IMPROVED PREDICTIONS OF SEVERE WEATHER

to reduce community risk

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Australian Government
Department of Industry and Science
Business
Cooperative Research
Centres Programme

Australian Government
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OVERVIEW

1) Project is almost up-to-date
2) Two subprojects completed, two well underway, two commenced recently
3) Journal articles: one in revision, one submitted, two in preparation.
4) Many conference presentations, etc.
5) Subprojects:
   a) Blue Mountains fire of October 2013 ← *Completed*
   b) Ember transport ← *Completed*
   c) East coast low of April 2015
   d) Pyrocumulus—modelling
   e) Pyrocumulus—Forecast tools ← *Preliminary results*
   f) Tropical Cyclone ← *Preliminary results*

BLUE MOUNTAINS FIRE OCTOBER 2013

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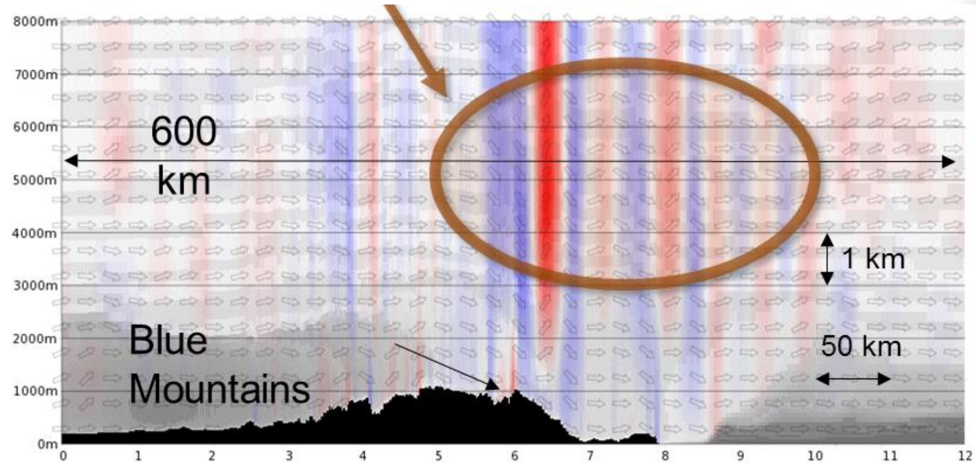
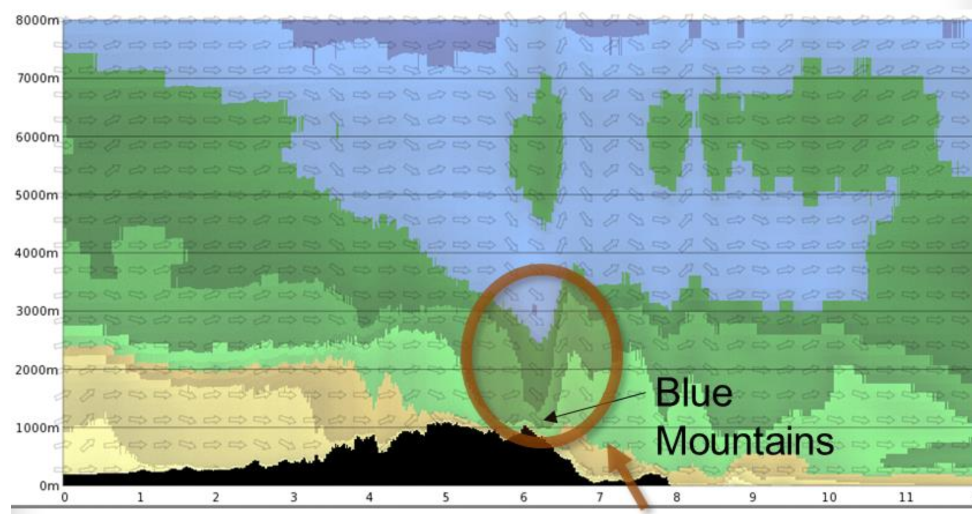
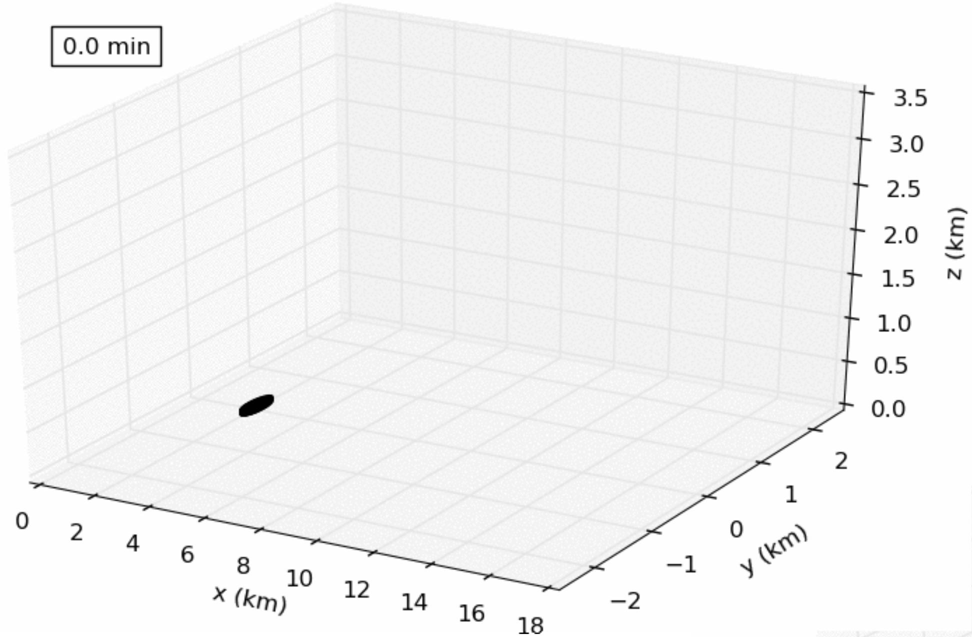
- **Key Results**

1) Narrow band of dry air passed over the fire ground.
2) Mountain waves developed, with,
3) a downward extension of strong winds at the fire ground.



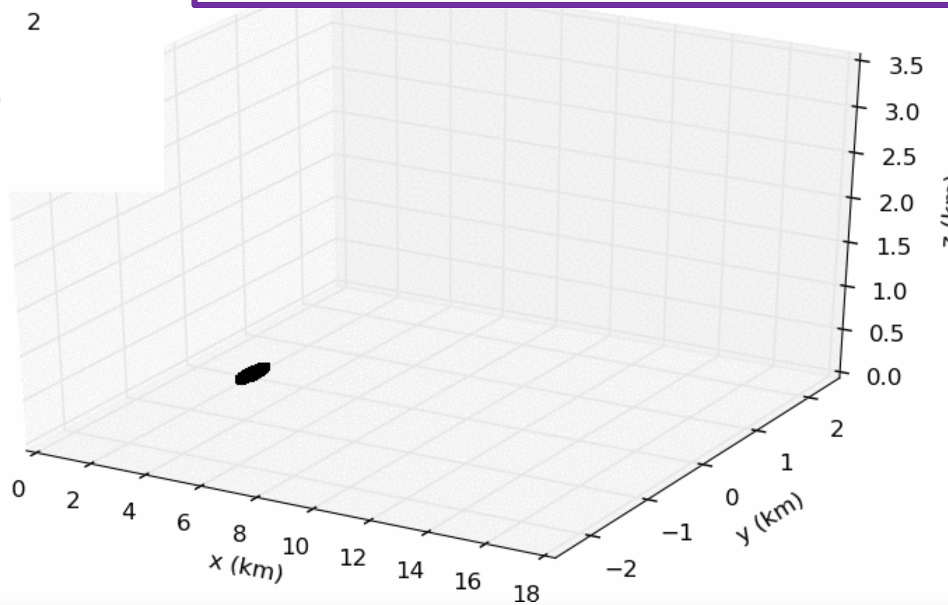


FIREBRAND TRANSPORT – 15 M S^{-1} WIND



Comparison between high res firebrand transport simulations and transport by the time-mean wind, provides information on how to construct a spotting parameterisation scheme based on statistical relationships between the time-mean flow and realistic firebrand distributions.

These statistical models are computationally cheap, which makes them ideal for application to firespread models.



EAST COAST LOW

1) 20 – 23 April 2015
2) Intense low pressure systems that form close to NSW coast
3) Strong winds, heavy rain, major flooding, major waves and coastal erosion
4) 4 deaths
5) Dozens of roofs lost, trees down, > 200000 houses without power, 57 schools closed

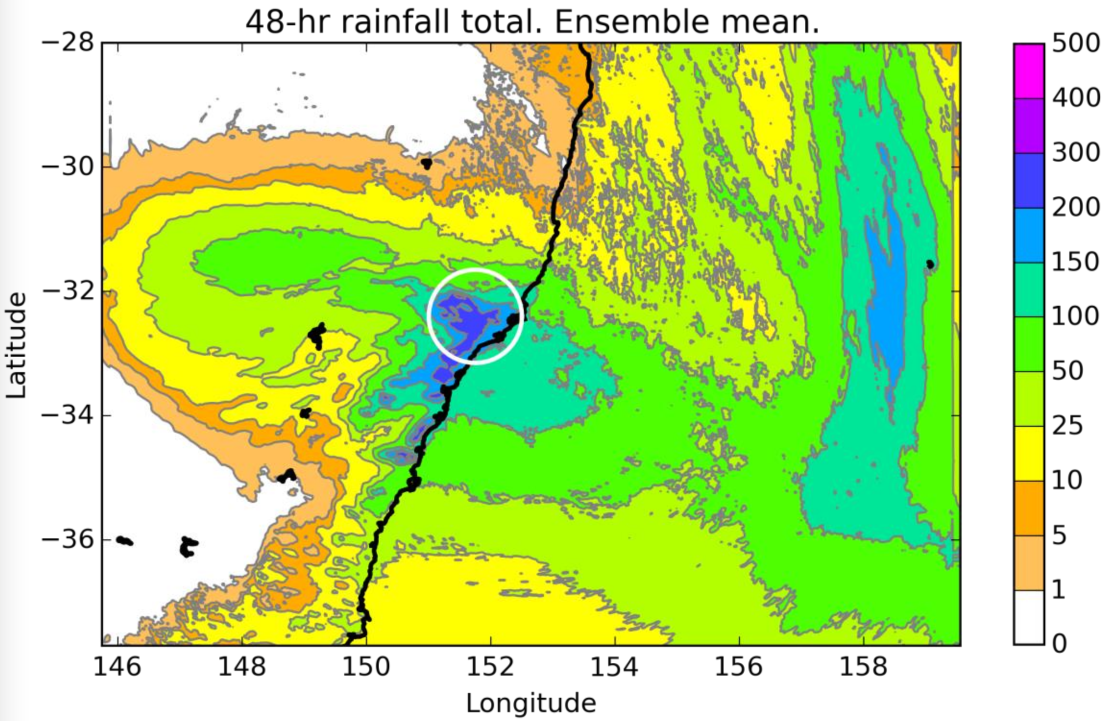
HIGH-RESOLUTION ENSEMBLE PREDICTION

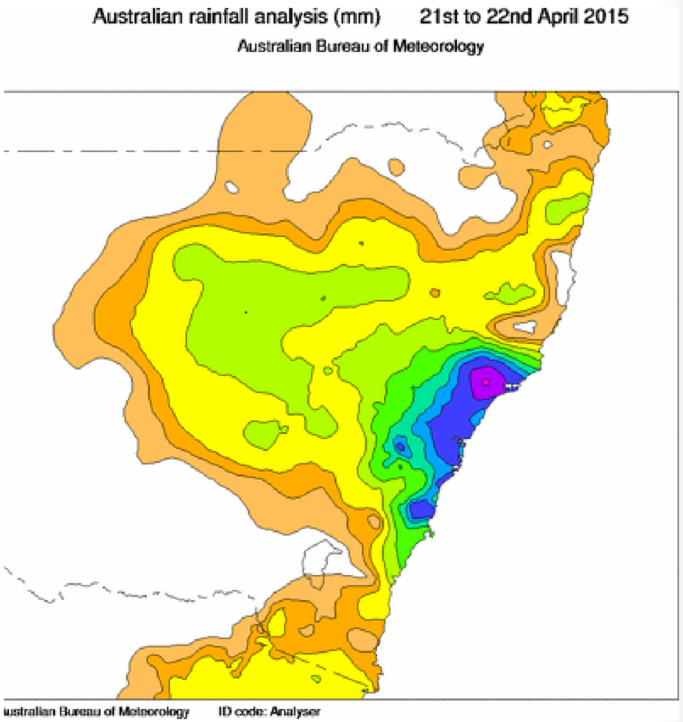
1) Motivation:
   a) Ensembles arriving soon. We need to learn how to best use ensemble data
   b) Severe ECL, high impact + scientific interest, worthy of study
   c) Good case to begin with: What can hi-res ensembles deliver in severe weather (BoM operations + emergency services)
   d) Good case to investigate ensemble-based sensitivity analysis

APPROACH

- Develop ensemble average threat maps and probabilities:
  - Plot ensemble averages of variables such as rainfall

48-HR RAINFALL VERIFICATION





Ensemble average, better than any individual member = **Improved Forecast**

APPROACH

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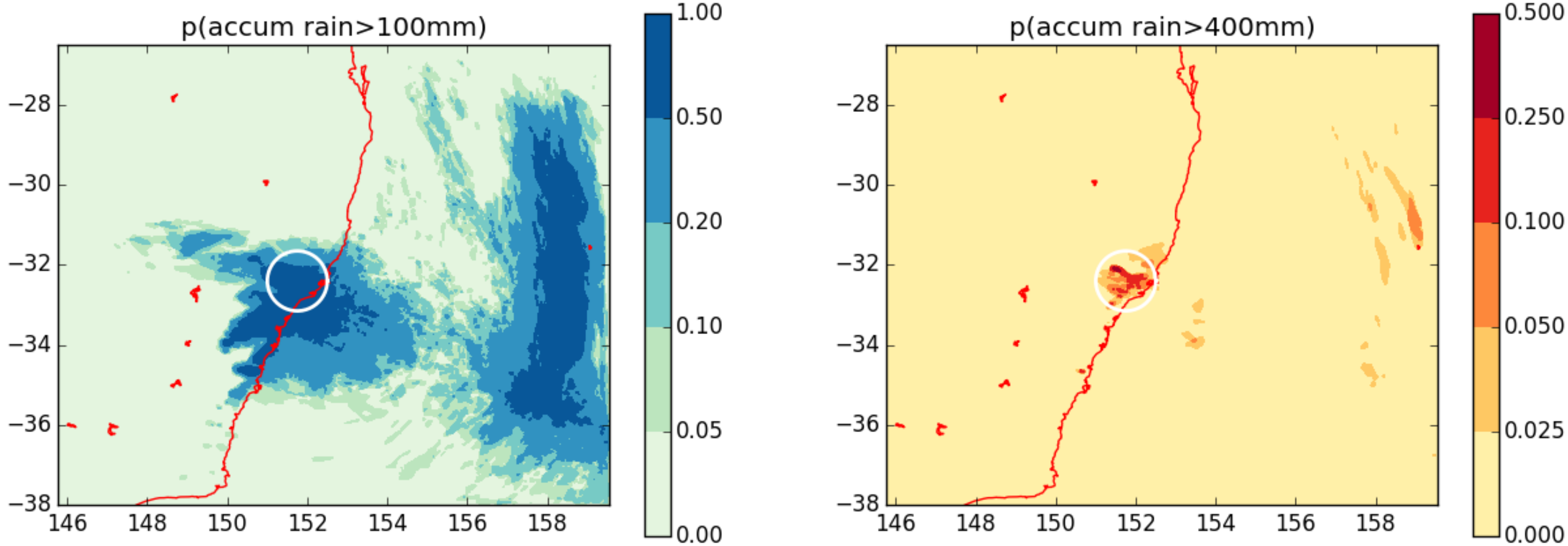
  - Plot ensemble averages of variables such as rainfall
  - Calculate the proportion of members that exceed certain thresholds

RAINFALL PROBABILITIES



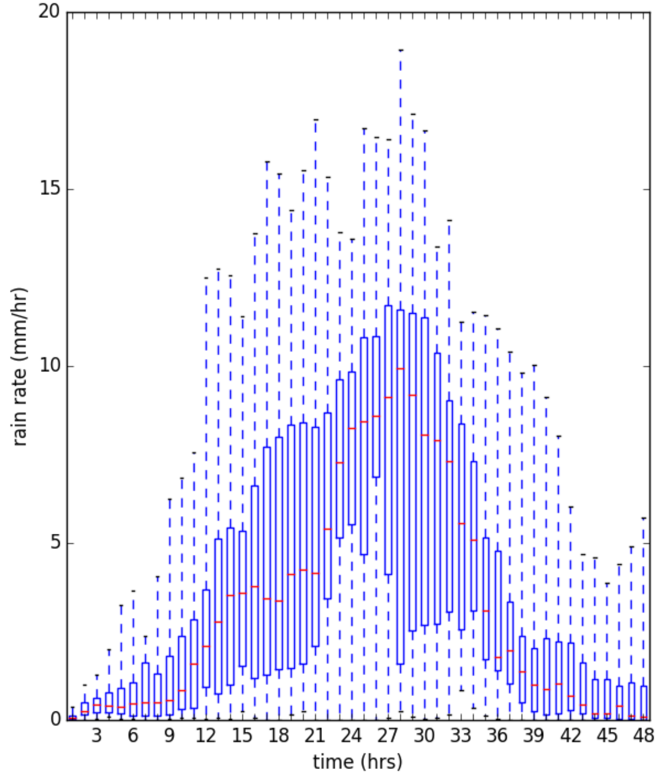
Probabilities of 48-hour total rainfall exceeding 100 mm and 400 mm

Based on ensemble member count, convolved over a radius of 5 gridpoints = 7 km.

APPROACH

- Develop ensemble average threat maps and probabilities:
  - Plot ensemble averages of variables such as rainfall
  - Calculate the proportion of members that exceed certain thresholds
  - Illustrate the variability between members at a specific location

RAINFALL DISTRIBUTION DUNGOG CATCHMENT

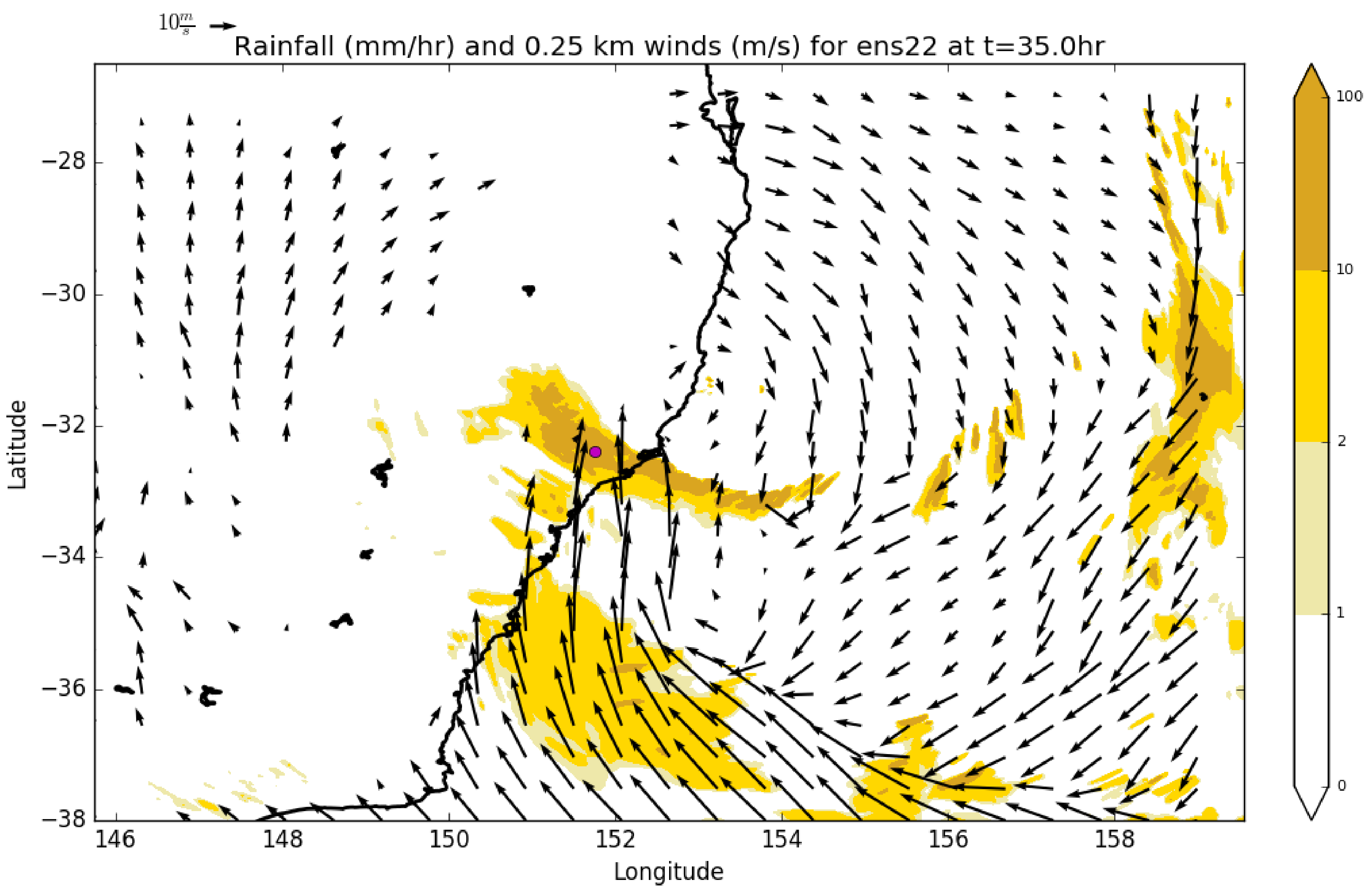


1) Hourly rainfall distribution
2) Averaged over 50-km circle centred on Dungog catchment

APPROACH (CONT.)

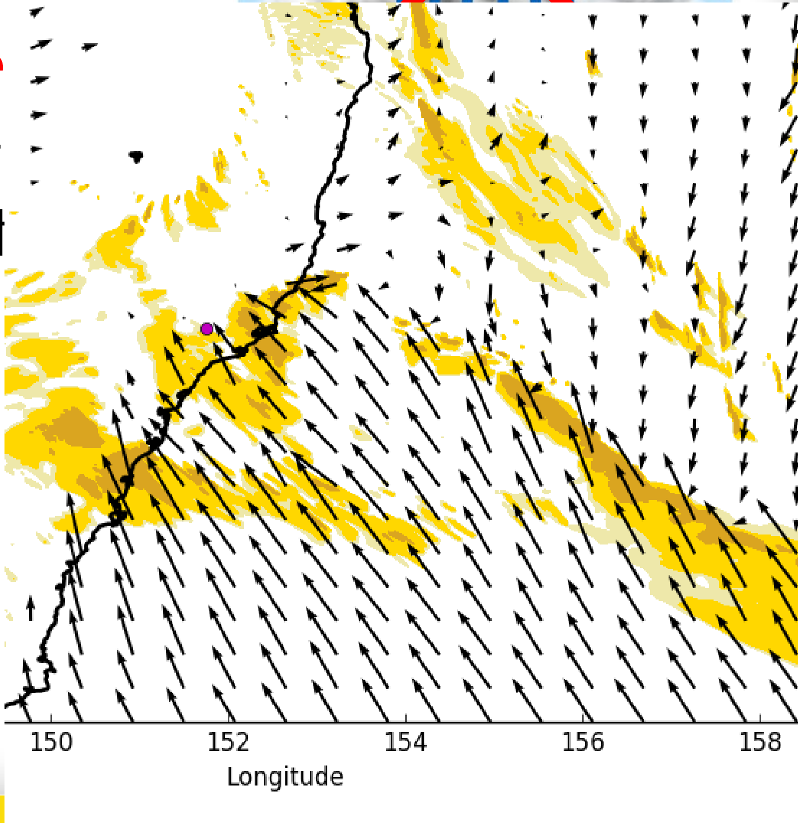
- Enormous amount of information available in the many ensemble forecasts:
  - How can we distil this information into something useful for forecasters and end-users?
- A study of the storm dynamics is underway to:
  - Identify features common (more predictable) to each ensemble member
  - Identify features that have the greatest variability (less predictable) between members

LOW-LEVEL WIND AND HOURLY RAINFALL: ENSEMBLE 22



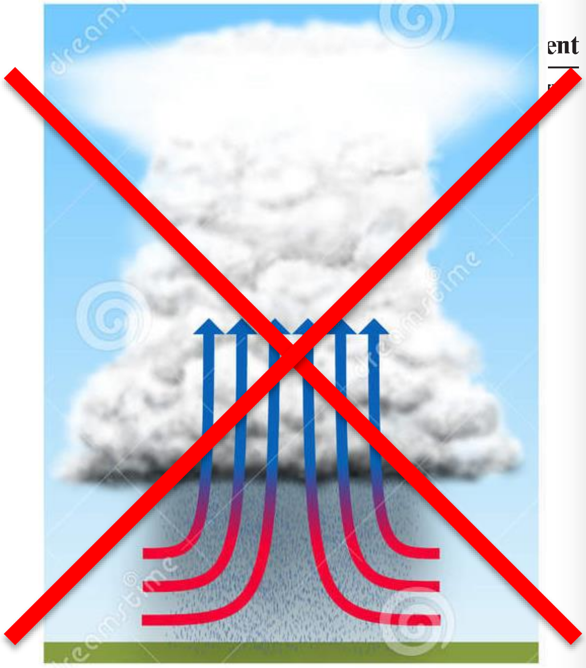
RESULTS

- Low is not symmetric:
  - Extreme winds are localized
  - Rainfall occurs in discrete regions within the low
  - *Can we better predict whe*
- Extreme winds associated wit strong near-surface temperat gradient ← *Still looking into this*



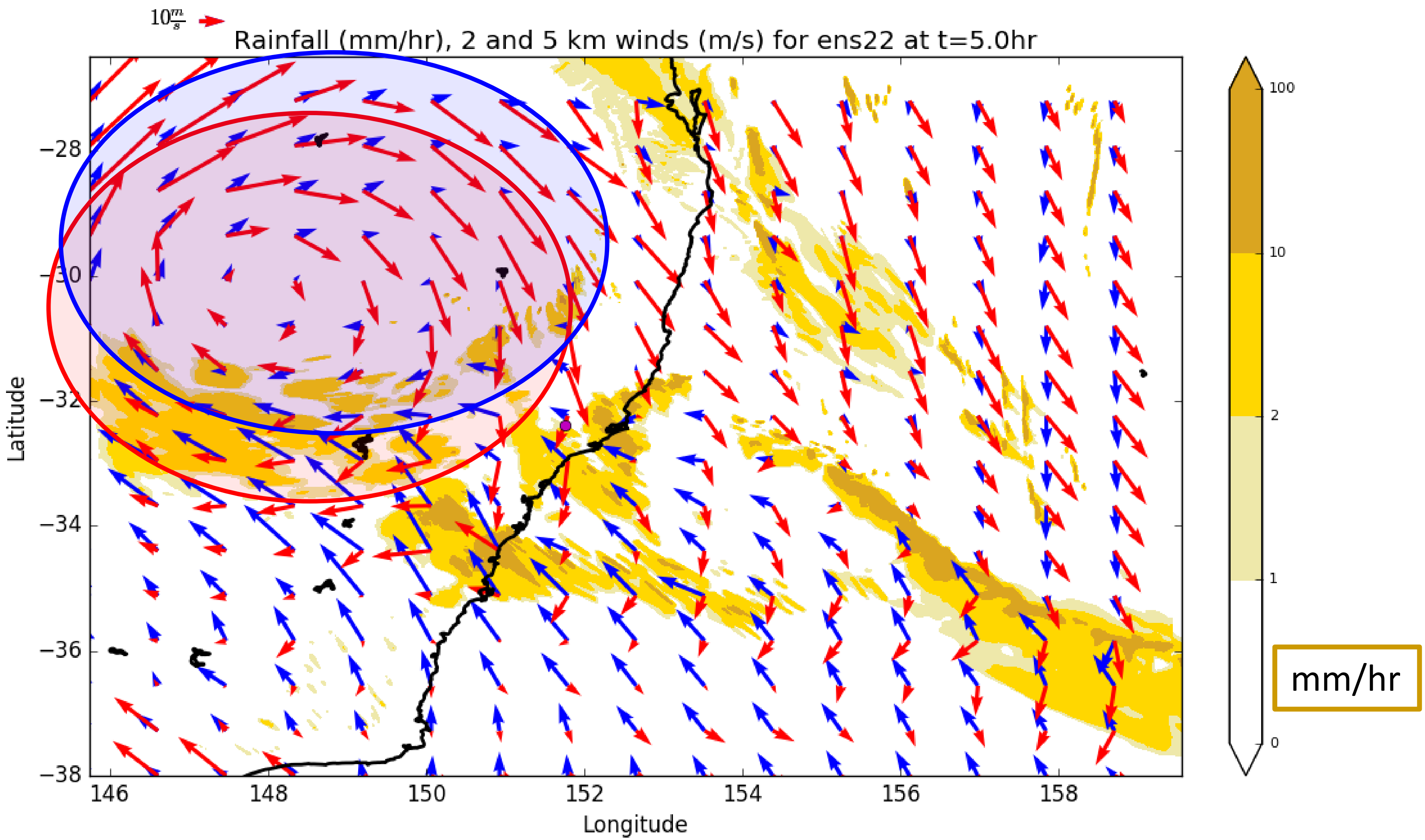
RESULTS

- Low is not symmetric:
  - Extreme winds are localized
  - Rainfall occurs in discrete regions within the low
  - *Can we better predict where?*
- Extreme winds associated with a strong near-surface temperature gradient ← *Still looking into this*
- Rain is caused by lifting:
  - From surface convergence
  - Up-slope flow
  - Some other mechanism?



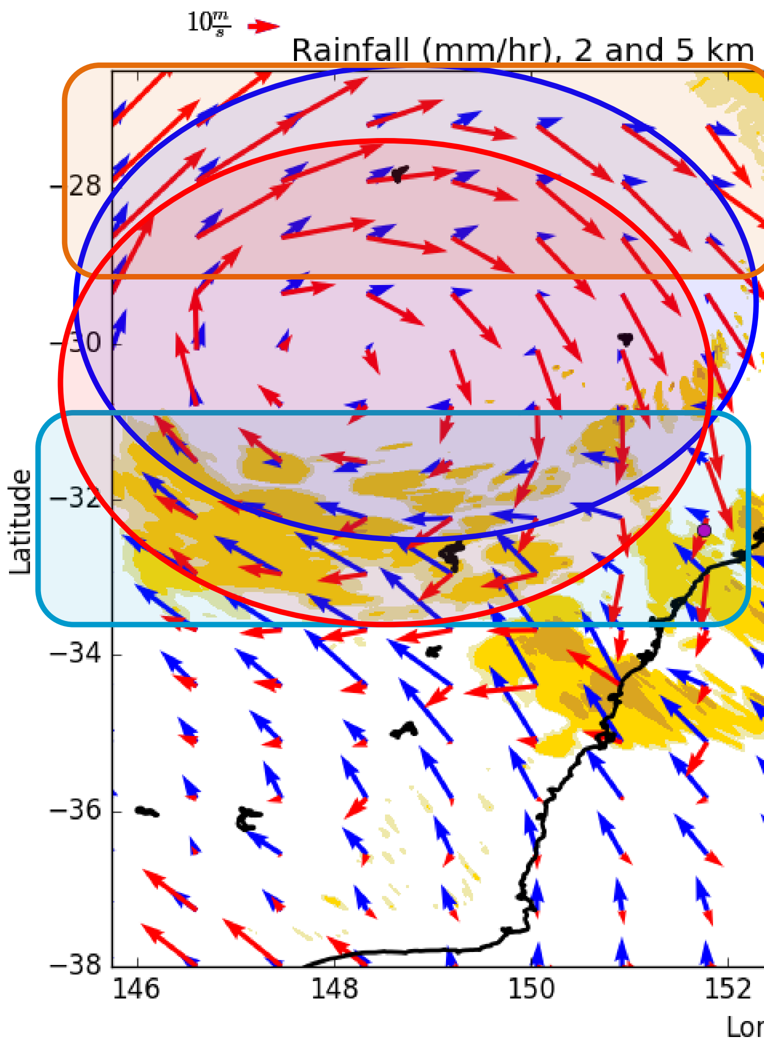
Low pressure
Rising warm, moist air
Cloudy weather

MID-LEVEL WINDS AND HOURLY RAINFALL:



5 km and 2 km wind vectors

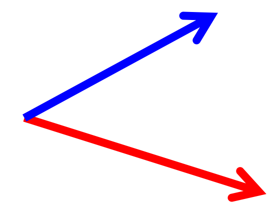
MID-LEVEL WINDS AND HOURLY RAINFALL:



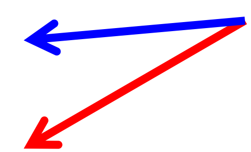
5 km and 2 km wind vectors

When circulations are not vertically aligned:

Air descends on the up-tilt side
where the 2 km wind vector points to the ***left*** of the 5 km wind vector
(*Southern hemisphere*)



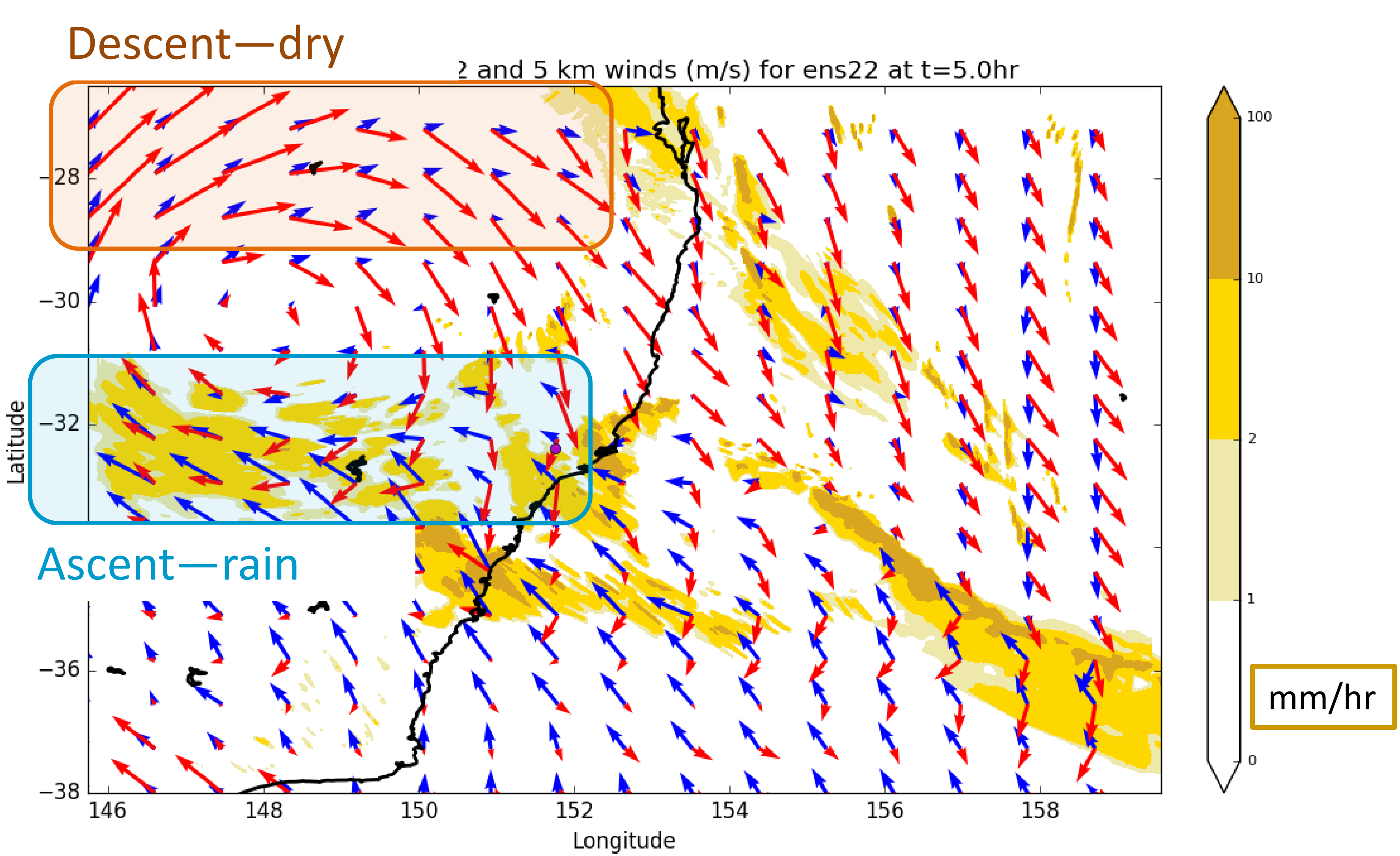
Air rises on the down-tilt side
where the 2 km wind vector points to the ***right*** of the 5 km wind vector
(*Southern hemisphere*)



Isentropic ascent rainfall diagnostic, 50+ years old:

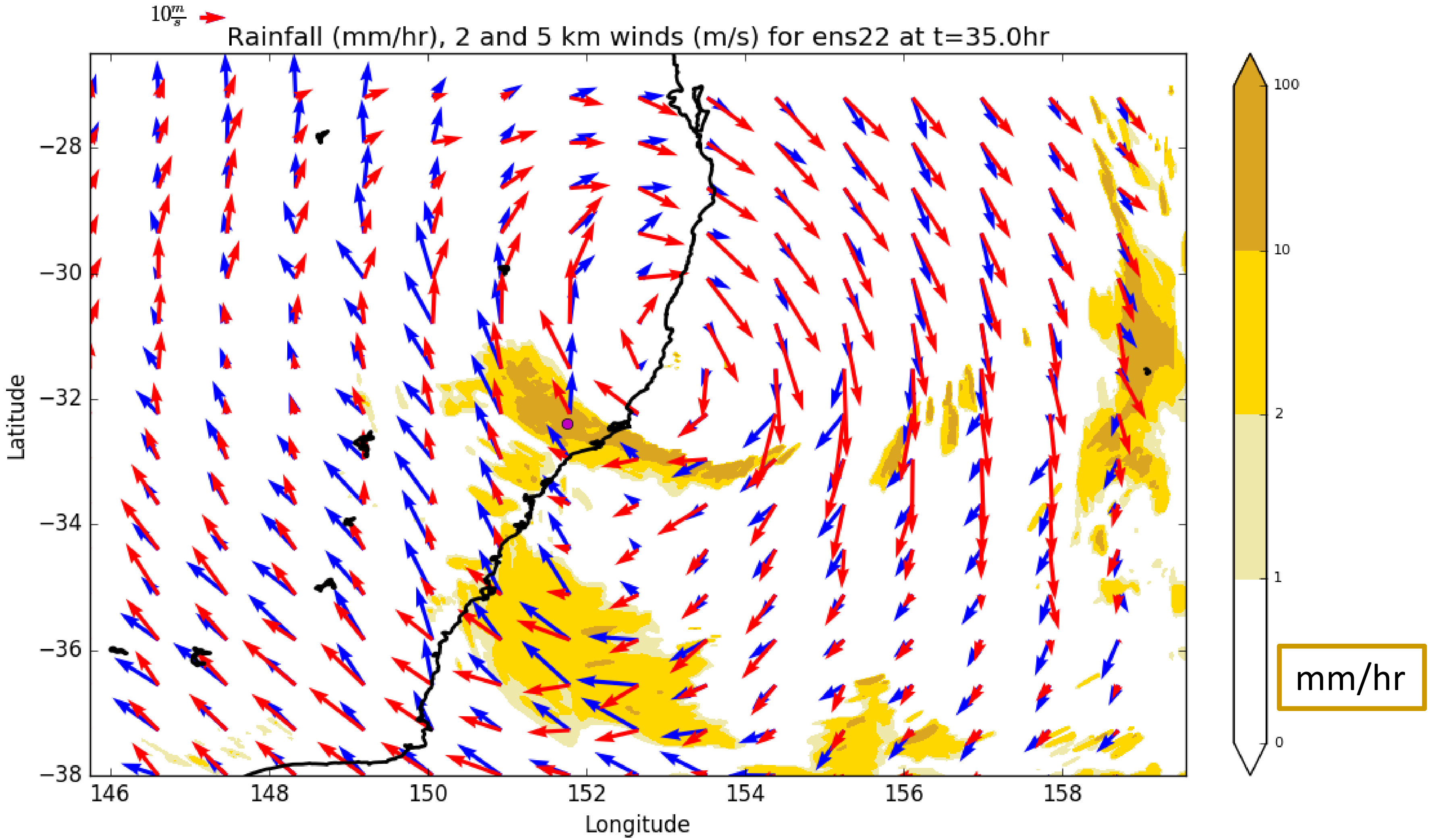
- works well in very high resolution data
- good for analysing ECLs
- ***Tilt of low more important than position!***

MID-LEVEL WINDS AND HOURLY RAINFALL:



5 km and 2 km wind vectors

MID-LEVEL WINDS AND HOURLY RAINFALL:



5 km and 2 km wind vectors

DIFFERENCES BETWEEN ENSEMBLE MEMBERS

- Each ensemble member is a realistic and plausible forecast
- Similarity between members → higher predictability
- Differences between members → lower predictability
- Studying the differences helps us understand what is predictable and what is not.
- Need to develop ensemble products for the lower predictable events, (i.e., probabilistic forecasts)

MID-LEVEL WINDS AND HOURLY RAINFALL:

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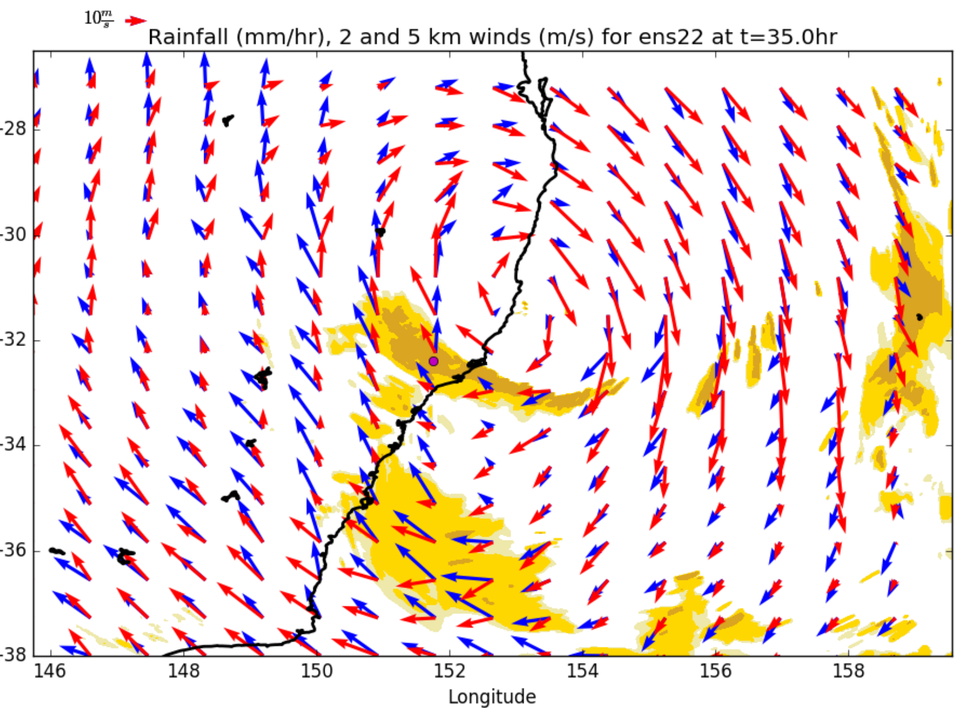
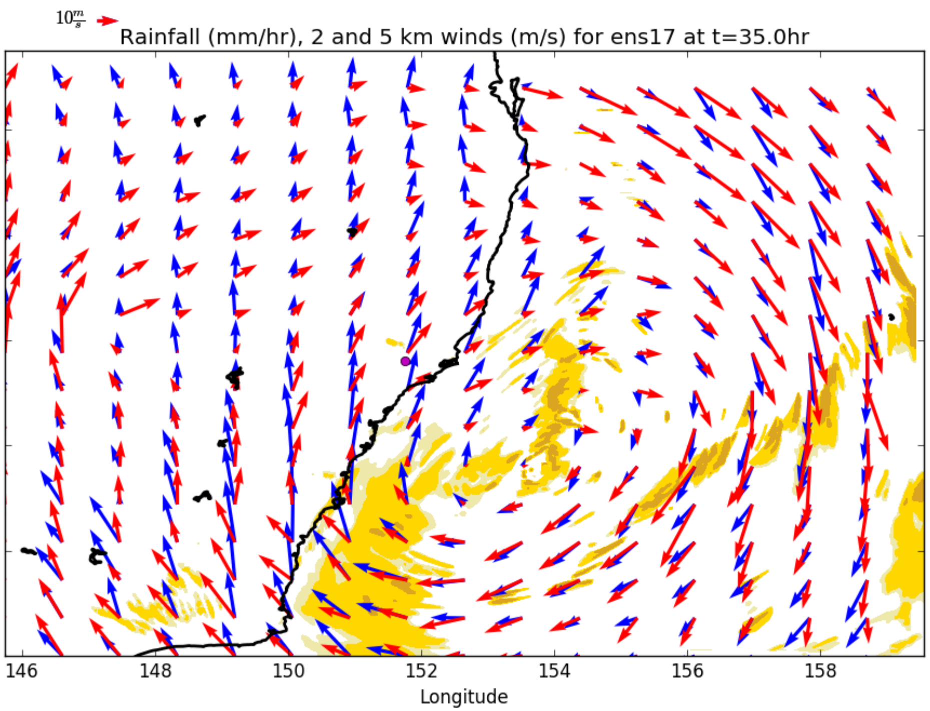
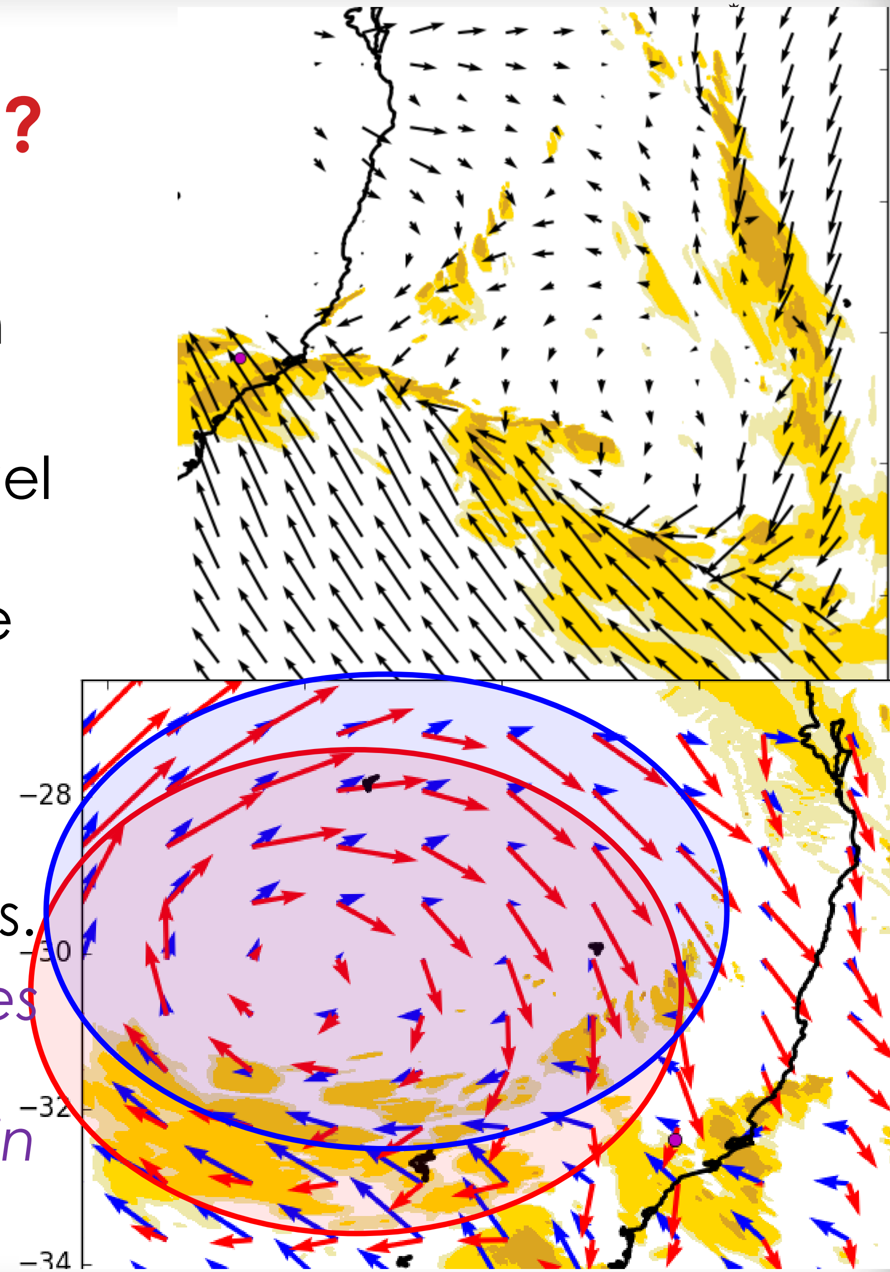




WHAT HAVE WE LEARNED?

- Rain occurs on low-level convergence lines on the eastern edge of the synoptic scale low
- Extreme winds occur on a low-level temperature gradient in a line extending outwards, ESE, from the Low core.
- Tilting of the low core produces ascent and descent with corresponding rain and clear skies.
- *Subtle differences in these features between ensemble members produces large local differences in extreme wind and rain.*



PYROCUMULUS DEVELOPMENT

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- 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 moisture source is becoming more clear:
  - Cunningham & Reeder (2009) – *moisture from fire required*
  - Trentmann et al. (2006) – *environmental moisture alone is sufficient*
  - Three recent studies – *fire moisture is insignificant*

1)Example: Hot dry fire in a moist boundary layer

Q = 30 KW M^{-2}, Q_{BL} = 4.0 G KG^{-1}

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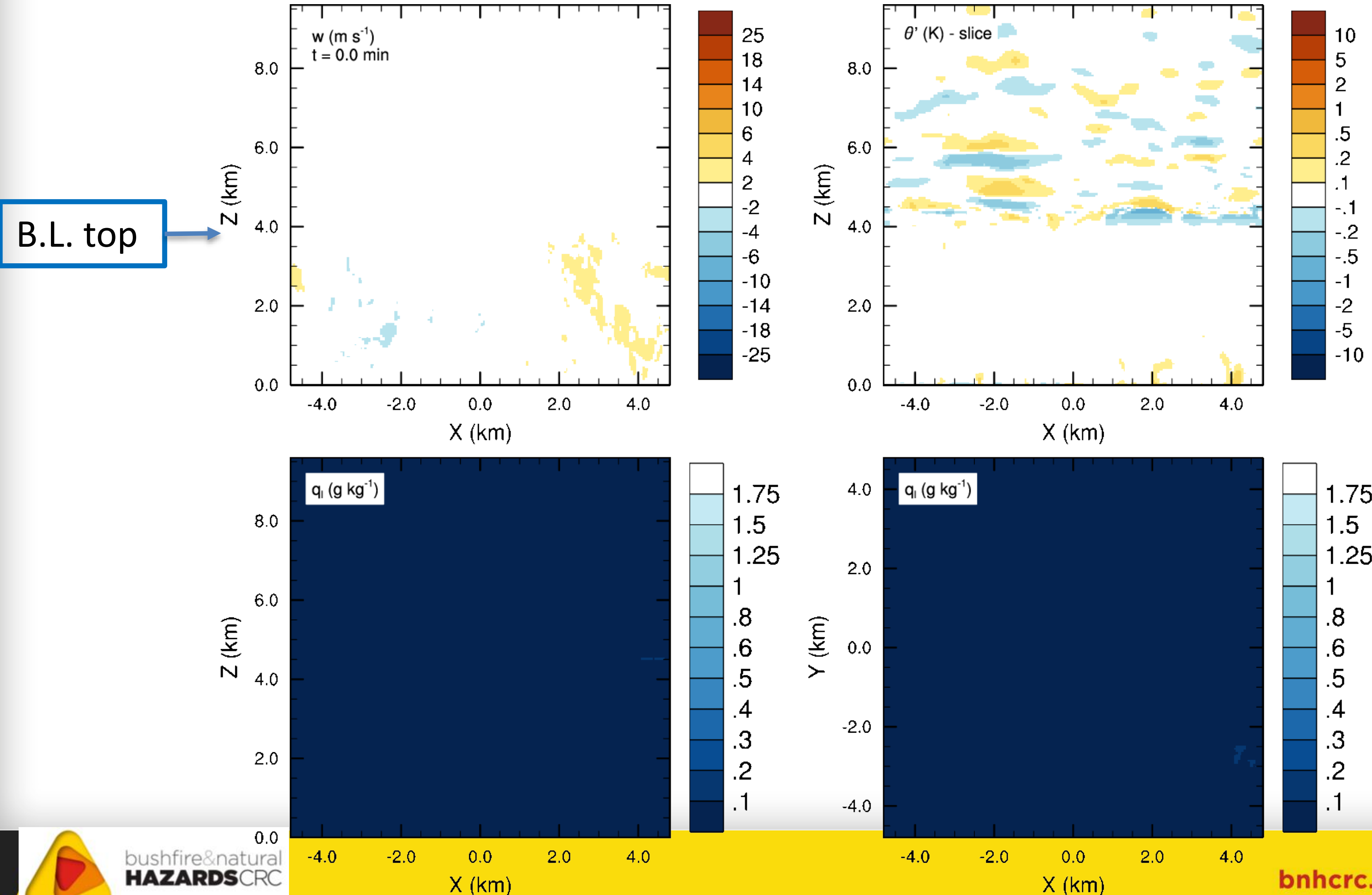

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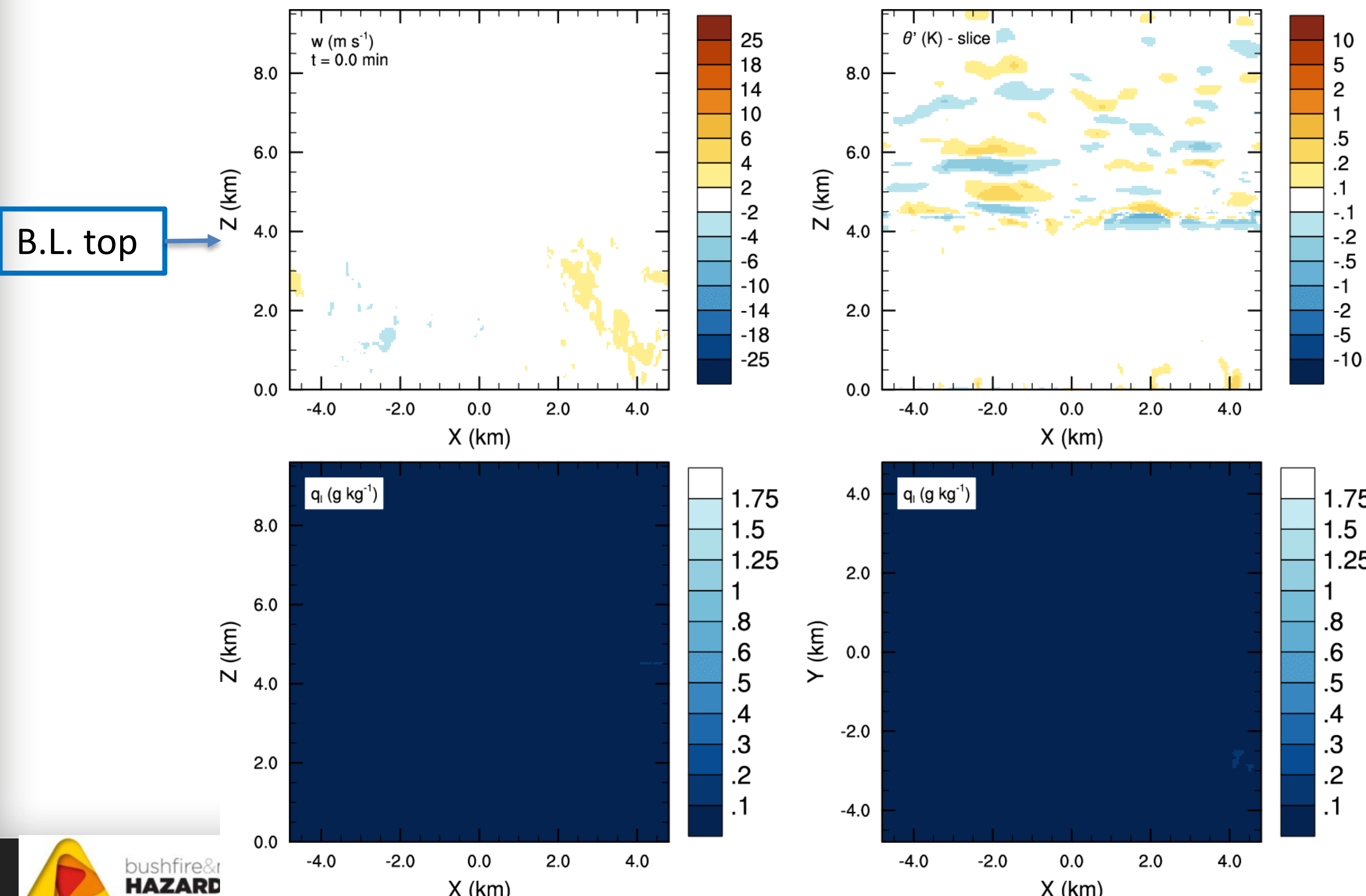
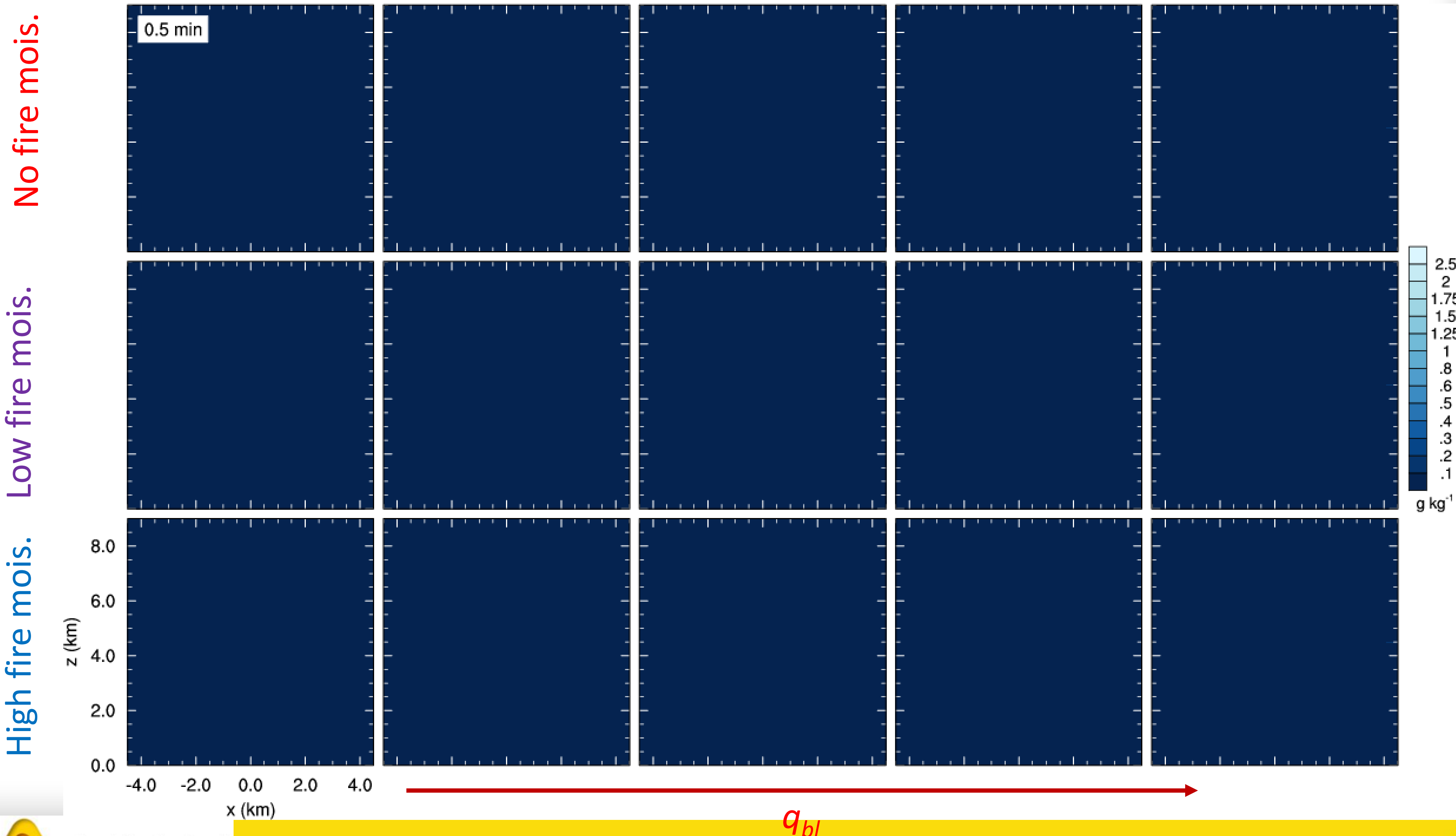


ENVIRONMENTAL VS. FIRE-DERIVED MOISTURE?



ENVIRONMENTAL VS. FIRE-DERIVED MOISTURE?

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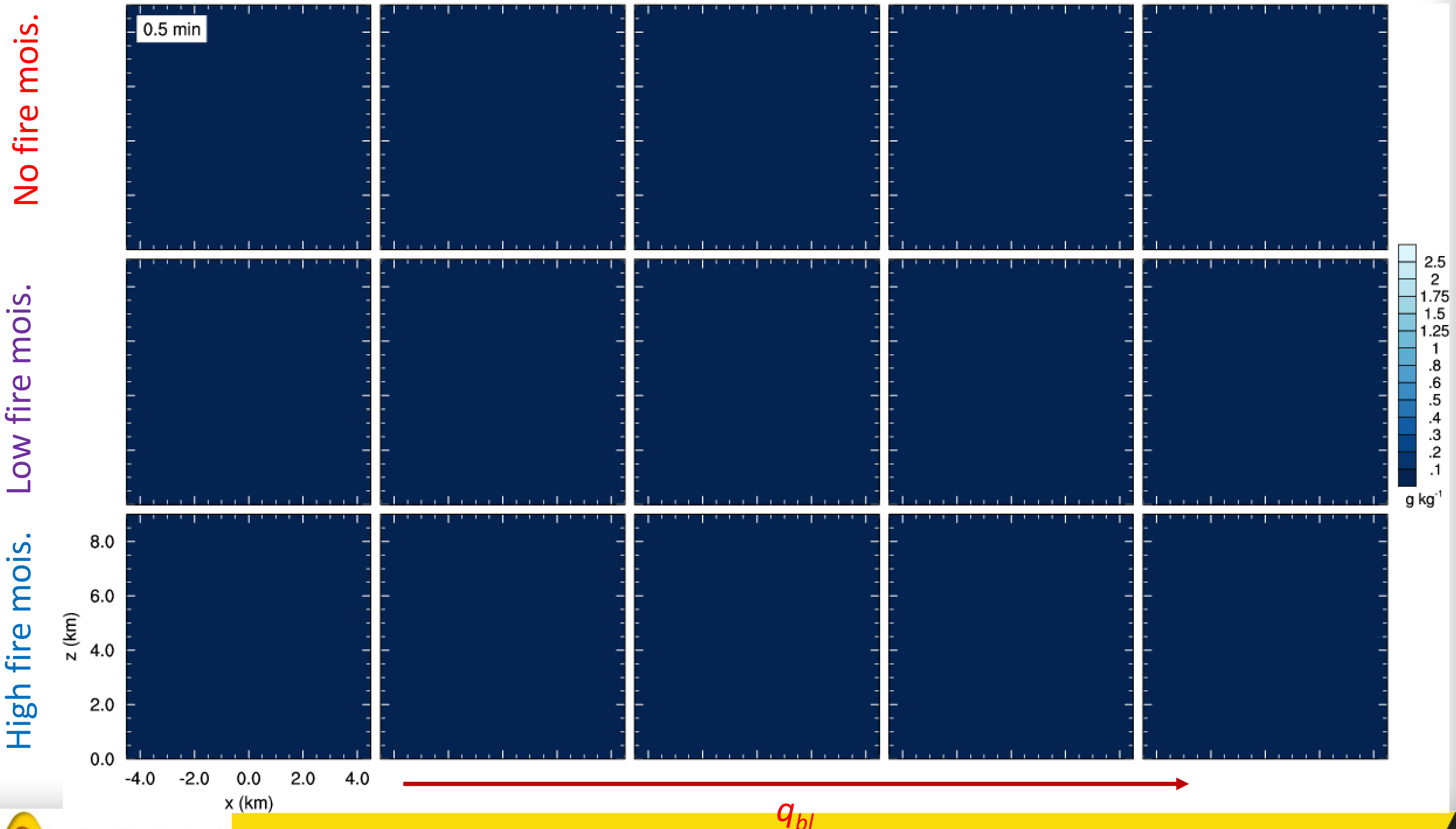


ENVIRONMENTAL VS. FIRE-DERIVED MOISTURE?

Implications for forecasting

Bald Fire August 2014, California, Lareau and Clements (2016):

- Deep well-mixed B.L.
- PyroCu cloud base ~5.5 km above sea level
- Meteorological cloud base estimate diagnostics, about 1000m lower
- New diagnostic that ignores fire moisture, but incorporates significant entrainment of environmental air into the plume, is very accurate.

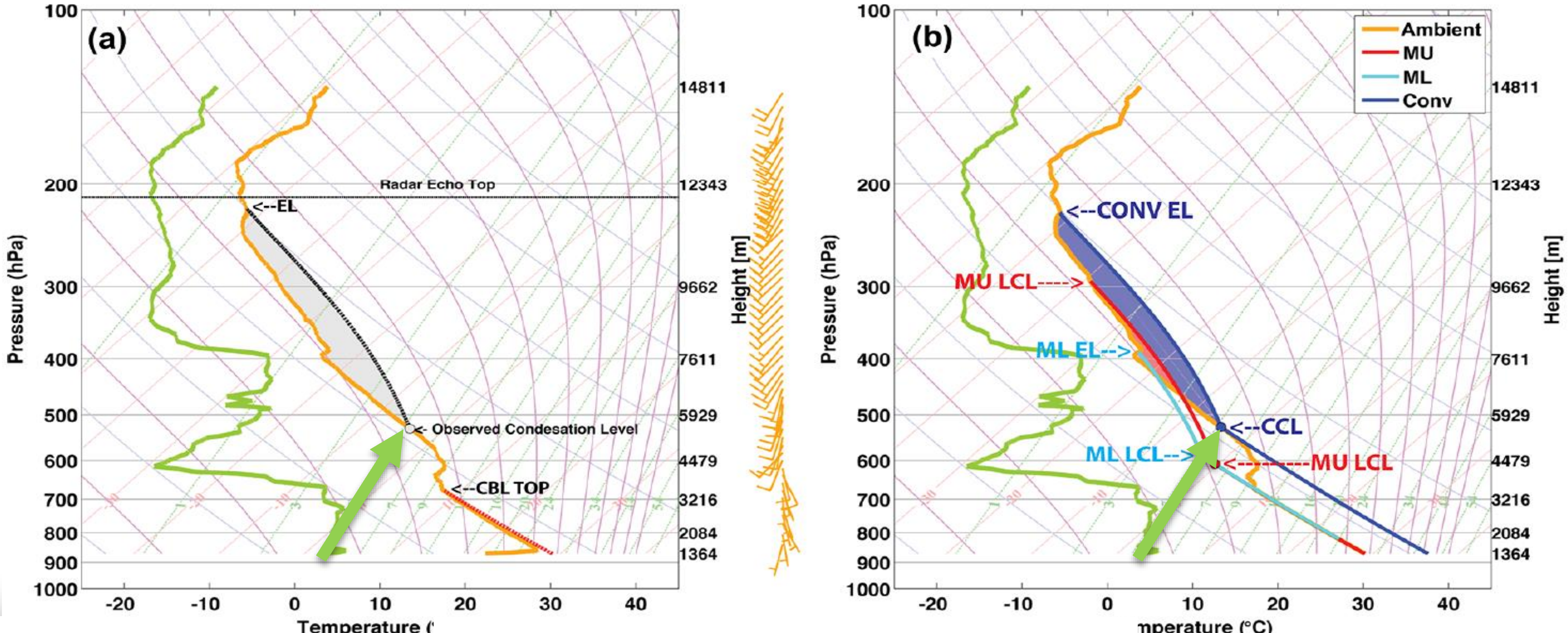


Fig. 9 of Lareau and Clements 2016

RECAP: FORMATION OF MOIST PYRO-CONVECTION

- Pyrocumulus is able to form without a source of moisture from the fire
  - *Fire sourced moisture is likely to have minimal impact on pyrocu development*
  - *Which simplifies pyrocu forecasting*

    Next stage of the project: Development of a Pyrocu forecast tool.

- Pyrocumulus formation leads to updraft resurgence at altitude

- More intense fires lead to stronger and deeper pyrocumulus

- More intense fires lead to taller and broader pyrocumulus

- Increasing environmental moisture reduces cloud-base height

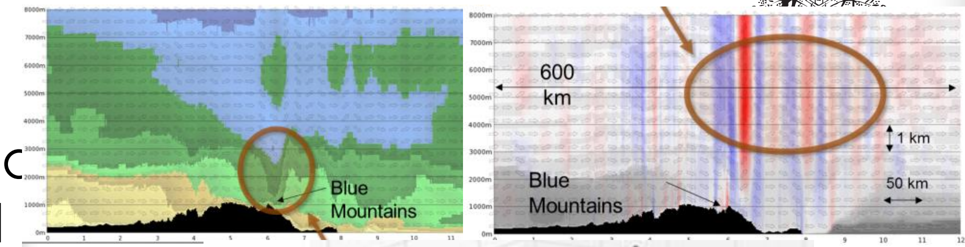
- The most-intense pyro-convection generates evaporatively cooled downdrafts
  - These downdrafts have the potential to generate sustained periods of intense surface wind gusts

PROJECT STATUS

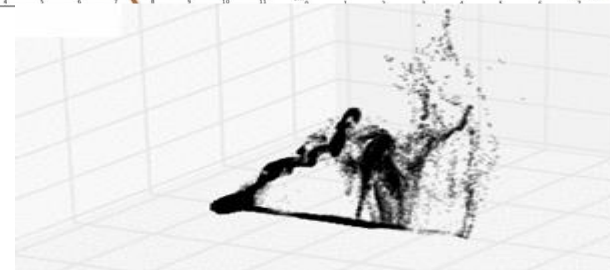
1) BNHCRC Milestones
   a) 64/73 due plus one not yet due (according to original schedule)
   b) Unmet ones are minor apart from one paper
2) Expect to finish project on time, assuming no setbacks
3) Have developed utilisation plan

SUMMARY

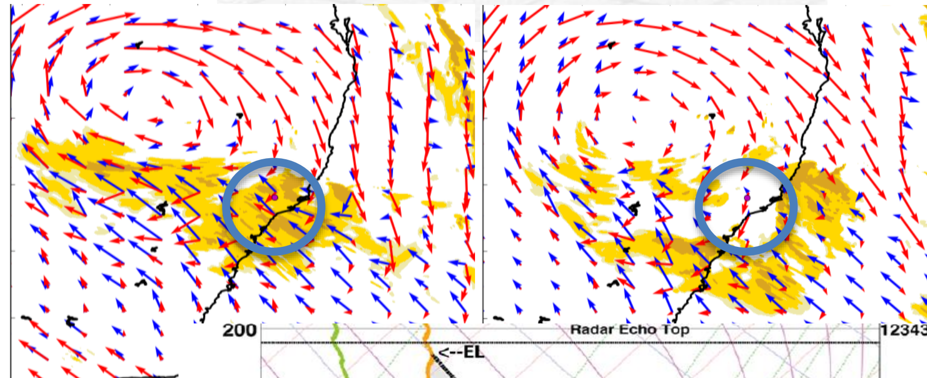
1) Blue mountains – dry slot + mountc waves: unexpected rapid spread



2) Ember transport – plume turbulence is crucial: Spotting distance doubles, greater lateral spread.



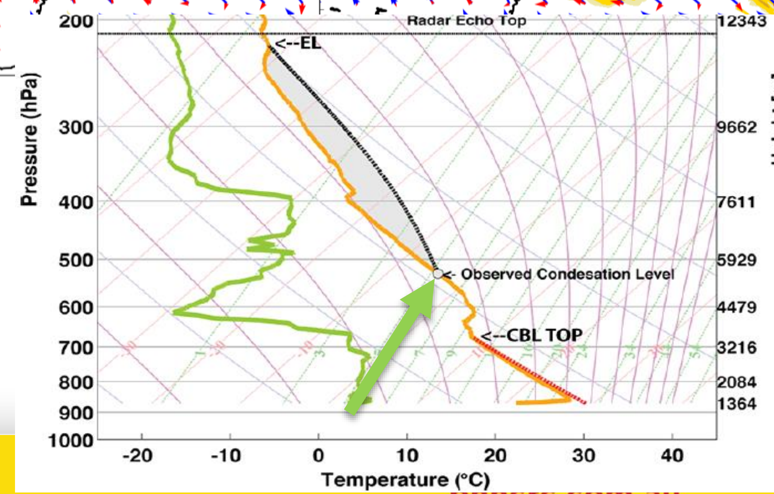
3) East coast low – Small synoptic differences, large local variation (wind, rain) ← Ensembles needed



4) Pyrocumulus:
   - is combustion moisture important?

   Rarely (we think)

   Which makes it easier to predict



UK MET OFFICE LARGE EDDY MODEL (LEM)

- Think of as a **simplified** numerical weather prediction model, but run at a **very-high resolution**
  - 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:

- 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 (± 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

MODELLING STRATEGY

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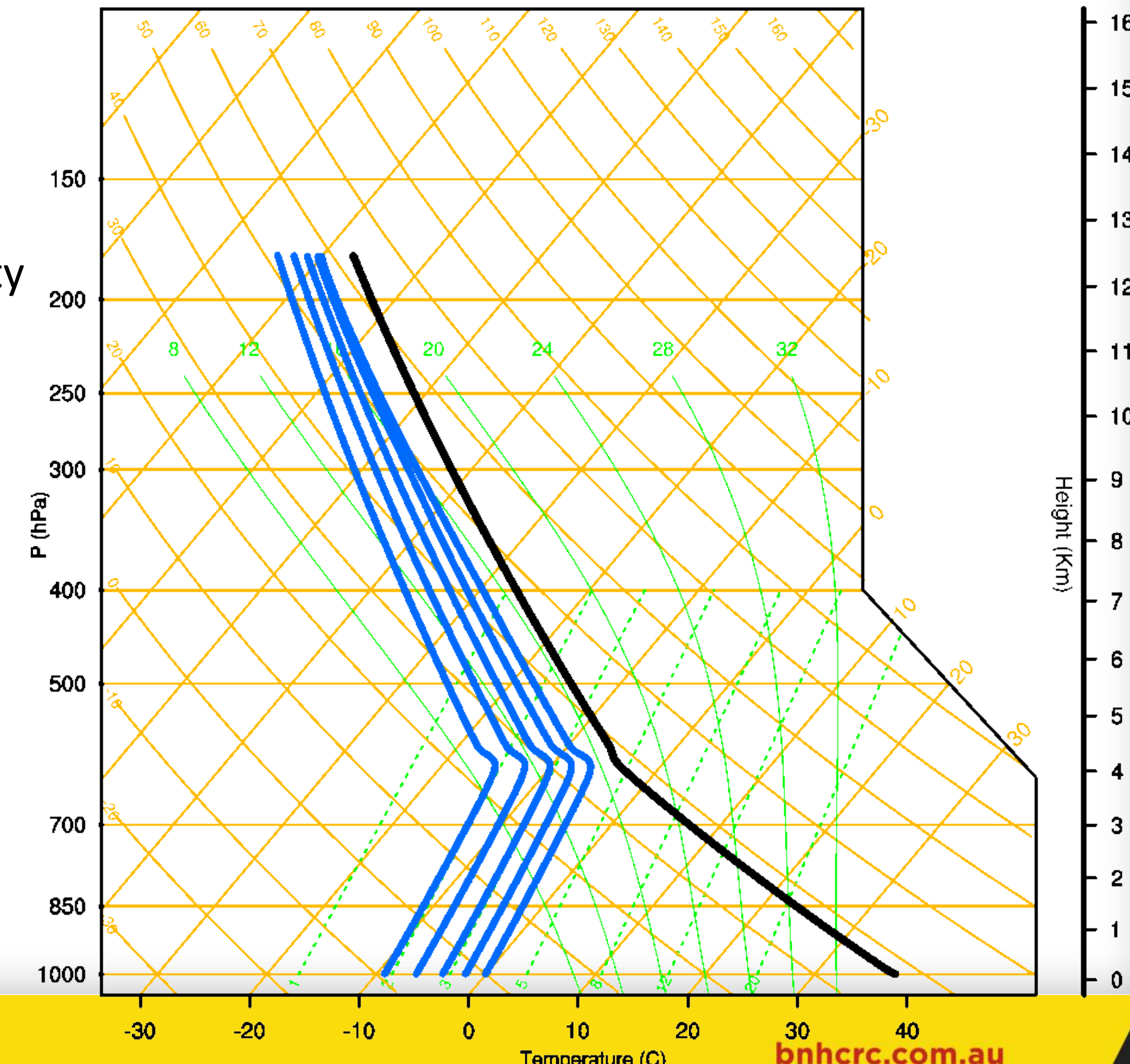
- Five different atmospheres
  - Identical temperature profiles
  - 4-km deep, warm boundary layer
  - Boundary-layer specific humidity q_{bl} = 2.0, 2.5, 3.0, 3.5 and 4.0 g kg^{-1}
- Four fire intensities
  - Q = 5, 10, 20, 30 kW m^{-2}
  - Smoothly increased for 5 min
  - Held at peak for 60 min
 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



EXAMPLE PROFILES

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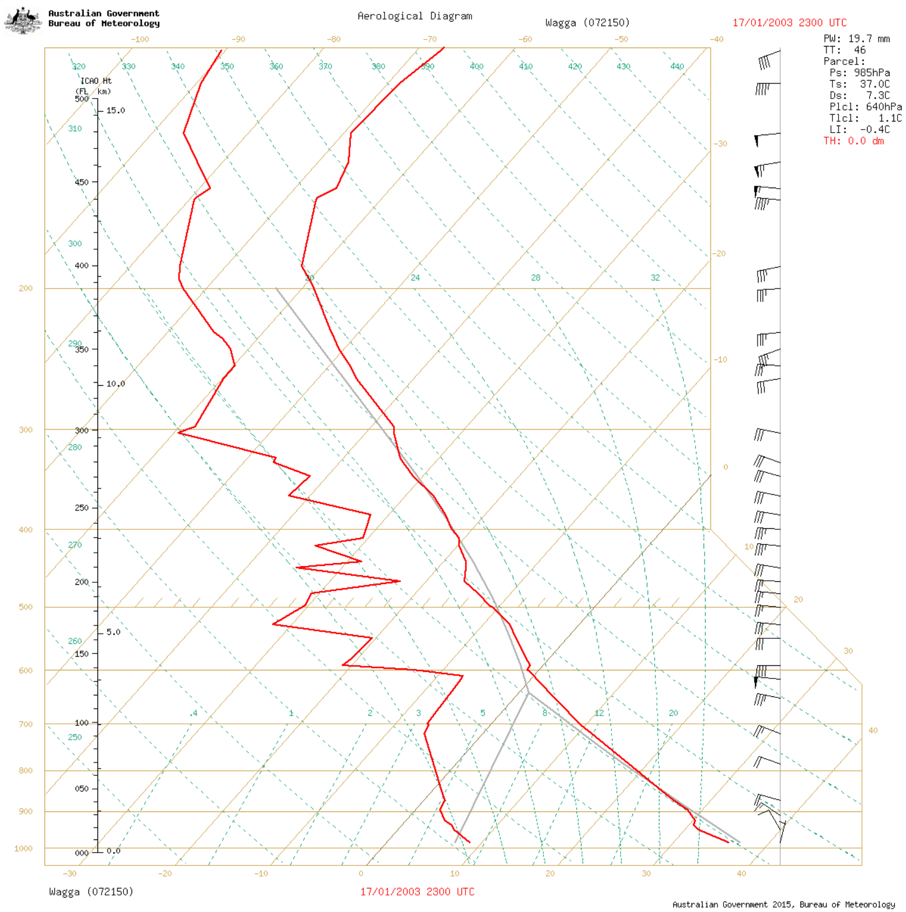
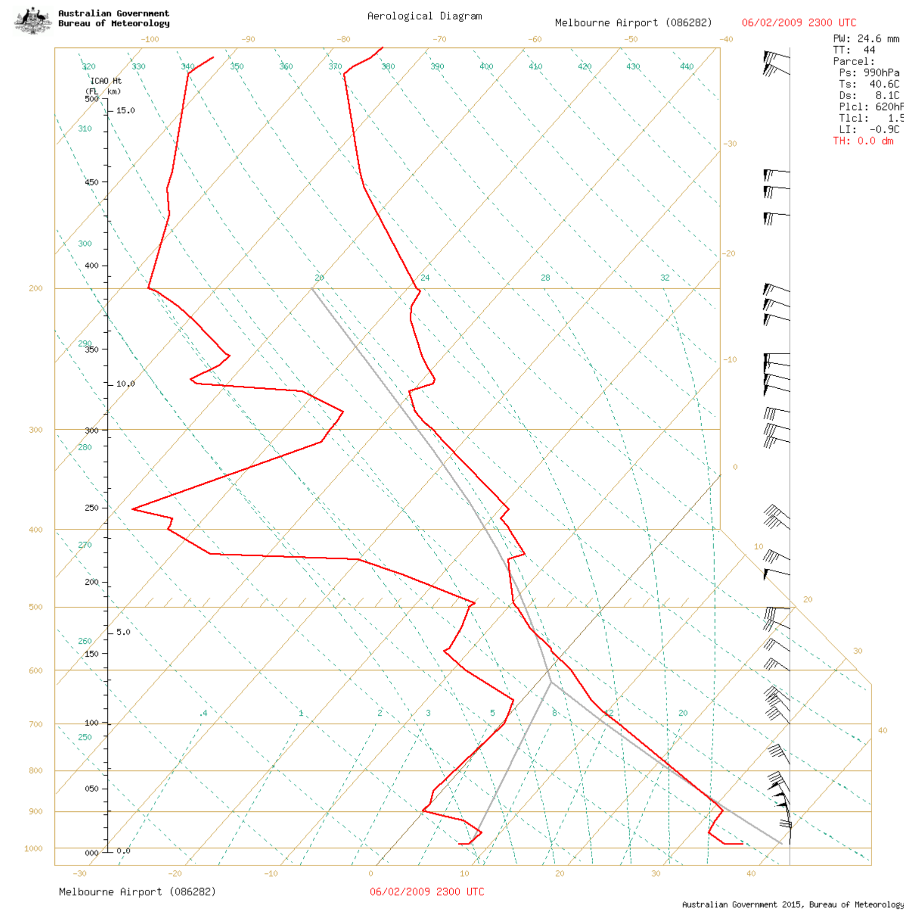


Canberra (2003)



Black Saturday (2009)

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