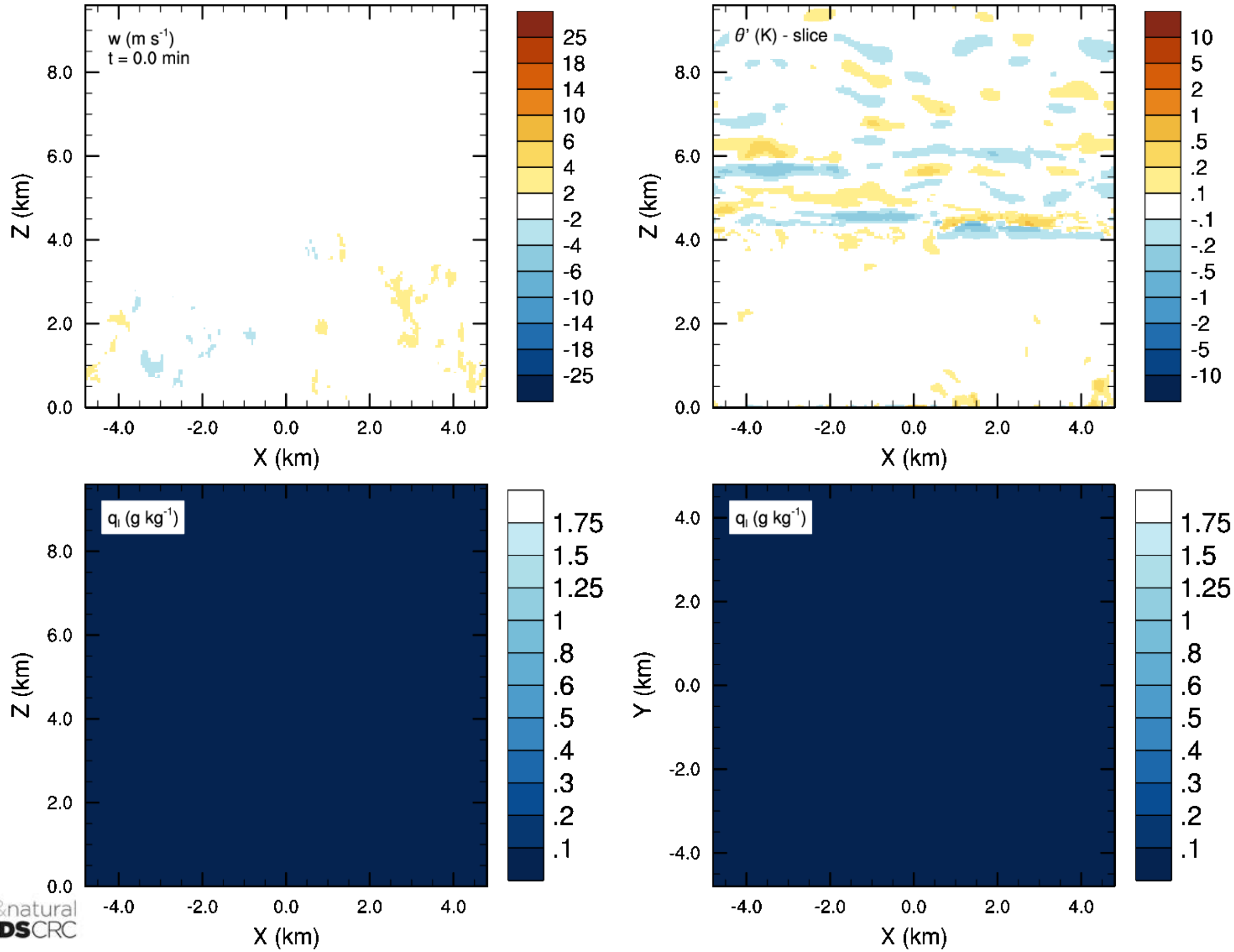
Q = 30 kW m^{-2}, q_{bl} = 2.0 g kg^{-1}



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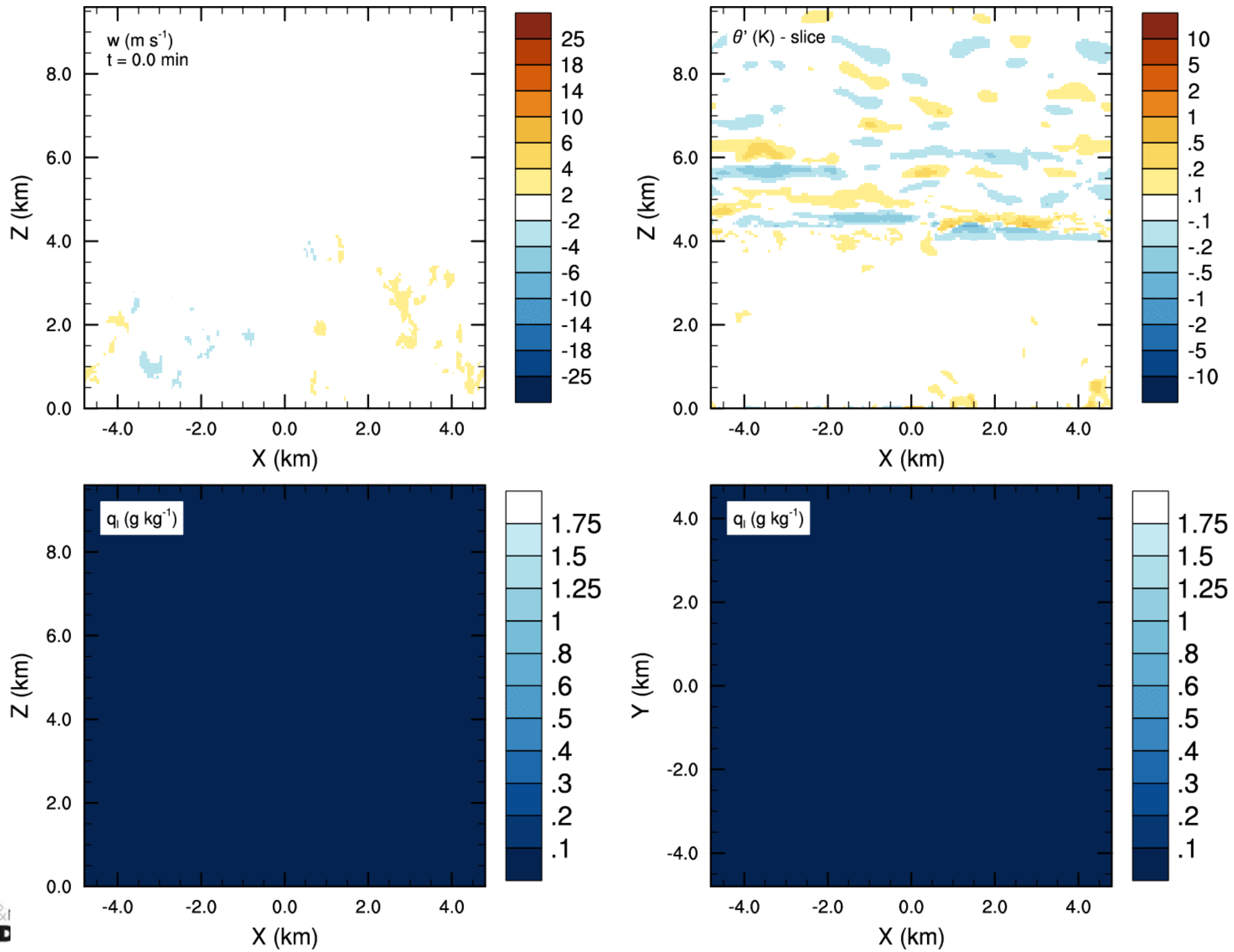

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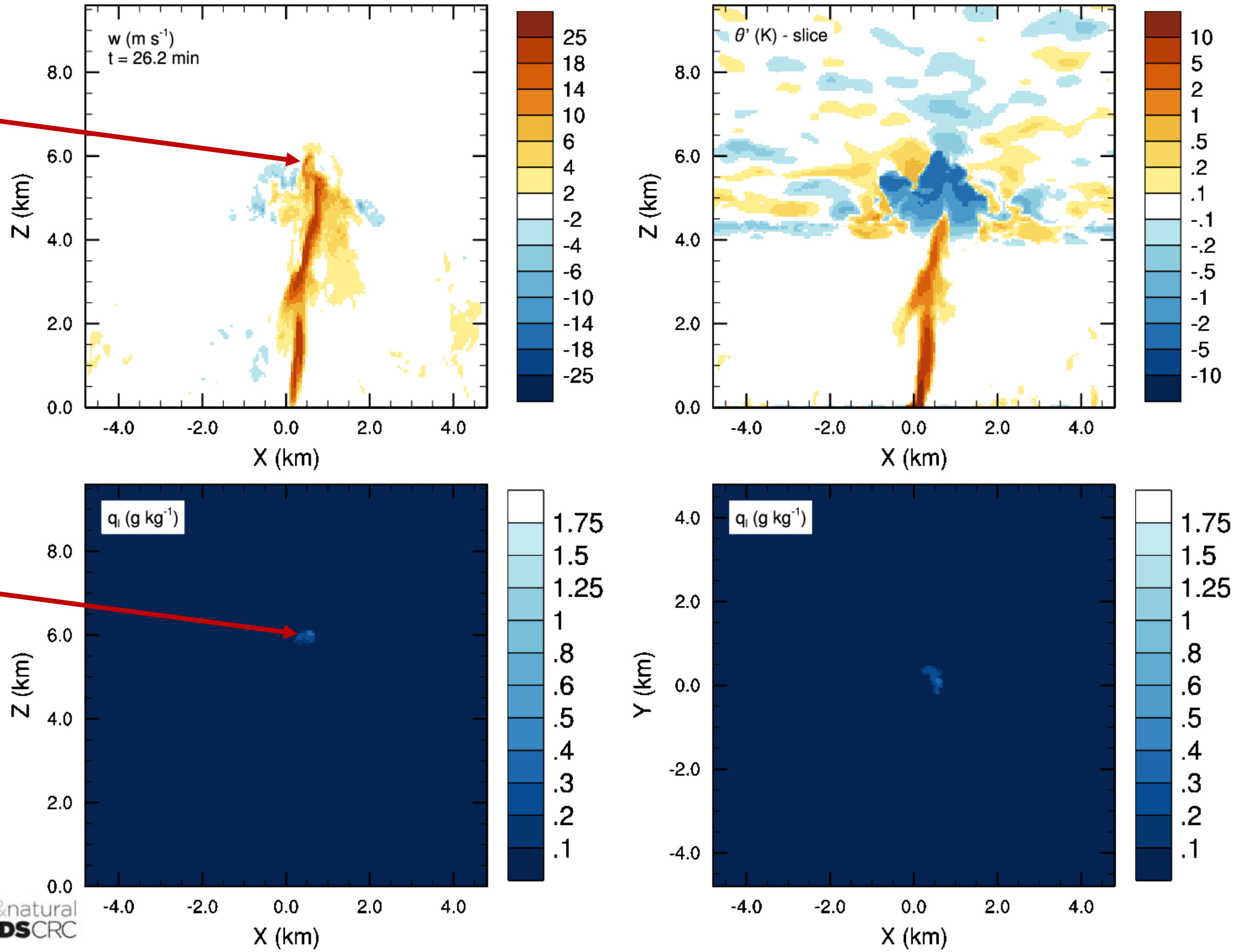

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Q = 30 kW m^{-2}, q_{bl} = 3.5 g kg^{-1}

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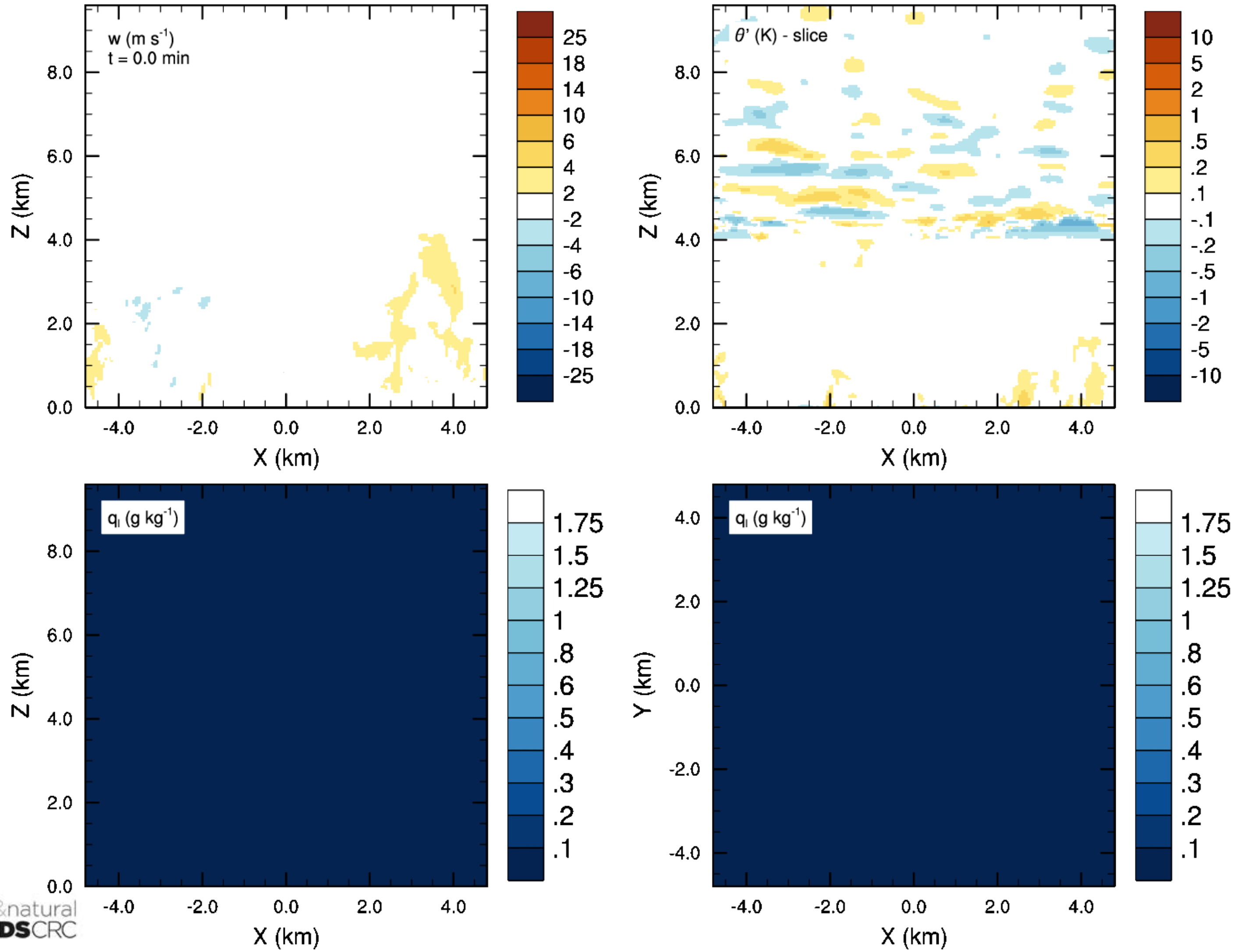

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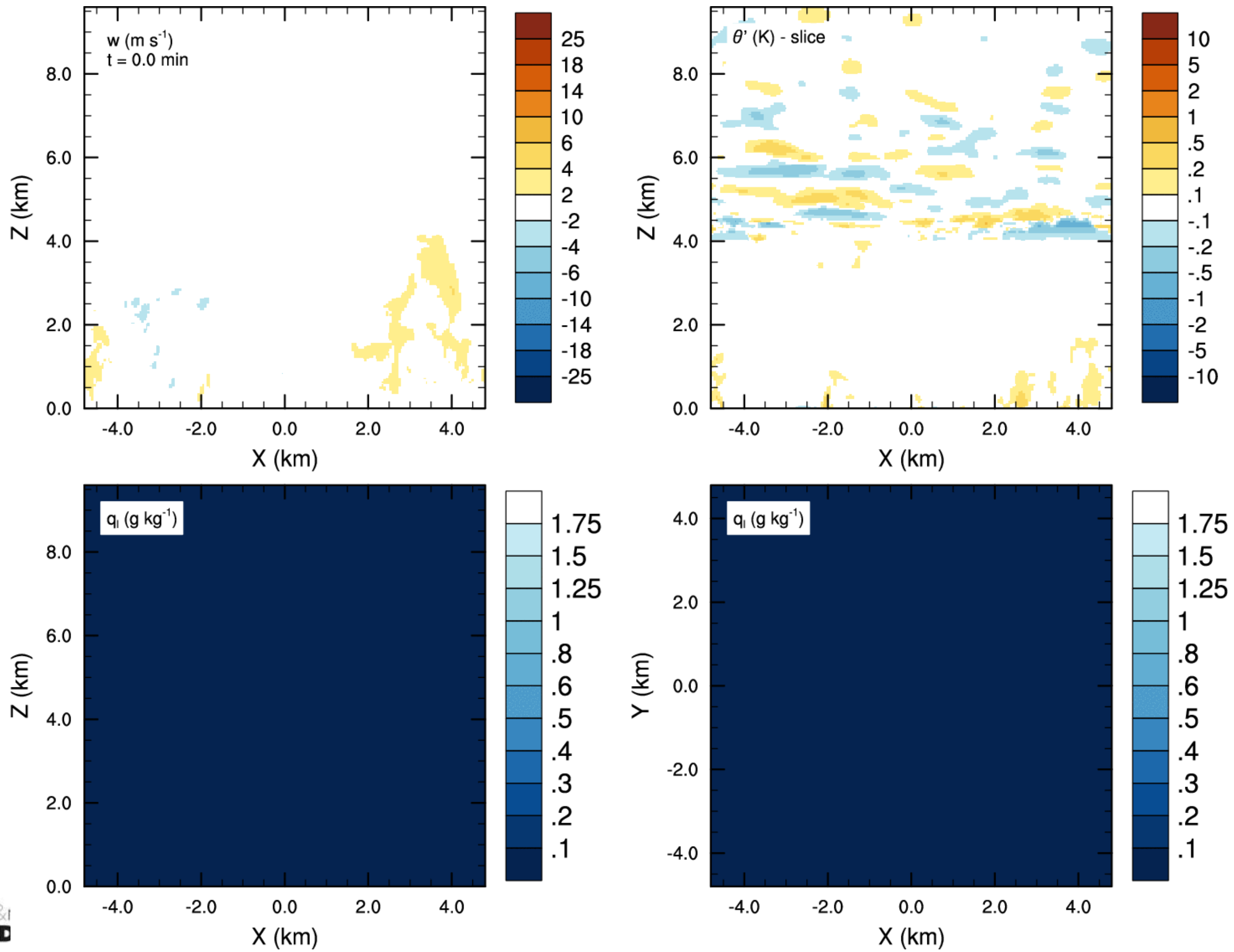

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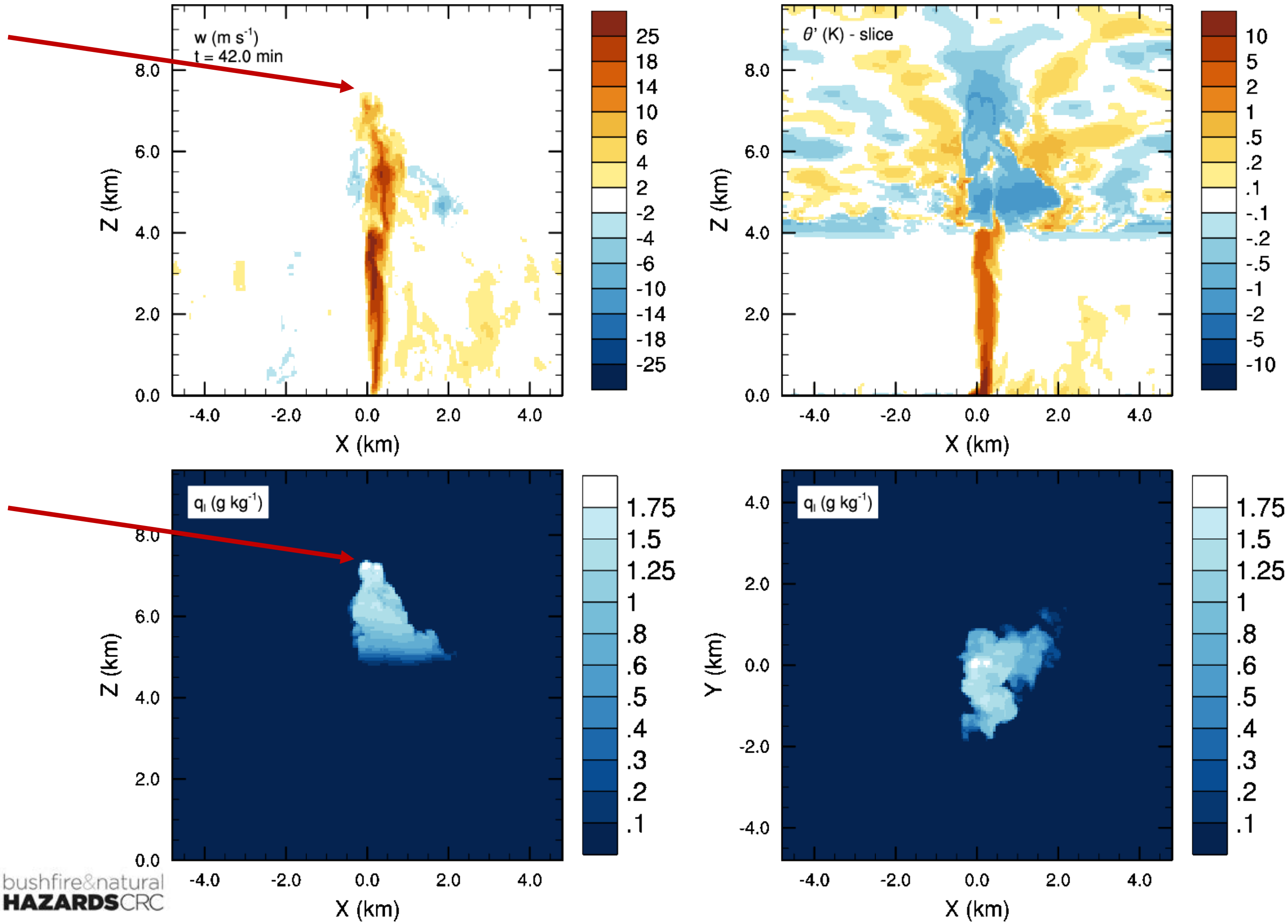

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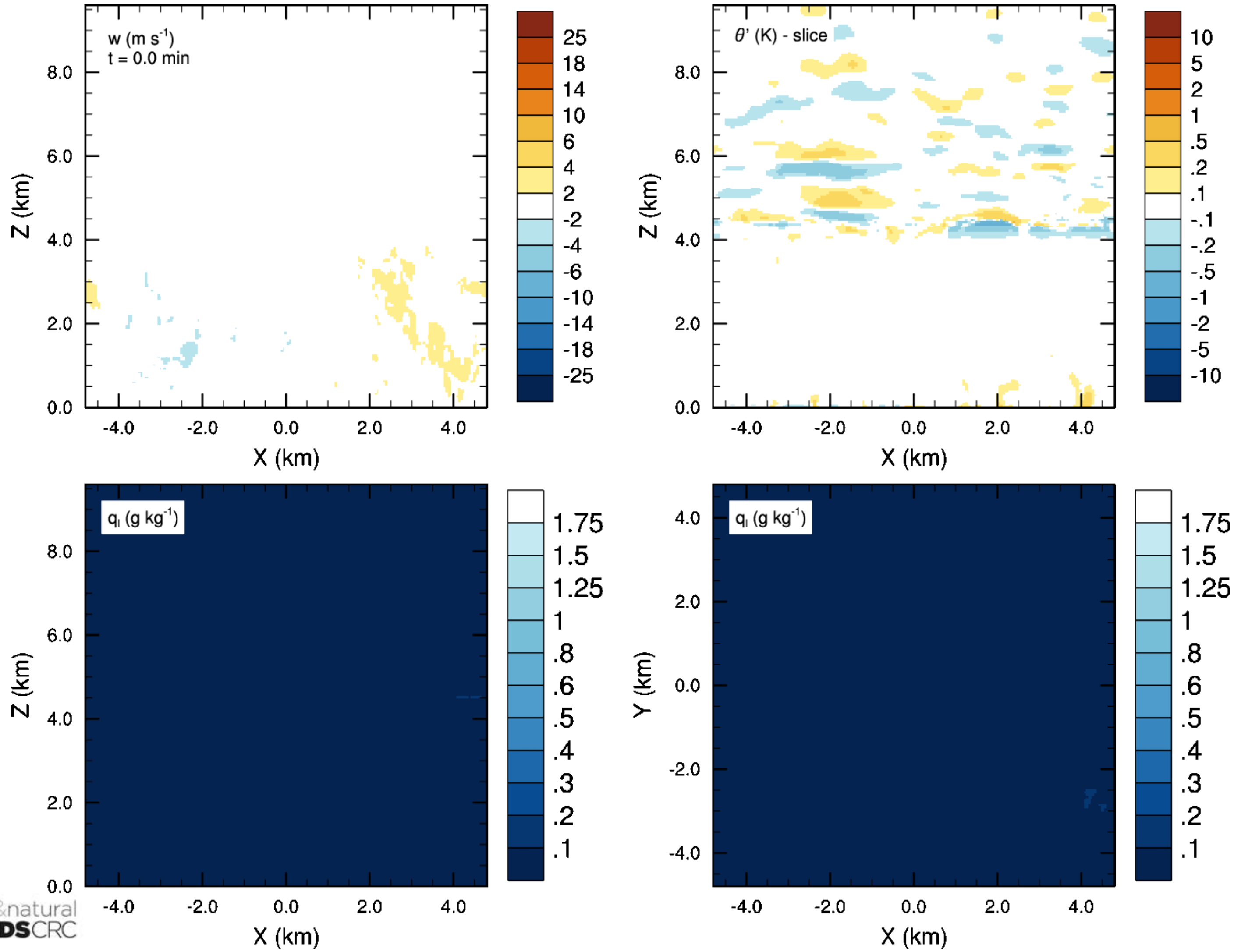

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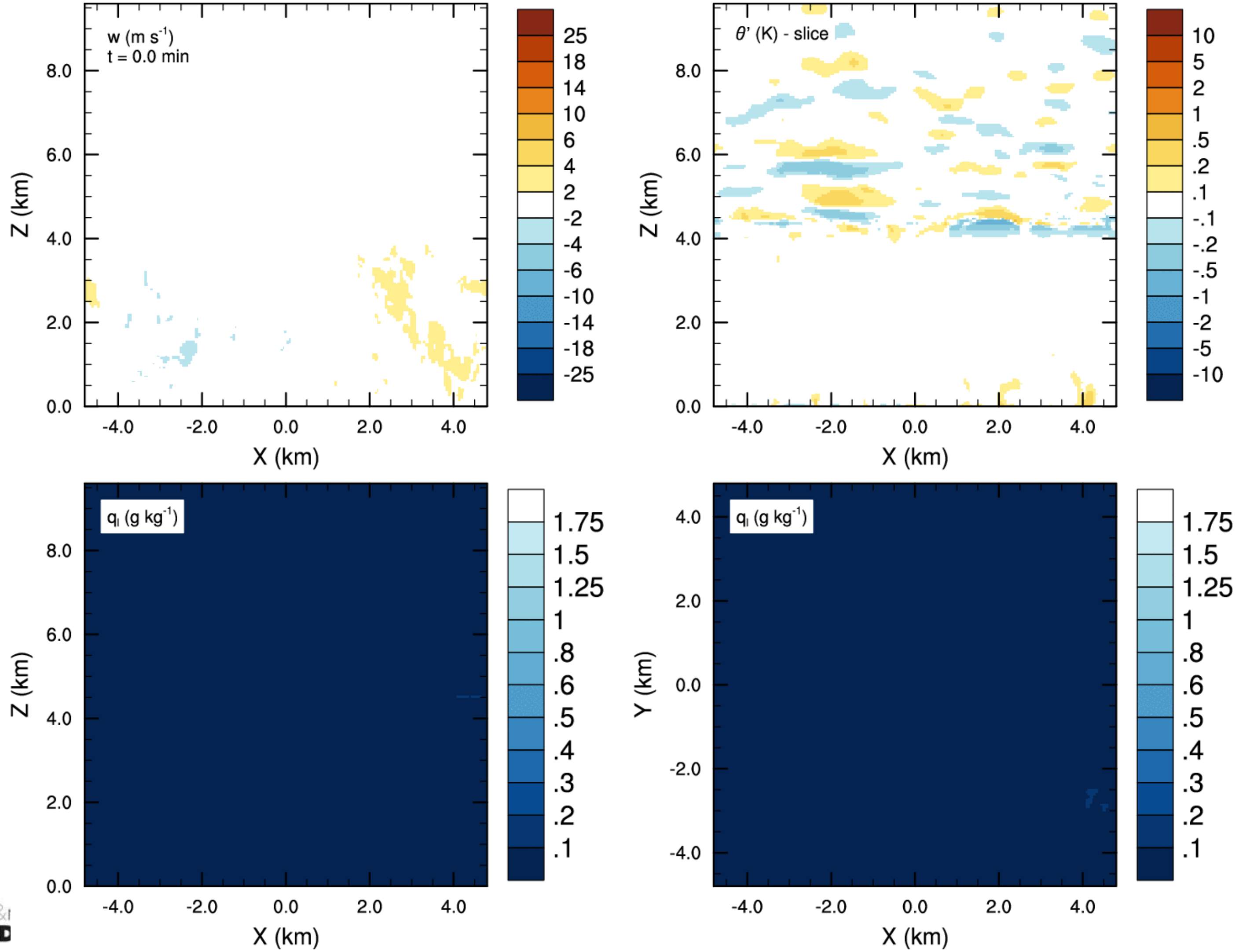

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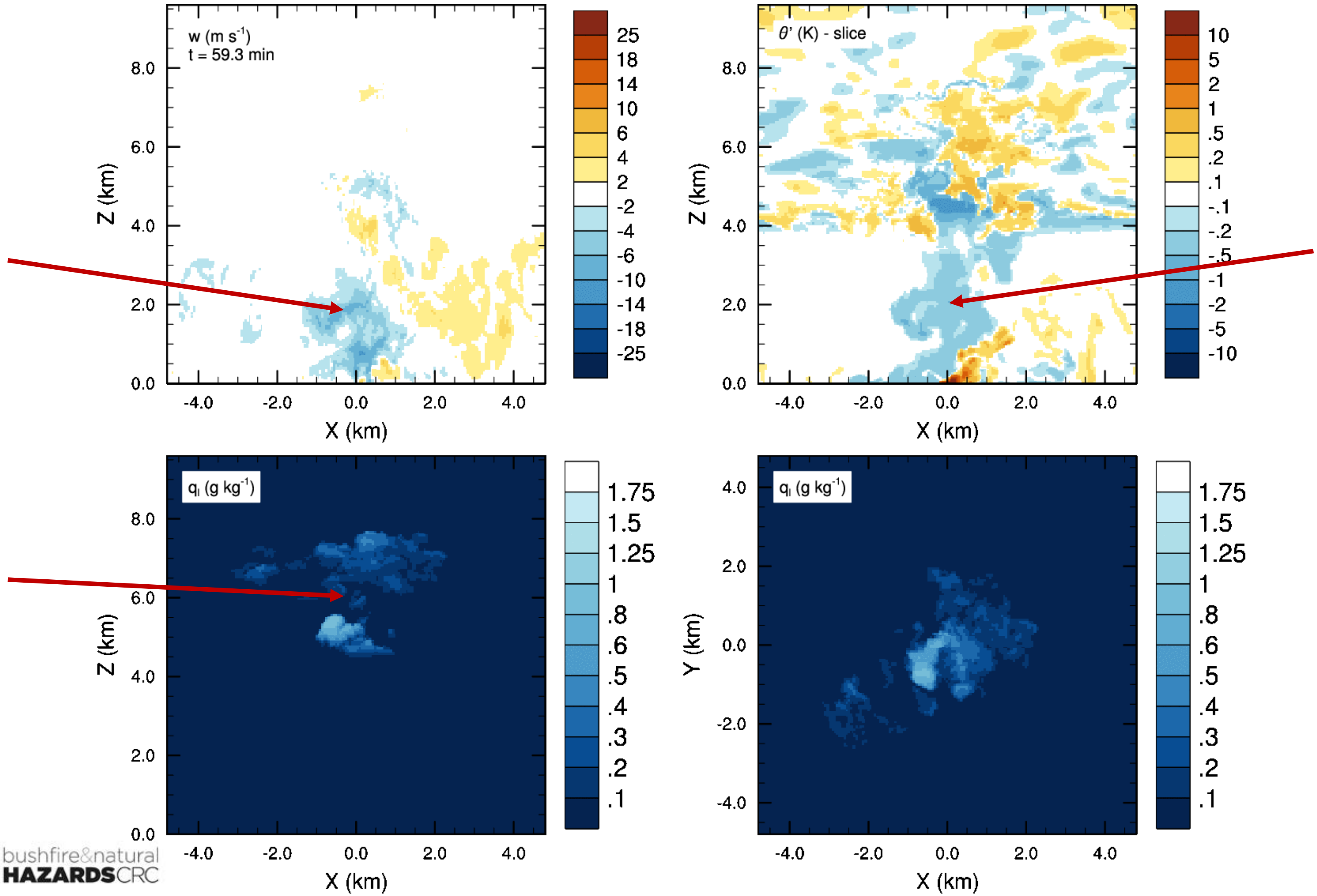

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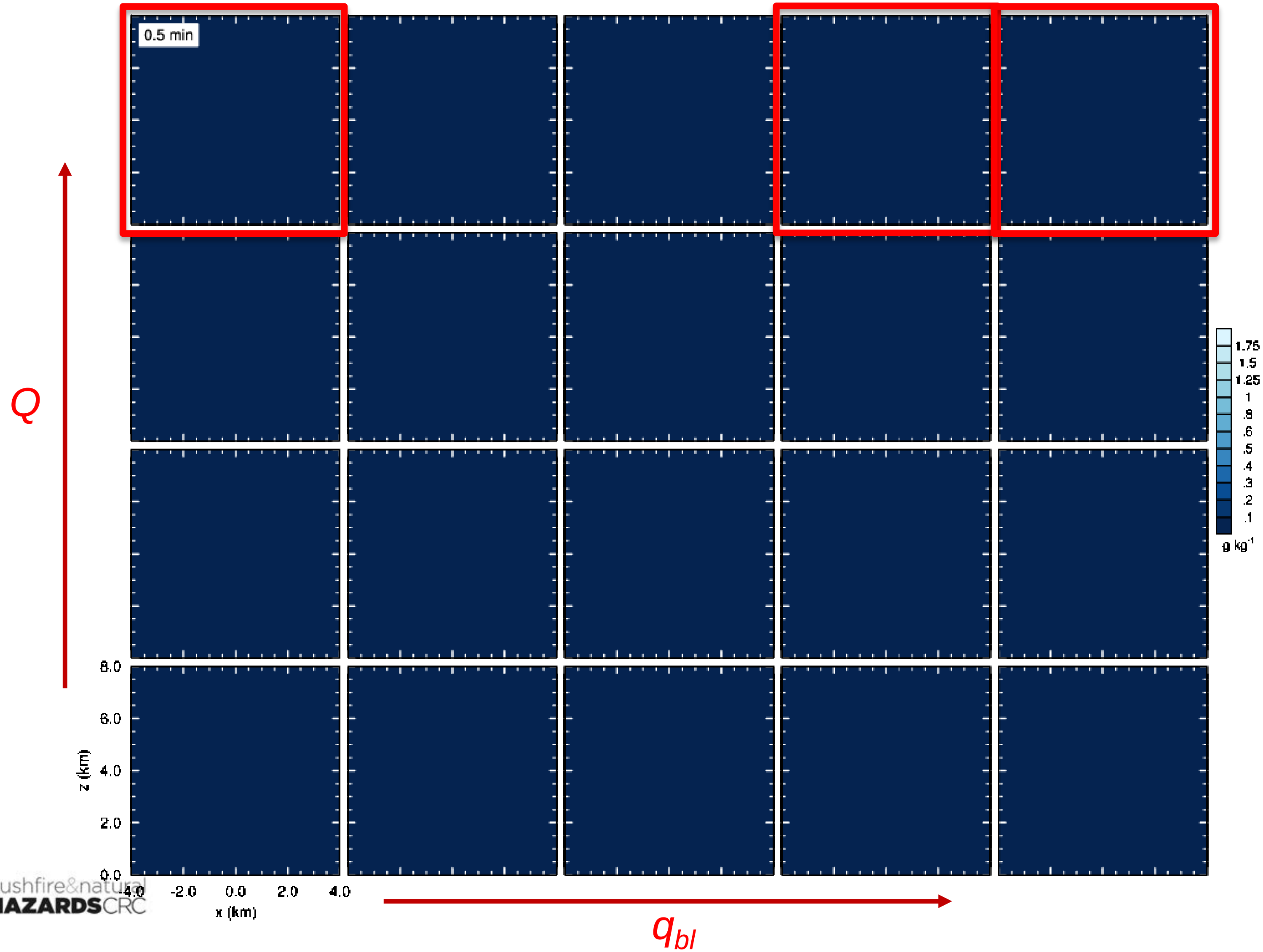
(Q , q_{bl}) parameter space



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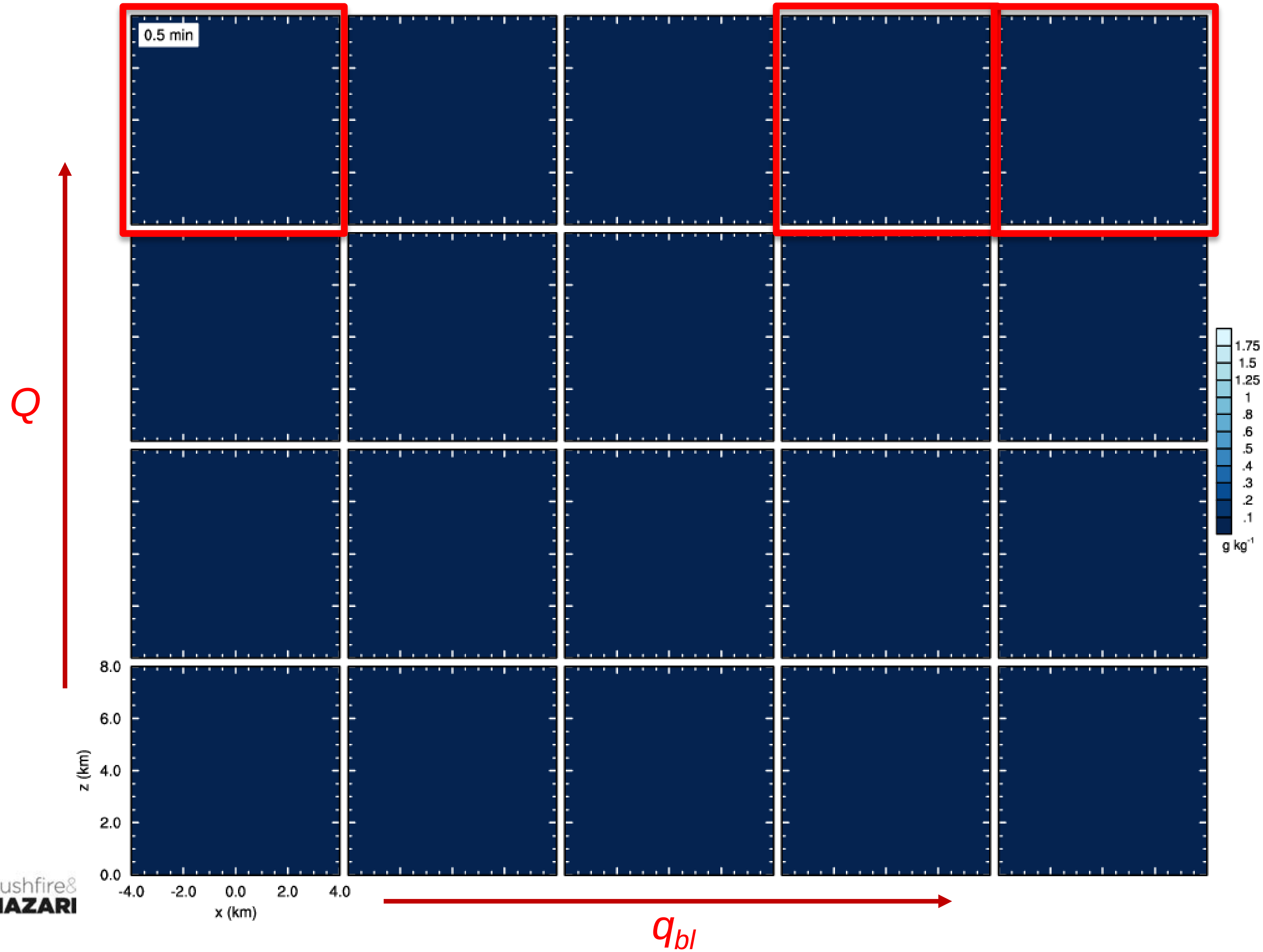

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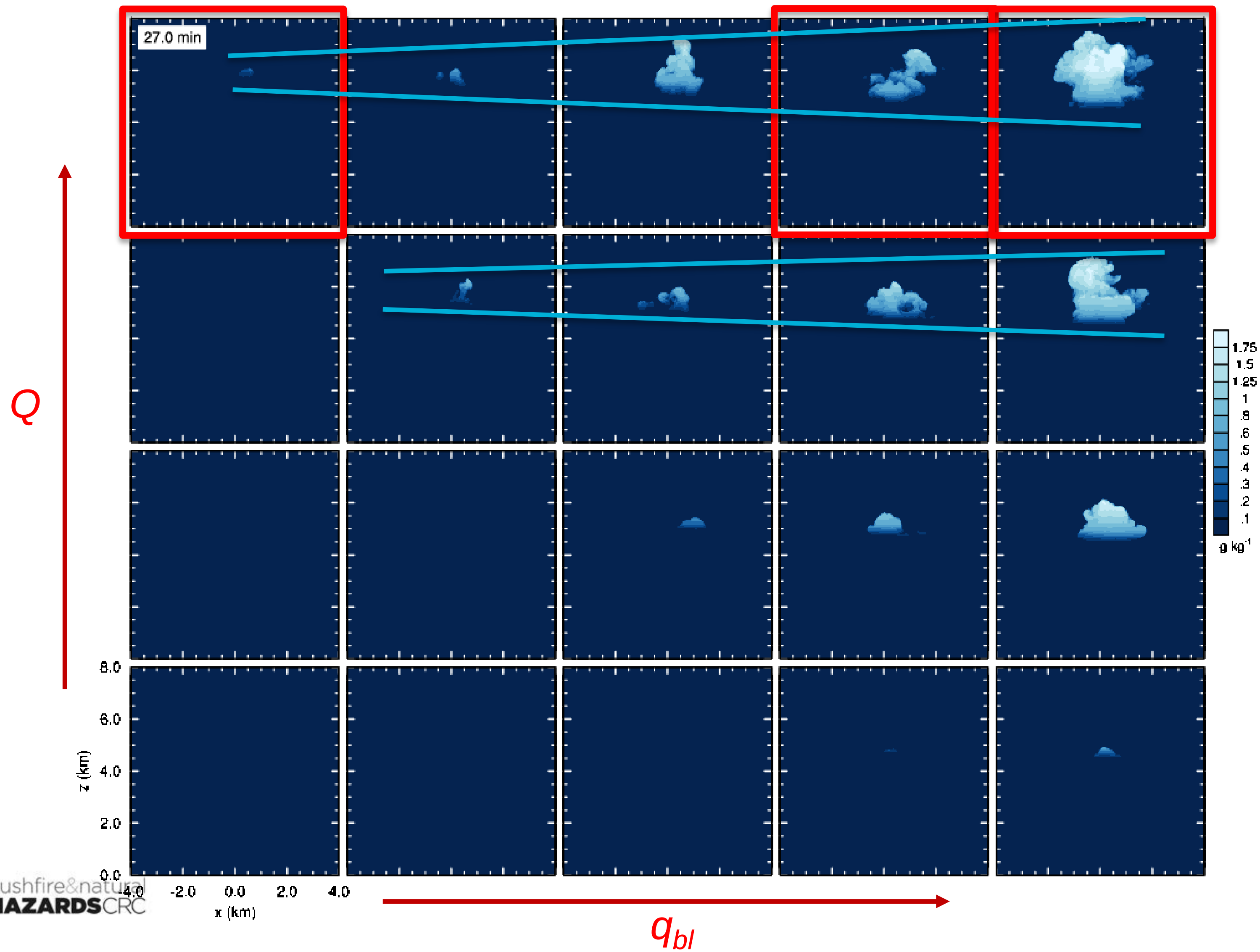

Formation of moist pyro-convection

- Pyrocumulus form in most-intense fires and most-moist atmospheres
- Pyrocumulus is able to form without a source of moisture from the fire
- **Pyrocumulus formation leads to updraft resurgence at altitude**
- More intense fires lead to taller and broader pyrocumulus
- Increasing environmental moisture reduces cloud-base height
- The most-intense pyro-convection generates evaporatively cooled downdrafts

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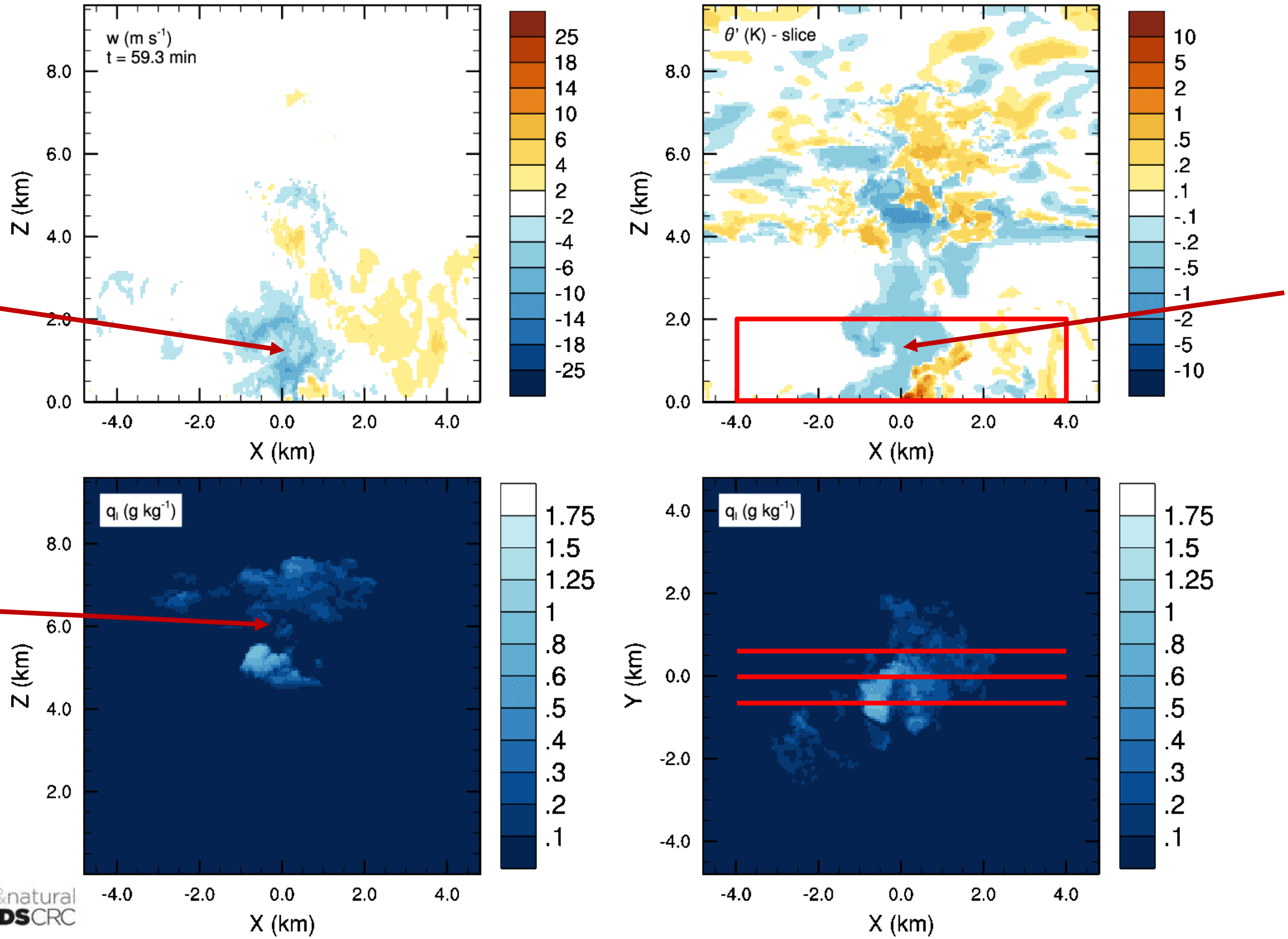
Downdraft vertical cross-sections



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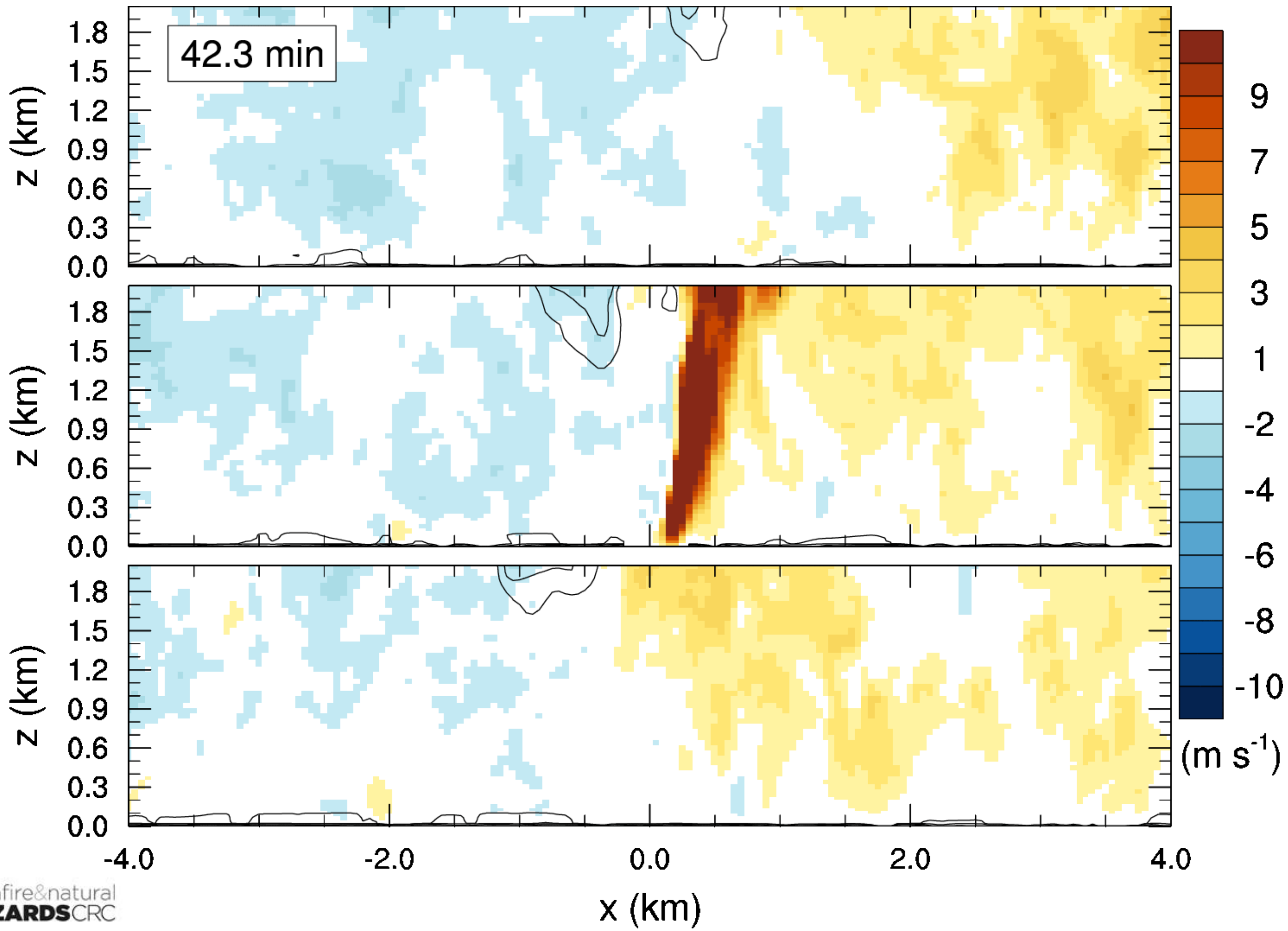

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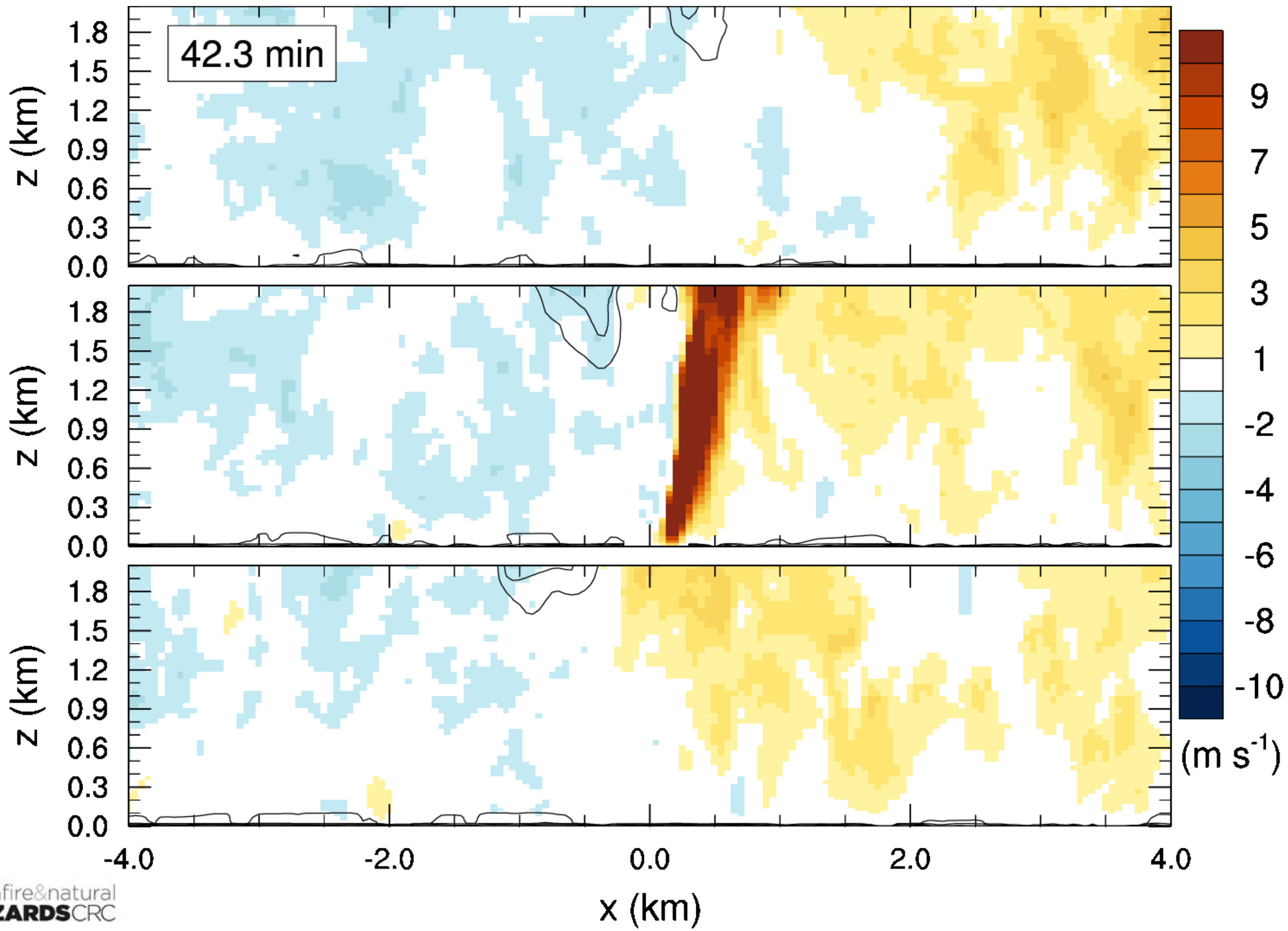

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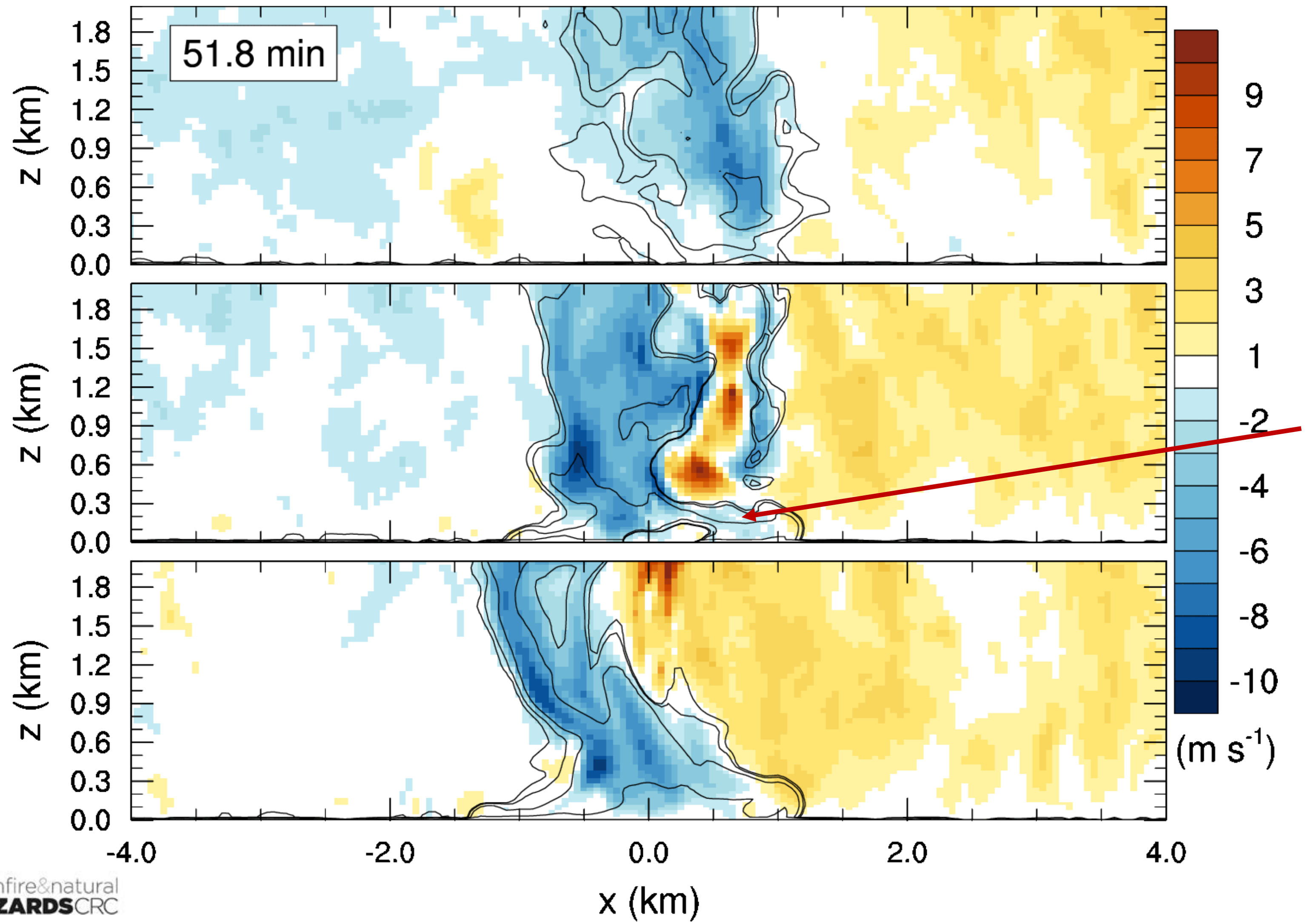

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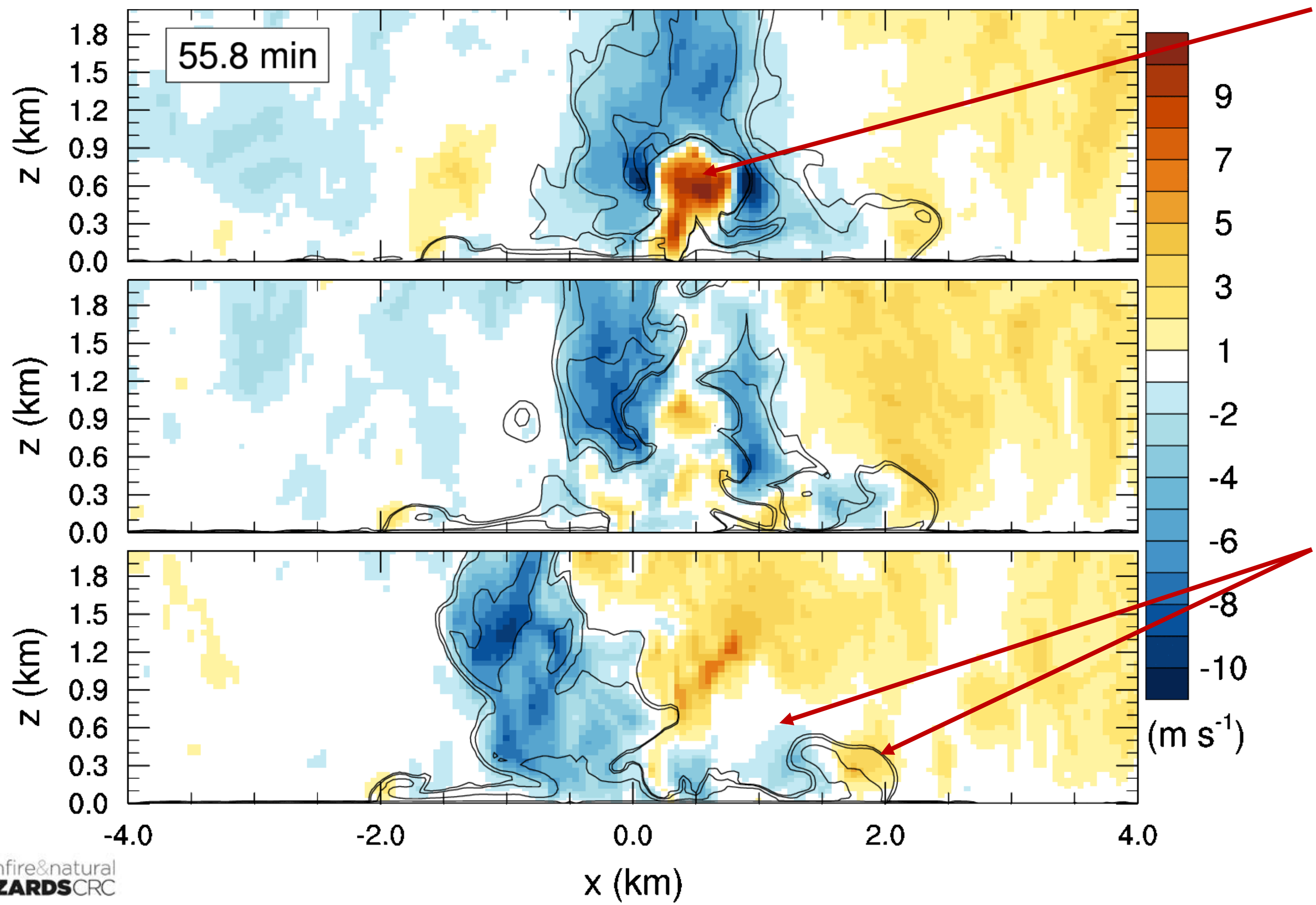
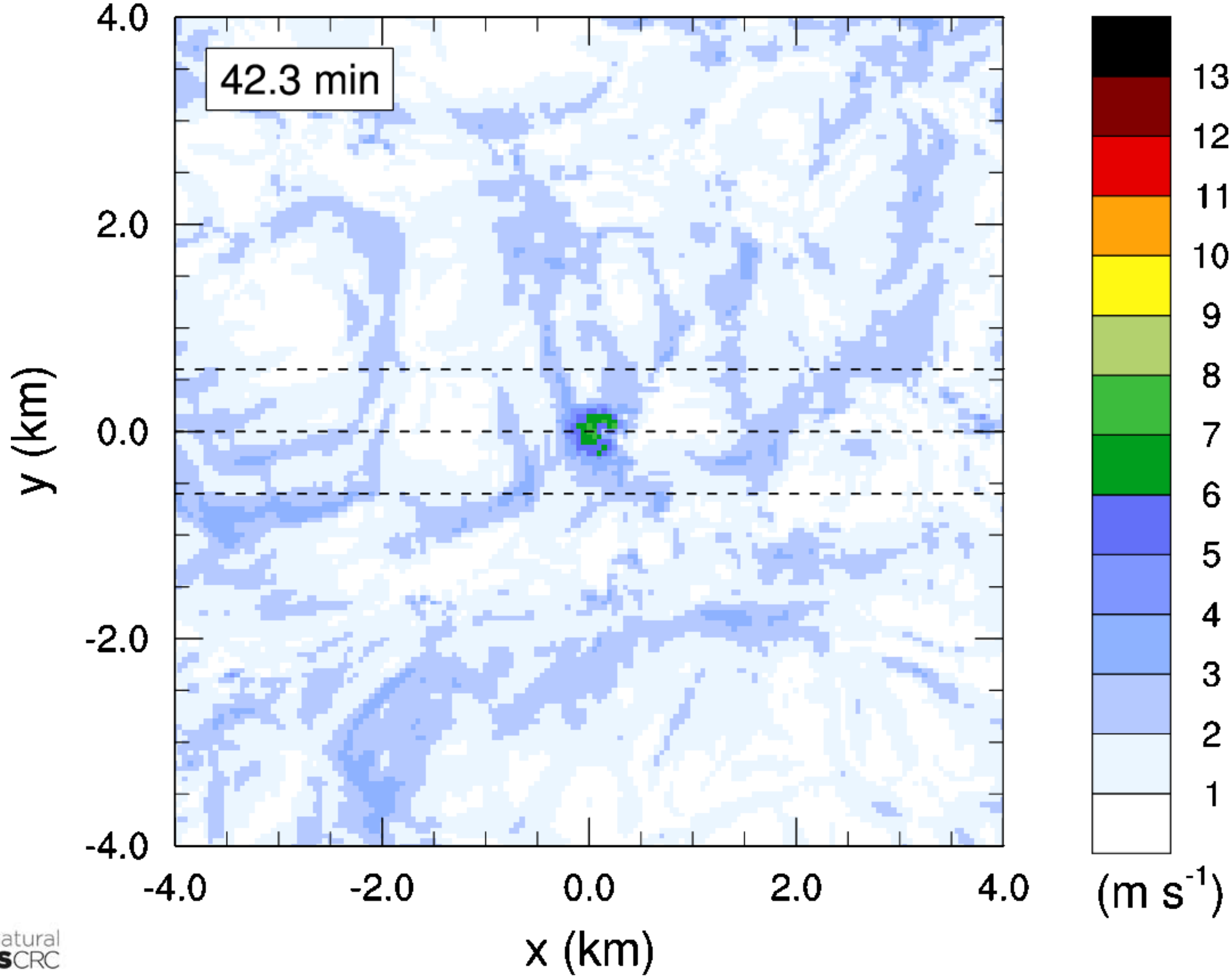


Gust-front evolution : 10-m wind speed



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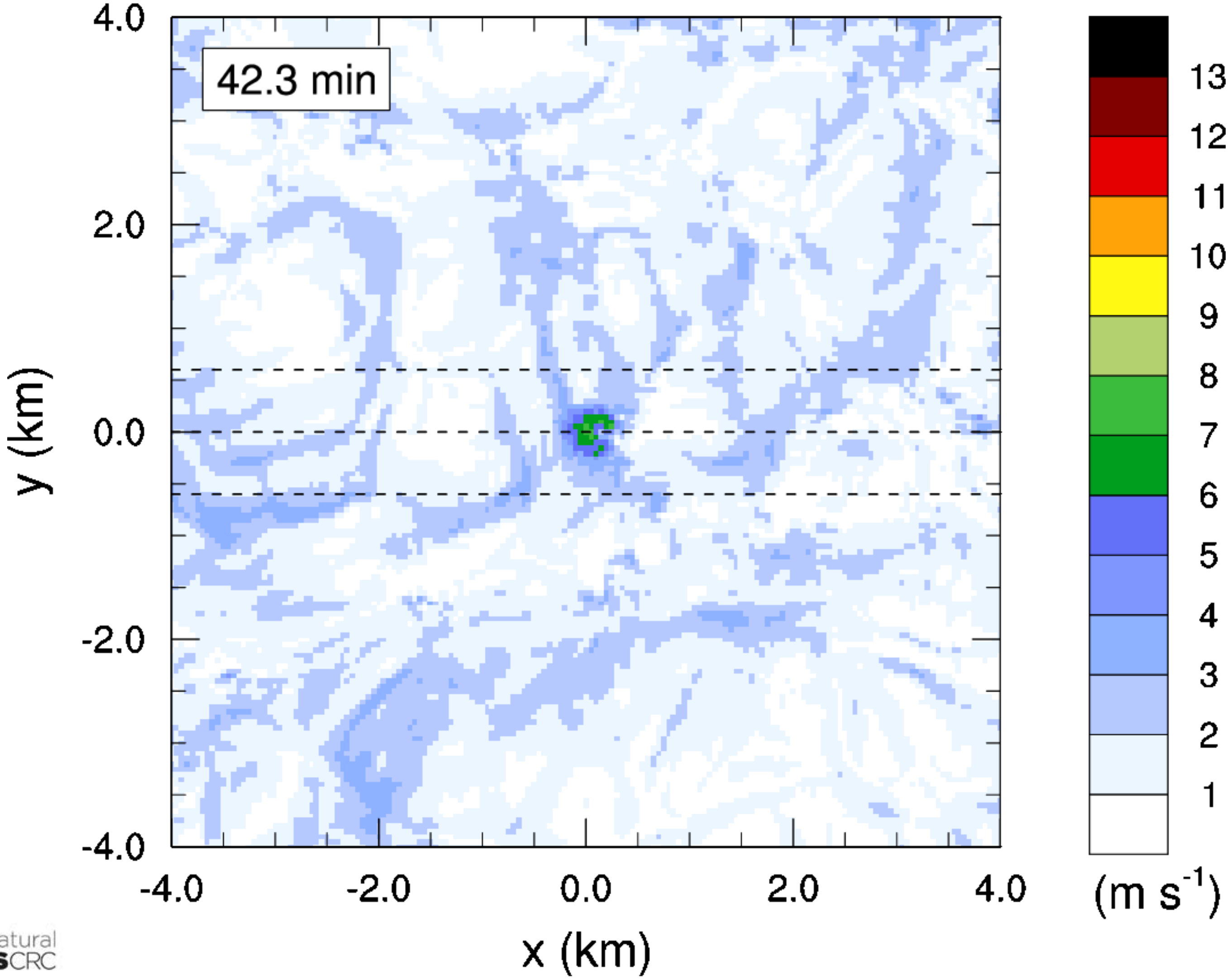

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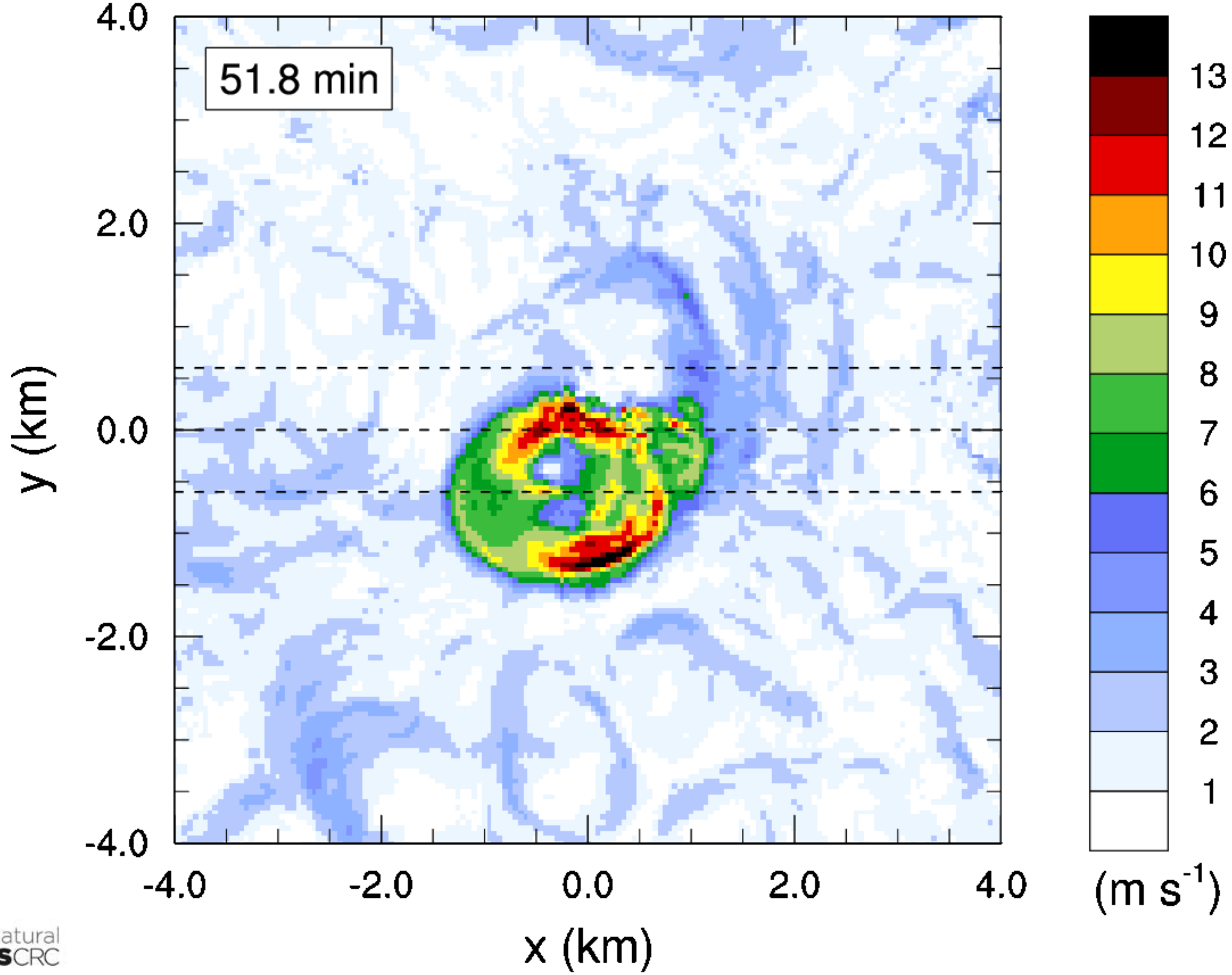

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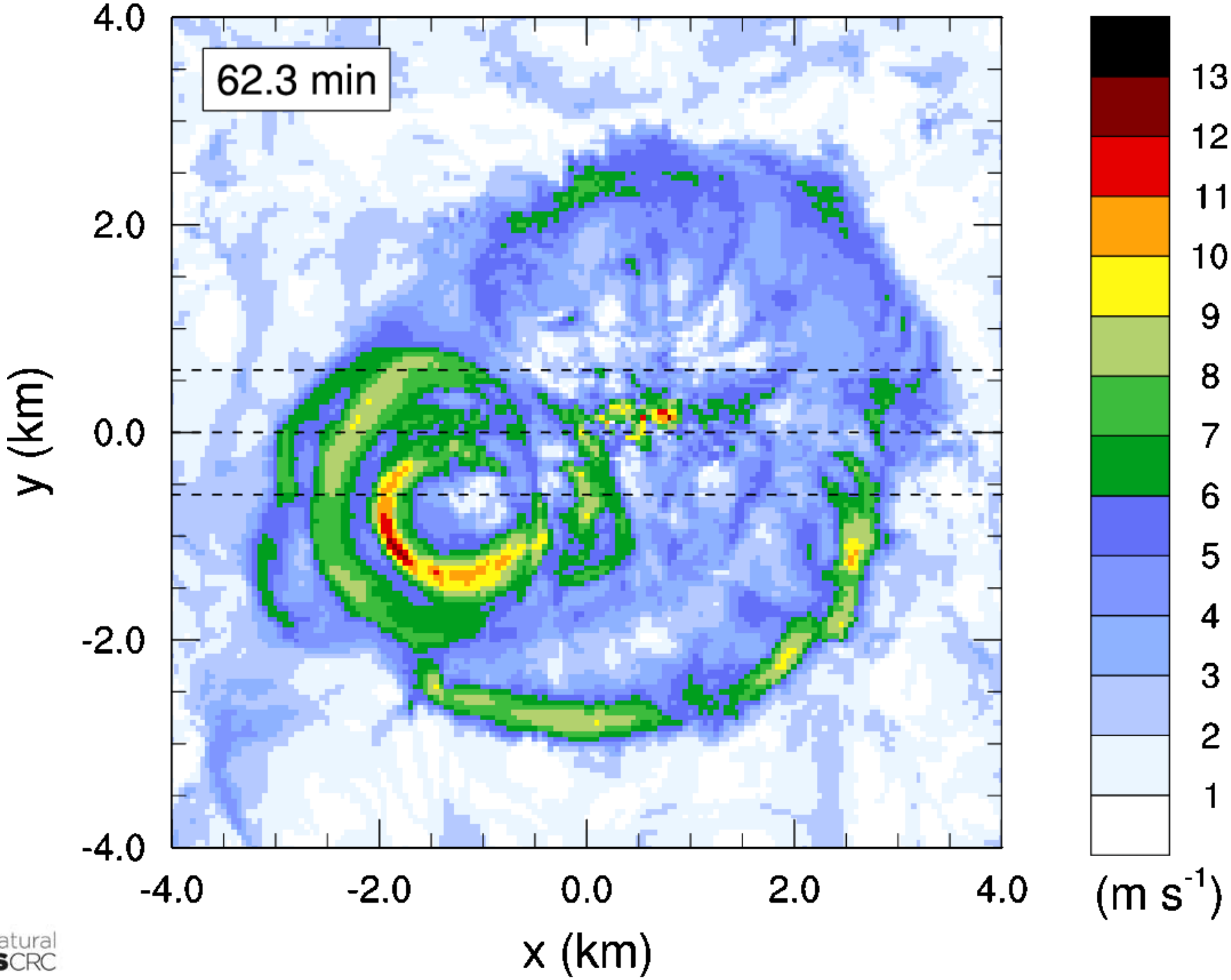

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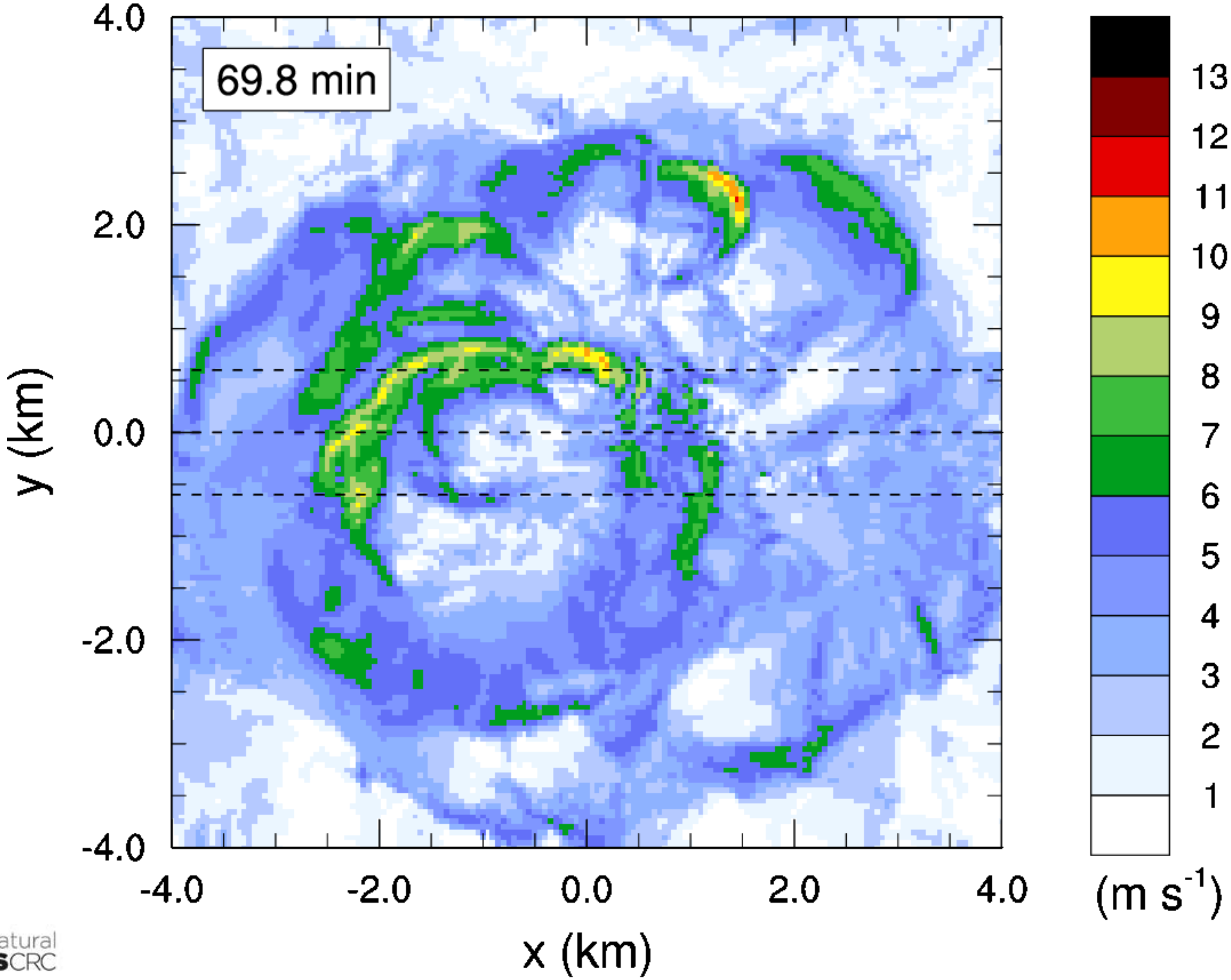

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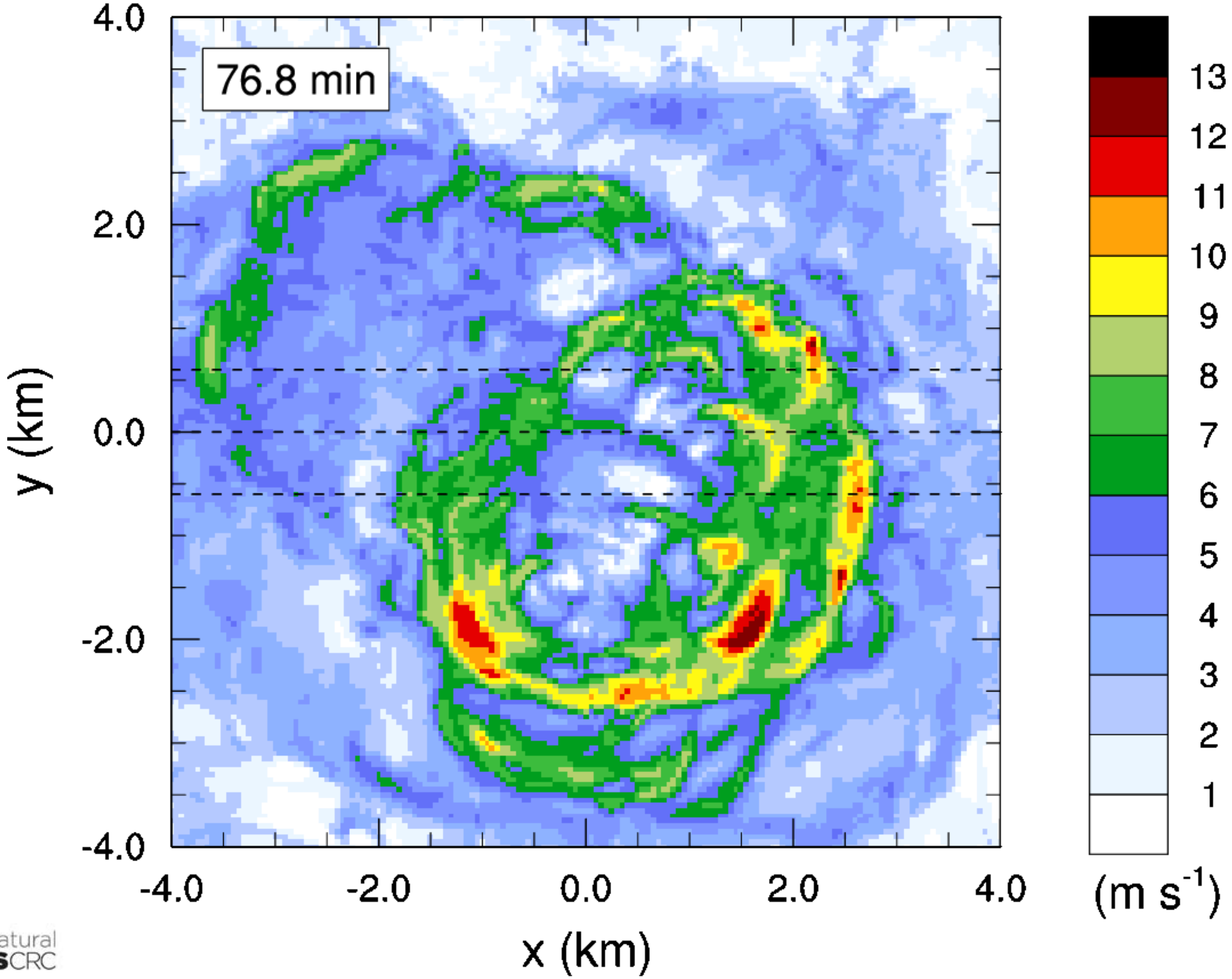
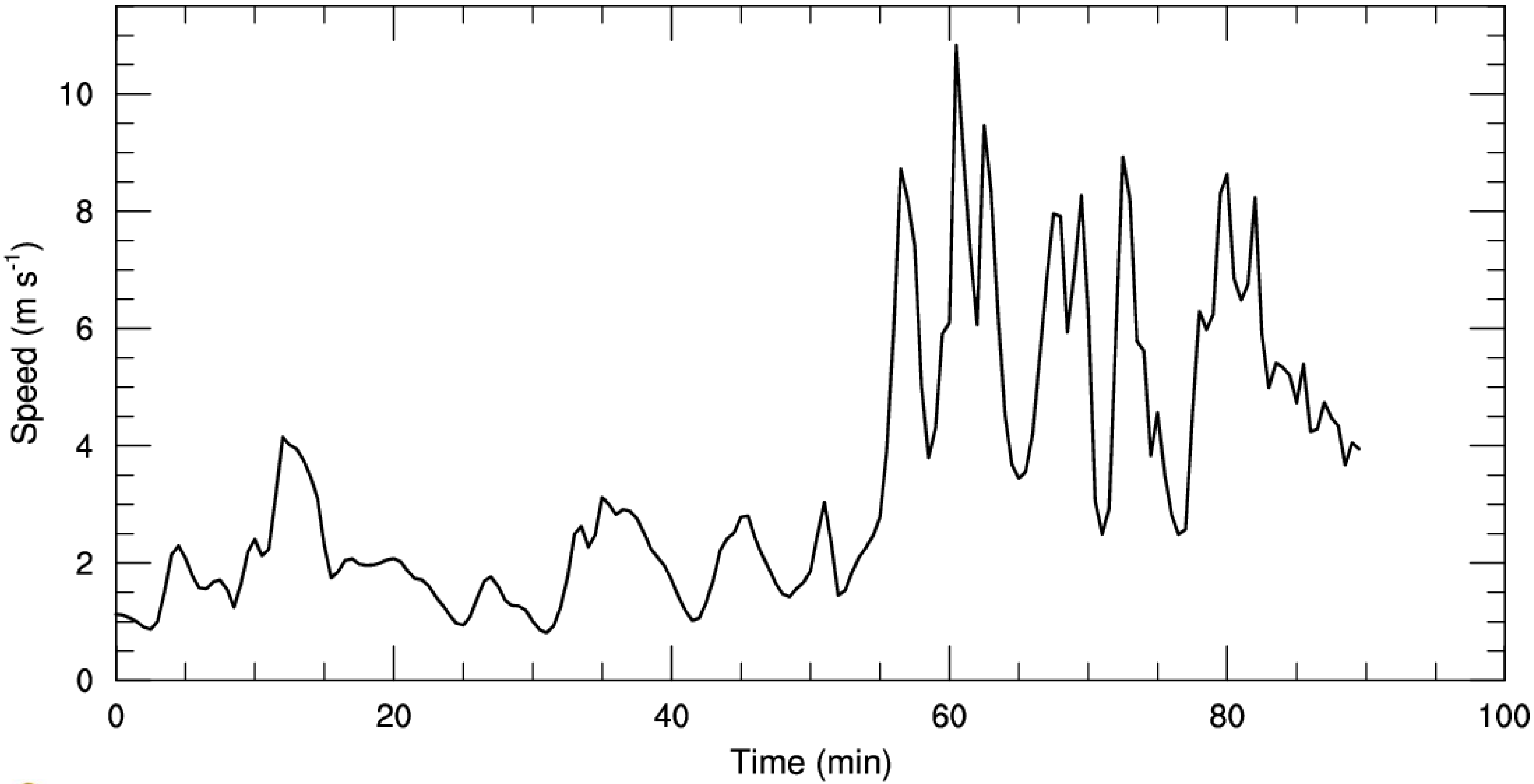


Gust-front point time-series



Formation of downdrafts

- If the fire is intense enough and the atmosphere moist enough, substantial precipitation occurs

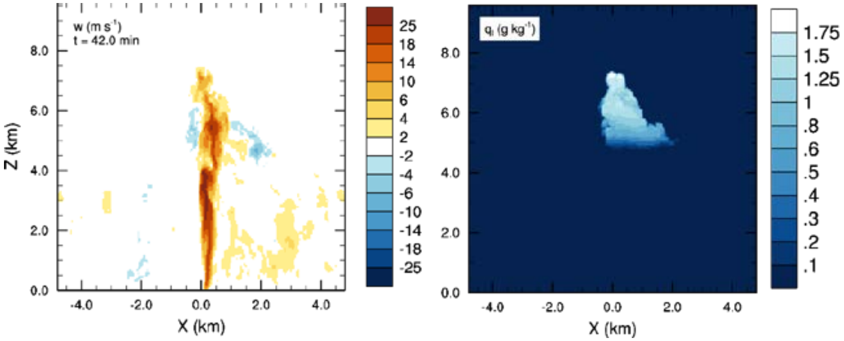
- As the precipitation falls through warmer, drier air it evaporates and generates negatively buoyant air

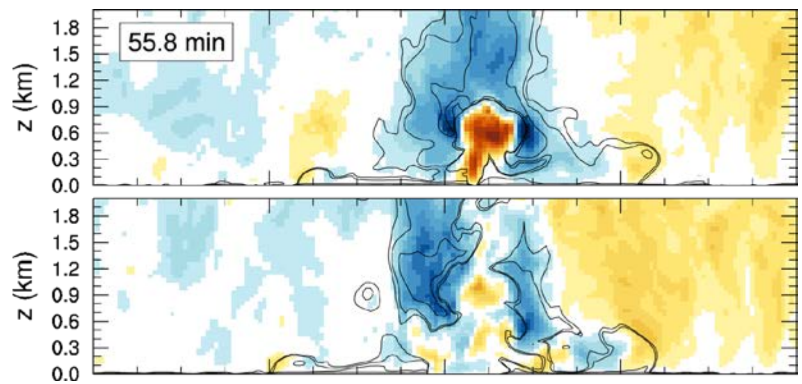
- These evaporatively cooled downdrafts have a complex structure and interact with the main plume updraft

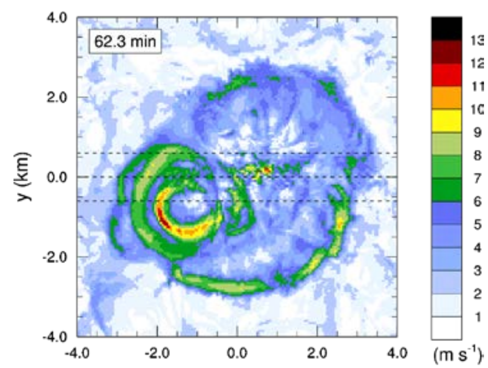
- Upon impacting upon the surface, the downdrafts spread out as a series of gust fronts with strong, highly variable winds for > 20 minutes

Summary

- Intense fires in moist atmospheres produce pyrocumulus clouds.
- This leads to enhanced updrafts, both in intensity and in altitude
- The most-intense pyro-convection generates evaporatively cooled downdrafts
- Downdrafts impact upon the surface as a series of complex, turbulent gust fronts
- Both the updrafts and the downdrafts have implications for fire spread
- Future work will quantify the relative importance of moisture from the fire and moisture from the environment







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