Thermodynamics of pyrocumulus formation

bushfire&natural HAZARDSCRC

Kevin J. Tory, Will Thurston and Jeffrey D. Kepert

High Impact Weather, Research and Development, Bureau of Meteorology and Bushfire & Natural Hazards CRC, Melbourne, Victoria

IN FAVOURABLE ATMOSPHERIC CONDITIONS, LARGE HOT FIRES CAN PRODUCE PYROCUMULONIMBUS CLOUD: DEEP CONVECTIVE COLUMNS RESEMBLING CONVENTIONAL THUNDERSTORMS. THESE IN TURN MAY GENERATE STRONG SURFACE WINDS, DANGEROUS DOWNBURSTS AND LIGHTNING STRIKES THAT MAY ENHANCE FIRE SPREAD RATES AND FIRE INTENSITY, CAUSE SUDDEN CHANGES IN FIRE SPREAD DIRECTION, AND IGNITE ADDITIONAL FIRES.

1. MOTIVATION

- PyroCb are not well understood and difficult to forecast
- This thermodynamic study offers useful insight into how the environment and fire properties influence plume condensation height and buoyancy.

2. MODEL

- A simple inverted-V atmospheric profile allows the environment to be defined by only two parameters (θ_{env} and q_{env})
- Fire heat is defined as a multiple of the environment temperature: $\theta_{fire} = \gamma\theta_{env}$ (units K)
- Fire moisture is defined as a fraction of the fire heat (φ) plus environment moisture consumed in combustion: $q_{fire} = \varphi(\gamma - 1)\theta_{env} + 0.86q_{env}$
- The plume is pure (undiluted) fire heat and moisture at combustion (dilution factor, $\alpha = 0$). Entrainment of environment air dilutes the fire gases as the plume rises, until the plume is almost entirely environment air (dilution factor, $\alpha \to 1$).
- The relative mix of fire and environment air anywhere in the plume is defined by the dilution, α :

$$\theta_{pl} = \alpha\theta_{env} + (1 - \alpha)\theta_{fire} \quad 1.$$

$$q_{pl} = \alpha q_{env} + (1 - \alpha)q_{fire}. \quad 2.$$

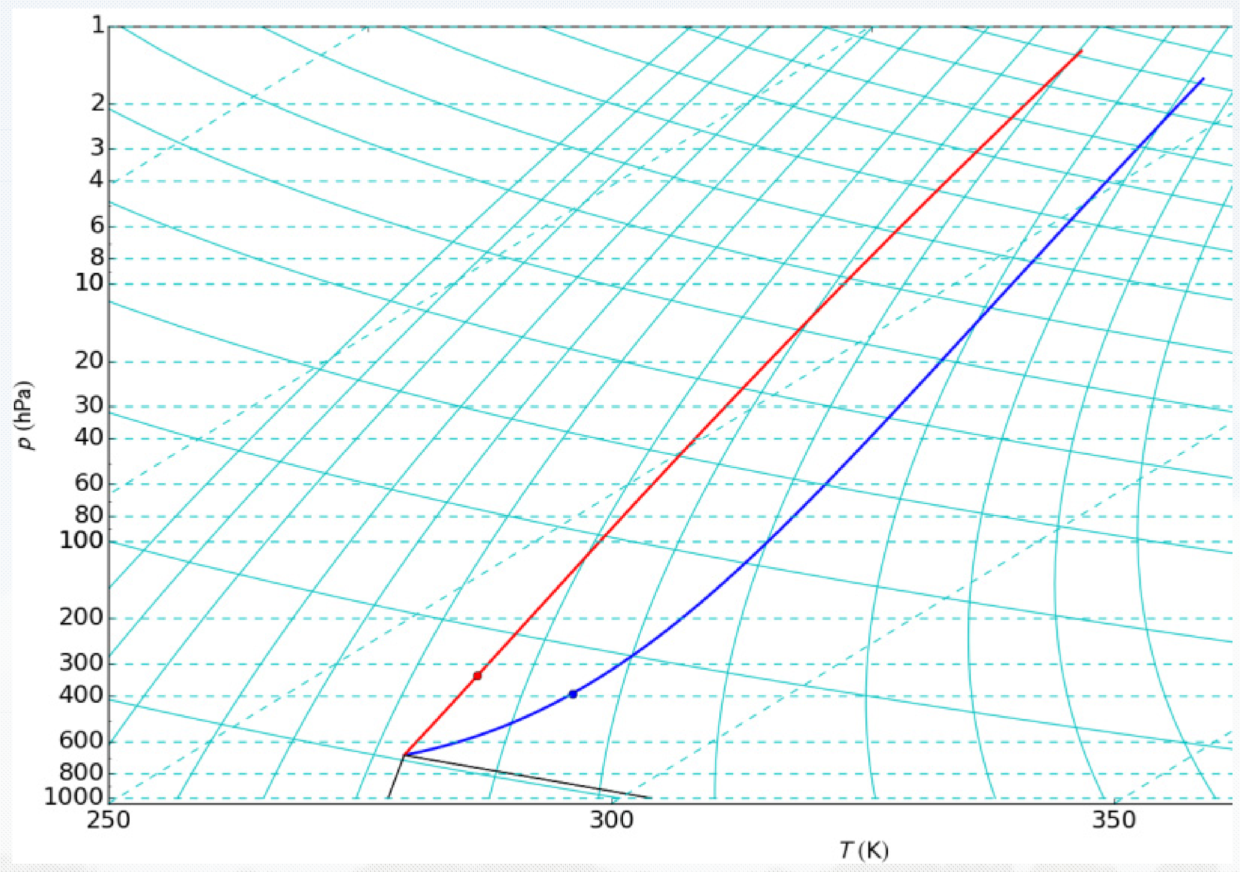

Figure 1: Saturation point curves for the dry (red) and moist (blue) fires, on a skewT-logP diagram. The apex of the grey lines of constant θ_{env} and q_{env} is the environment saturation point, i.e., the lifting condensation level (LCL).

3. RESULTS: Plume condensation

- The Lifting Condensation Level (LCL) for a warm environment is evident in Fig. 1, as the *environment* saturation point (SP, apex of θ_{env} and q_{env} lines). Analogous *plume* saturation points can be plotted for all values of α ($\alpha = 0 \to 1$) to produce plume SP curves. Fig. 1 contains SP curves for two hot fire ($\gamma = 5$) plumes, one relatively dry and one moist ($\varphi = 3$ and $15 \times 10^{-5}\ kgkg^{-1}K^{-1}$, red and blue).
- The lower and upper ends of the curves correspond to $\alpha = 1$ and 0 respectively, and $\alpha = 0.95$ is marked on the SP curves with dots.
- Fig. 1 corrects a common misconception that PyroCb formation requires plumes with undiluted cores. (These undiluted cores would need to be lifted more than 45 km before condensing.)
- Typically condensation occurs near the LCL, where dilution is close to 100%.

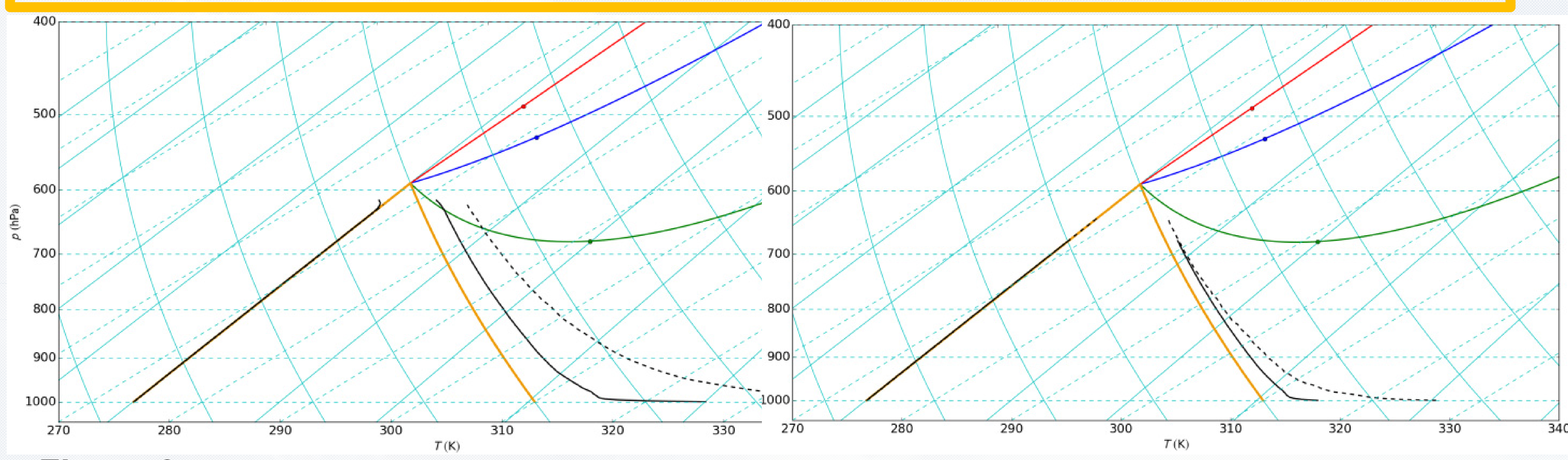

Figure 2: As in Fig. 1 but with mean (solid) and maximum (dashed) plume temperature traces in a hot and dry ($\theta_{env} = 310$ and $q_{env} = 4 \times 10^{-3}$), zero wind environment from LEM simulations with a steady 250 m radius surface fire. SP curves for dry (red) moist (blue) and extremely moist (green) fires are included ($\varphi = 3, 15$ and 100×10^{-5}). (a) hot fire ($Q = 30\ kWm^{-2}$) (b) cool fire ($Q = 5\ kWm^{-2}$).

4. RESULTS: Plume temperature traces

- The SP curves tell us what height a hypothetical plume element will condense, but nothing about actual plume elements.
- Figure 2 includes temperature traces from a large eddy model (LEM) plume simulation for the mean (solid) and maximum (dashed) plume temperature for a hot (left) and cool (right) fire.
- The hot fire traces show significant buoyancy as they approach the SP curves, and indeed this simulation produced intense PyroCb with a strong downburst.
- The cool fire produced only occasional short-lived puffs of cloud.

5. CONCLUSIONS

- Realistic plumes have substantial dilution when they condense (at least 95%)
- Increasing fire moisture lowers the plume condensation heights
- Plume elements have a range of dilution amounts (compare maximum and mean plume temperature traces in Fig. 2) and thus can have a range of condensation heights beginning near the LCL
- Sufficiently positive buoyancy at the SP curve is required for PyroCb development

END USER STATEMENT

Pyrocumulonimbus events are of very considerable concern for fire managers, and therefore for fire weather forecasters. Forecasters and fire managers need to be aware of the possibility of pyroCb development to allow for the chance of erratic fire behaviour. The environments that support pyroCb development, then, are an important topic of study for the Bushfire and Natural Hazards CRC, and the results of this research project will be of great interest to all involved in the planning for and management of dangerous wildfires.

Dr Paul Fox-Hughes, Tasmanian Regional Office, Bureau of Meteorology.

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

Australian Government Bureau of Meteorology