Effect of Latent Heating on Mesoscale Vortex Development During Extreme Precipitation: Colorado, September 2013

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- WRF simulations performed to explore the role of latent heating in mesovortex development and dominant microphysics processes involved
- Latent heating had strong impact on surface flow field, leading to enhanced upslope, convection, and precipitation over Boulder, CO
- High potential vorticity values in lower troposphere are associated with increasing latent heating with height from cloud water condensation
- A 50% reduction of the latent heating contribution from cloud water condensation resulted in no mesovortex development and significant reduction in precipitation along northern Colorado Front Range

Background

On the evening of 11 September, Boulder experienced flash flooding as a result of high rain rates accumulating over 180 mm of rain in 6 hours (Fig. 1). From 0400-0700 UTC 12 September, a mesoscale vortex (mesovortex) was observed to travel northwestward towards Boulder. This circulation enhanced upslope flow and was associated with localized deep convection (Fig. 2). The mesovortex originated in an area common for lee vortex formation (e.g. the Denver Cyclone), yet we hypothesize the mesovortex developed through the release of latent heat.

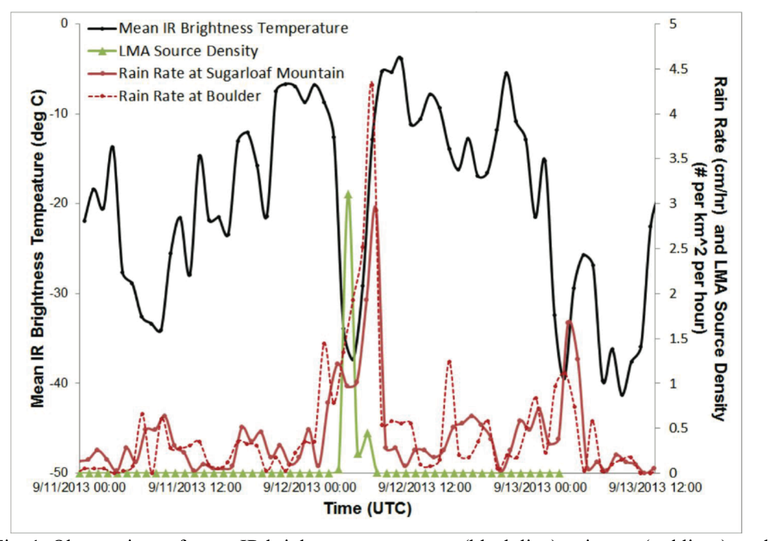

Fig. 1. Observations of mean IR brightness temperature (black line), rain rate (red lines), and lightning mapping array (LMA) source density (green line) (from Gochis et al. 2015).

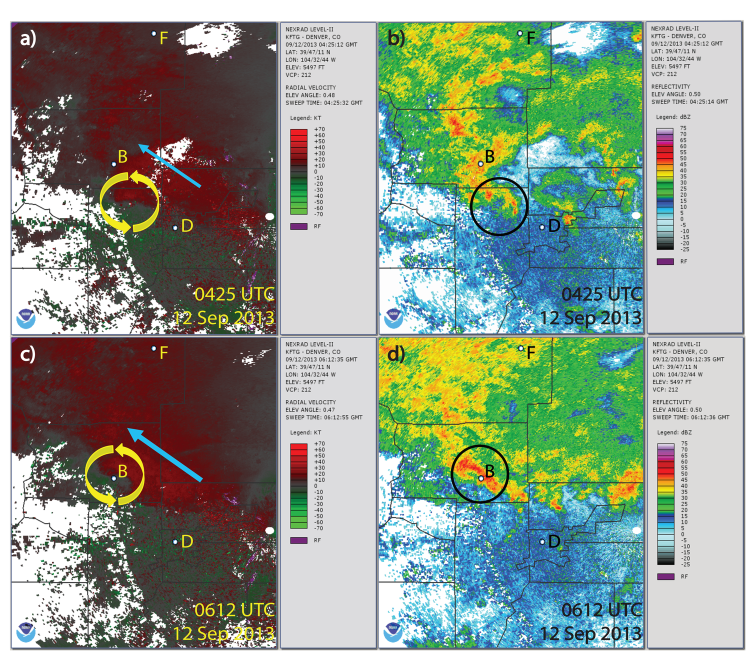

Fig. 2. Observed radial velocity (left) and radar reflectivity (right) from the Denver (KFTG) radar for 12 September 2013 at (top) 0425 UTC and (bottom) 0612 UTC.

Project Objectives

- Explore whether mesovortex was associated with lee vortex formation or through dynamic feedbacks from release of latent heat
- Understand the role of latent heating to mesovortex development
- Explore dominant microphysical processes and test sensitivity of mesovortex and precipitation to strength of latent heating

Methods

Model Configuration

- Advanced Research WRF v3.3.1
- 60 hr forecast, initialized at 0000 UTC 11 September 2013
- Two-way nested grid, 3 domains: horizontal grid spacing (Δx) of 36km, 12km, and 4km
- 36 stretched vertical levels, 50-hPa model top
- Timesteps: 144 sec, 48 sec, and 16 sec (respectively)
- Initial and boundary (updated every 3 hrs) conditions from 0.5° NCEP GFS model

Parameterizations	
Cumulus (for d01 and d02)	Grell-Devenyi 3 (G3)
Shortwave; Longwave Radiation	Dudhia; RRTM
Land surface	Noah
Microphysics	Thompson
Boundary layer	YSU

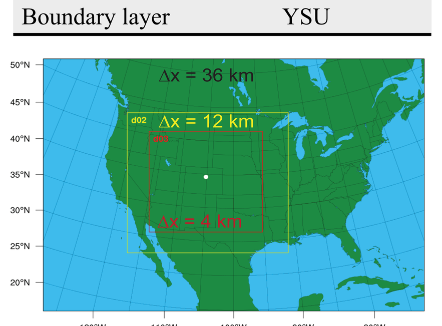

Fig. 3. WRF model domains. White dot is location of Boulder, CO.

Experimental Design

Initial Model Simulations					
Forecast Time	Latent Heating (LH)				
11 Sept 00-18 UTC	ON	OFF	ON	OFF	ON
11 Sept 18 UTC – 13 Sept 12 UTC	ON	OFF	OFF	ON	Reduced by 50%

CONTROL (LH_ON): Make sure main features of event are well represented before experimenting

LH_OFF: Test if LH had any effect on vortex development (initial testing)

LHON_LHOFF: Test if precipitation on prior day has impact on the vortex development on Sept 12th

LHOFF_LHON: Test if precipitation on Sept 12th has impact on vortex development that same day

LHON_LHHALF: Directly reduce the LH contribution from cloud water condensation by 50%

- Done by adjusting physical parameter describing the energy released per unit mass of vapor converted to liquid (leaving the rate of mass condensation unaffected)
- Hypothesis: Any process that could reduce the energy released from cloud water (CW) condensation would lead to weakening of vertical gradient in LH and less potential vorticity (PV) enhancement (i.e. mesovortex development)

$$\frac{d(PV)}{dt} \approx (\zeta + f)\frac{d\dot{\theta}}{dz}$$

Results

Latent Heating Experiments

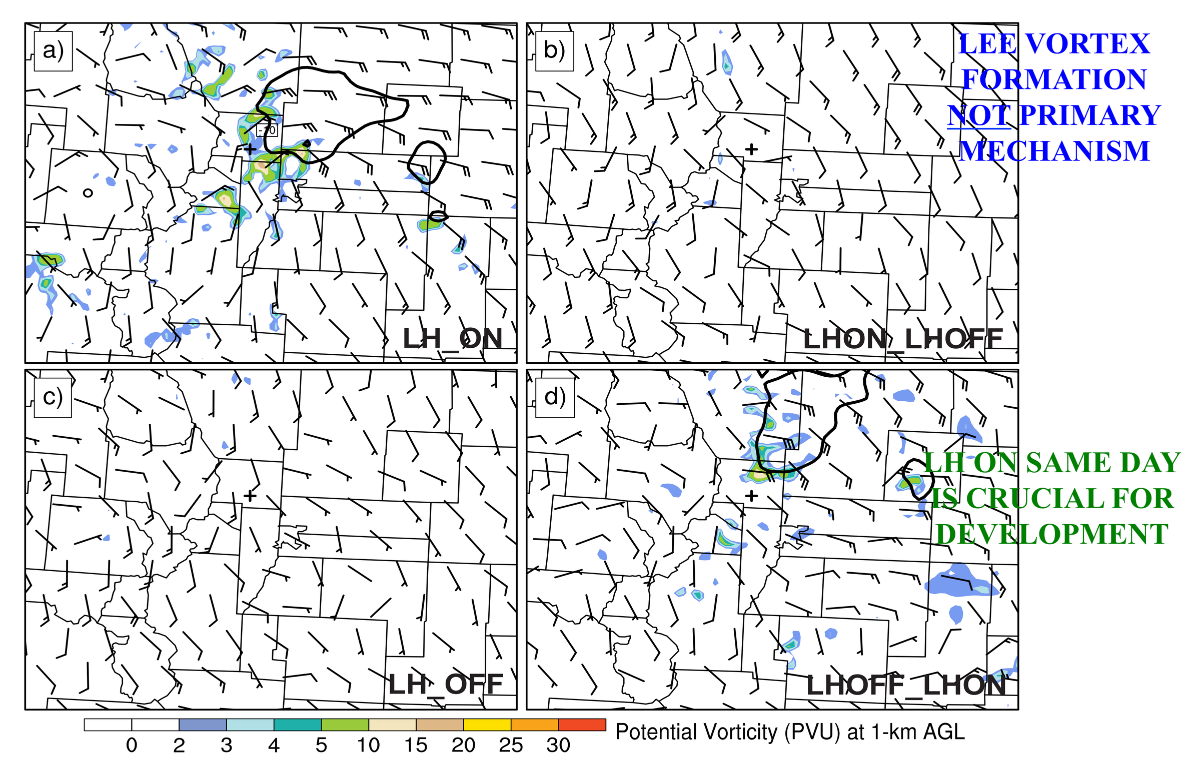

Fig. 4. Simulated potential vorticity (PVU, color), u-wind (m/s, solid black line), and wind barbs (kts) at 1-km AGL at 0300 UTC 12 September 2013. (a) LH_ON (control), (b) LHON_LHOFF, (c) LHOFF, and (d) LHOFF_LHON experiments. U-wind contour interval is 5 m/s, starting at -10 m/s.

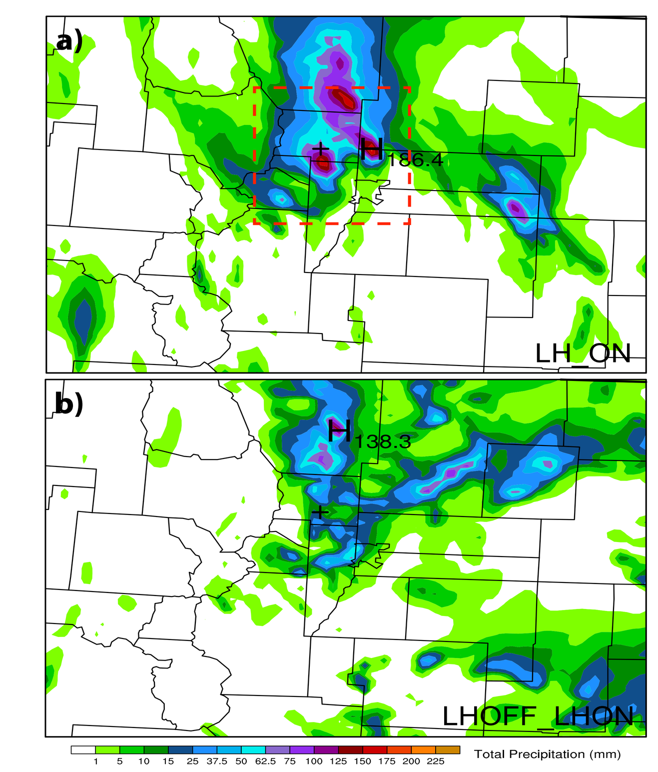

Fig. 5. Total precipitation (mm) for 0000-0600 UTC 12 September. (a) LH_ON and (b) LHOFF_LHON experiments. Dashed red square denotes domain where horizontal averaging was performed, corresponding to Fig. 6 and 7.

Exploring Control Simulation

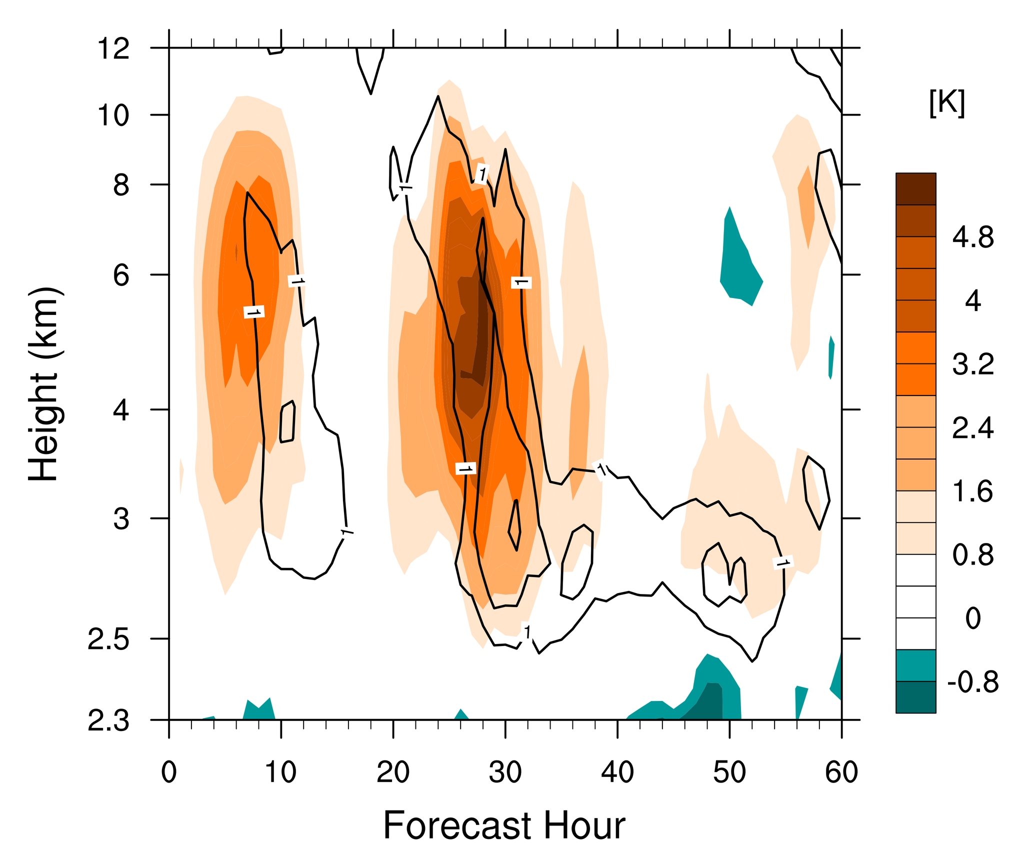

Fig. 6. Time-height plot of domain-averaged accumulated microphysics heating (K, color) and potential vorticity (PVU, black contours) for every forecast hour starting at 0000 UTC September 11. Potential vorticity contour interval is 0.5 PVU from 1 to 2 PVU. The vertical axis is geopotential height (km MSL). Averaged domain shown in Fig. 5a by dashed red square.

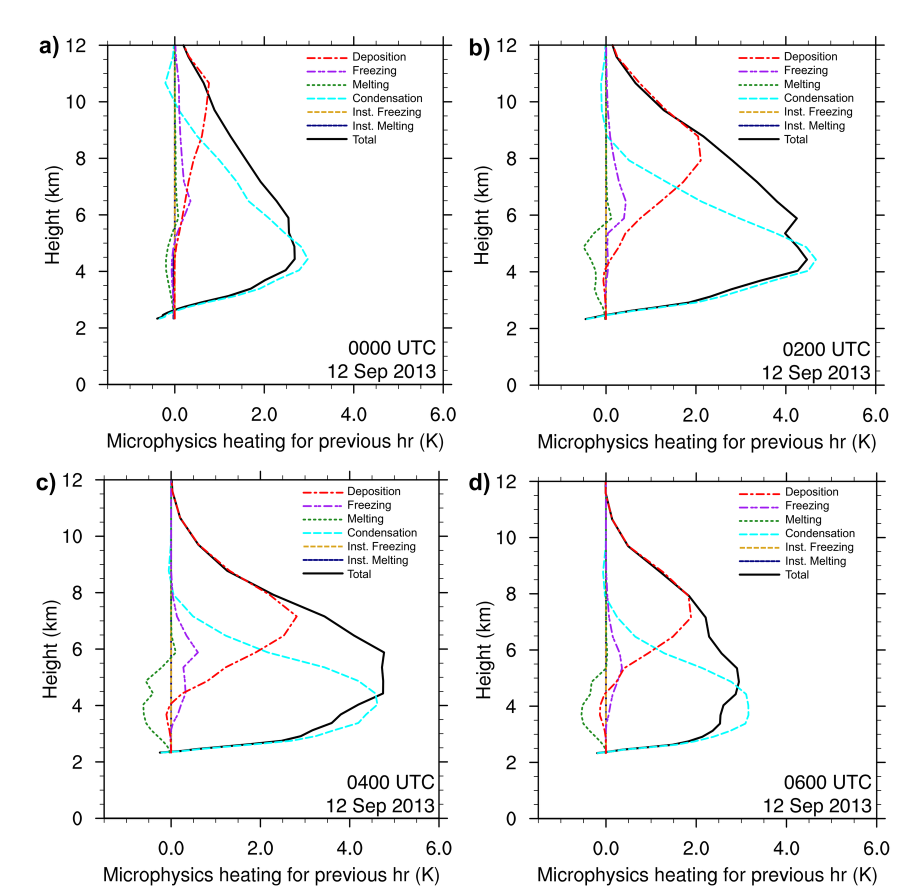

Fig. 7. Vertical profiles of domain-averaged hourly accumulated microphysics heating (K) for each "bulk" microphysics term. The profiles are for 12 September 2013 at (a) 0000 UTC, (b) 0200 UTC, (c) 0400 UTC, and (d) 0600 UTC. Averaged domain shown in Fig. 5a by dashed red square.

Sensitivity to Latent Heating Reduction

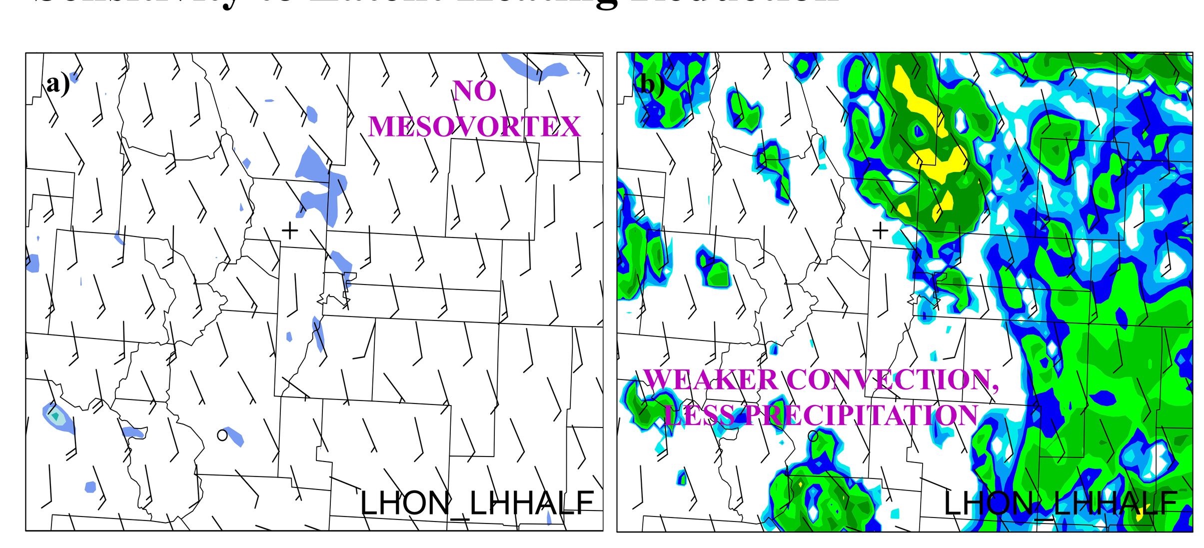

Fig. 8. (a) Potential vorticity (same as Fig. 4) and (b) radar reflectivity (dBZ) at 1-km AGL at 0600 UTC 12 September for the LHON_LHHALF experiment.

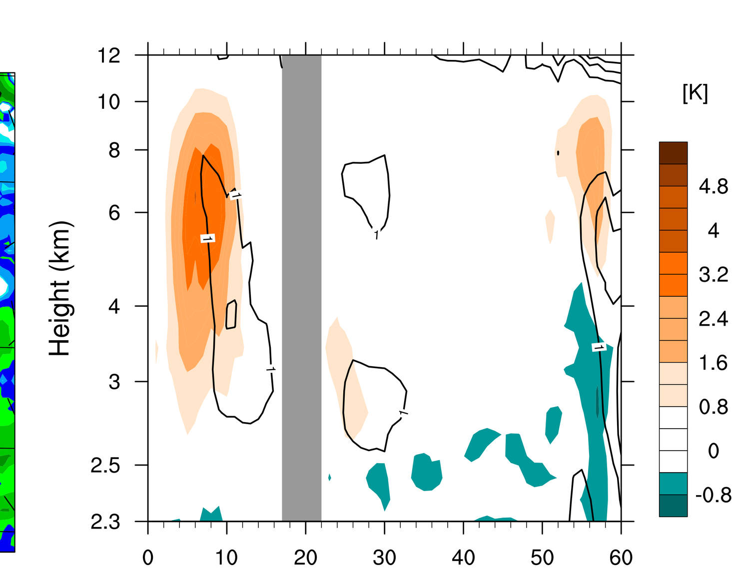

Fig. 9. Time-height plot of accumulated microphysics heating and PV (same as Fig. 5) for LHON_LHHALF.

Conclusions

Latent Heating Experiments

- LHON_LHOFF results in no mesovortex development and weaker flow in northern Colorado
  - Lack of enhanced PV suggests lee vortex formation is not primary mechanism for mesovortex development
- LHOFF_LHON shows features similar to those associated with the mesovortex (enhanced PV and low-level jet)
  - Suggests LH is needed to enhance pre-existing circulation and develop mesovortex
- LH had strong effect on surface flow field (feedback process)
  - Low-level jet enhanced in response to upward motions caused by LH, leading to enhanced upslope, which enhanced convection and surface precipitation

Exploring Control Simulation

- 12 Sept heating profiles had convective characteristics, consistent with observations
- High values of PV near the surface were associated with a strong, positive vertical gradient in LH located in the lower troposphere
  - Cloud water condensation was dominant process responsible for increase of LH with height

Sensitivity to Latent Heating Reduction

- Reducing the LH contribution from cloud water condensation by 50% (after 1800 UTC 11 Sept.) resulted in no mesovortex development and significant reduction in precipitation along northern Front Range
- Uncertainties do remain with respect to effect of LH on subsequent precipitation amount, thus future research is needed to explore complex dynamic-thermodynamic relationships involved in feedback process

Simulations and sensitivity studies suggest that the mesovortex was indeed responsible for the increased rain rates observed on 12 Sept. over Boulder, CO. Mesovortex development was more akin to a mesoscale convective vortex (MCV) than to the Denver Cyclone.

Acknowledgements

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