Large-Eddy Simulation of Deep Orographic Convection in the Colorado East River Basin During SAIL

Jialin Liu[a], Daniel J. Kirshbaum[a], Ethan Gutmann[b]
[a] Department of Atmospheric and Oceanic Sciences, McGill University, Montreal, QC, Canada
[b] NSF National Center for Atmospheric Research, Boulder, Colorado, United States
jialin.liu2@mail.mcgill.ca

1: Introduction

In this study, several mechanisms responsible for diurnal deep convection initiation (DCI) over complex terrain are investigated by synthesizing 1) large-eddy simulation (LES) with 2) observations from the SAIL field campaign, the latter took place over the Colorado East River Basin (ERB). The investigation is presented as a case study of the day of July 2, 2022.

2: Modeling framework (WRF)

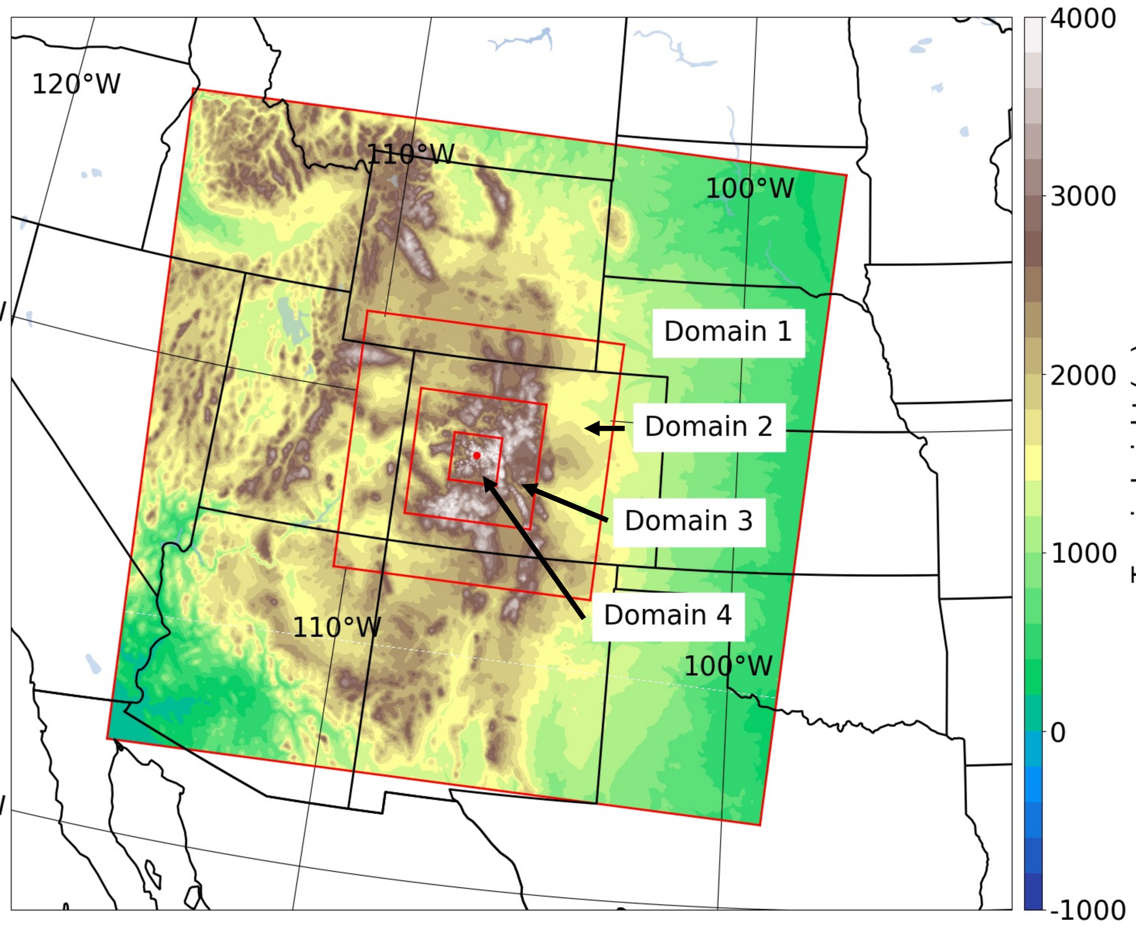

Fig. 1: WRF domain setup. Red squares denote the boundaries of each domain. Horizontal grid spacing decreases from 3 km to 111.11 m from domain 1 to 4.

3: Model verification

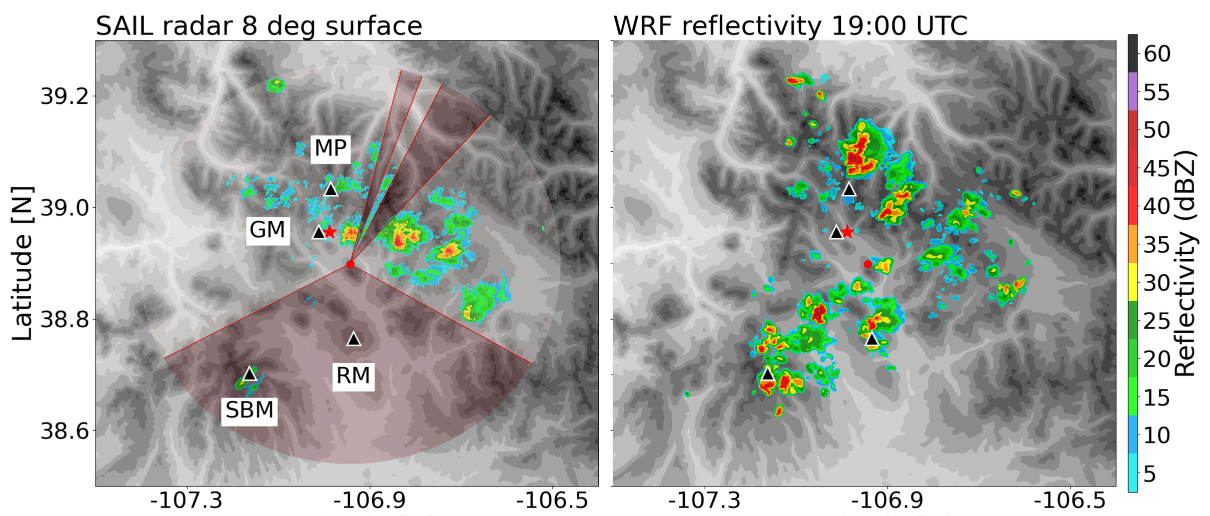

Fig. 2: Verification of WRF simulation against SAIL observations at 19 UTC. Red dot denotes the radar; red shadings denote sectors of beam blockage. Red star denotes the surface observation site, and black triangles denotes 4 locations of DCI.

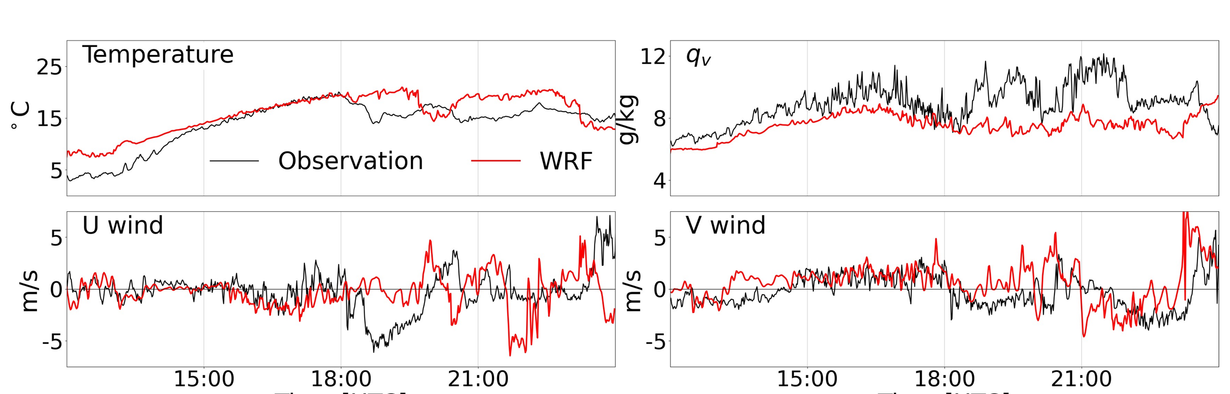

Fig. 3: ERB surface verification.

4: Deep convection initiation

We focus our analysis on the following locations (Fig. 2):

1. **Maroon Pass (MP): where DCI (i.e., 40 dBZ reflectivity) first take place.**
2. **South Baldy Mountain (SBM): gradually deepening clouds prior to DCI.**
3. **Red Mountain (RM): similar development as SBM but over smaller-scale peak.**
4. **Gothic Mountain (GM): not a convection hotspot, but sudden DCI occurs in the afternoon.**

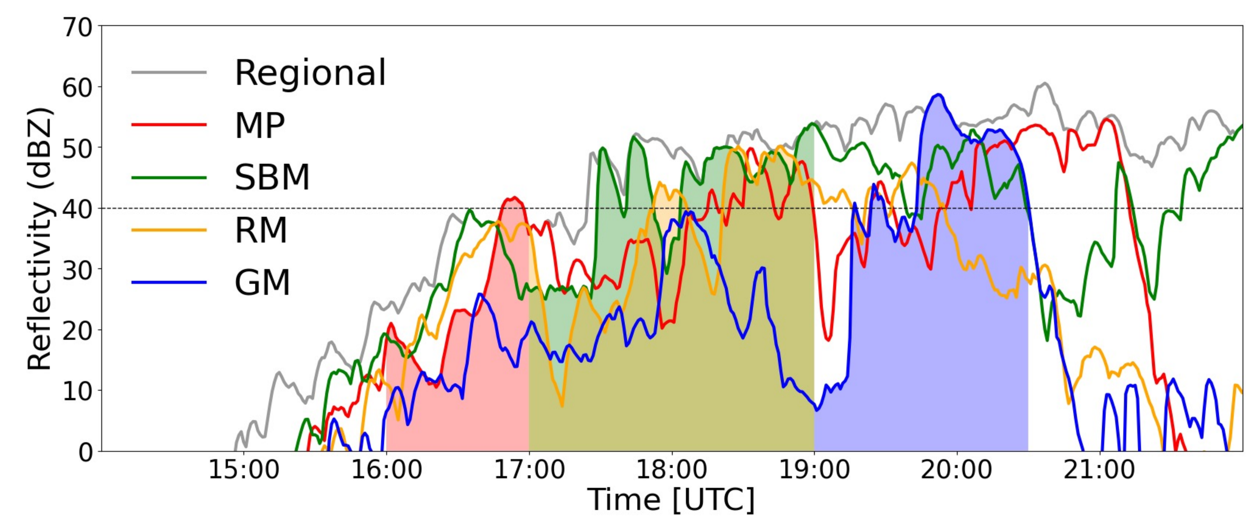

Fig. 4: Time series of maximum composite reflectivity in the vicinity of the ERB and DCI locations. Shadings indicate the respective analysis periods.

4a: DCI over MP

The first 40 dBZ echoes reached as a shallow cloud deepens within a 15-min period directly over the mountain pass (Fig. 5).

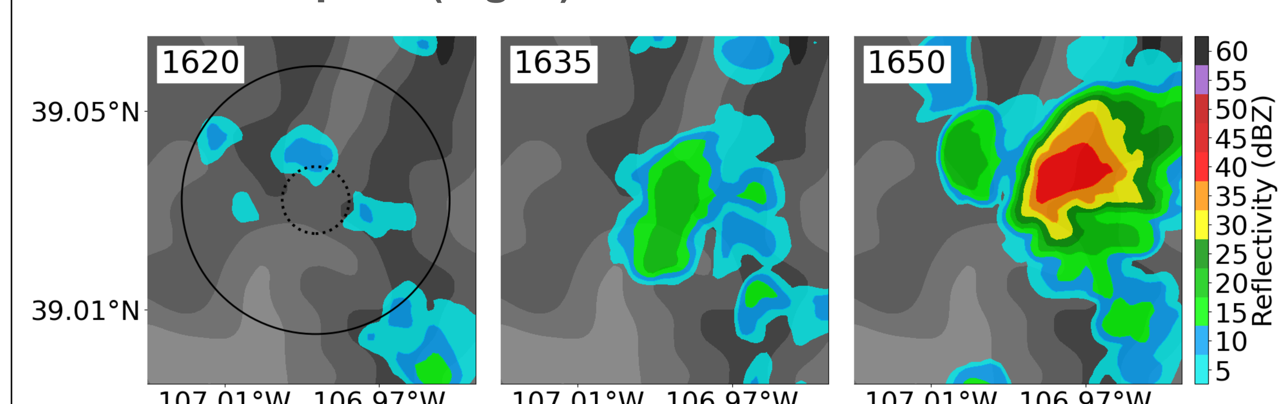

Fig. 5: Snapshots of composite reflectivity over MP. Timestamps are shown in UTC. Black solid and dotted circles denote the area for maximum reflectivity calculation (i.e., in Fig. 4) and mass flux analysis (i.e., in Fig. 6).

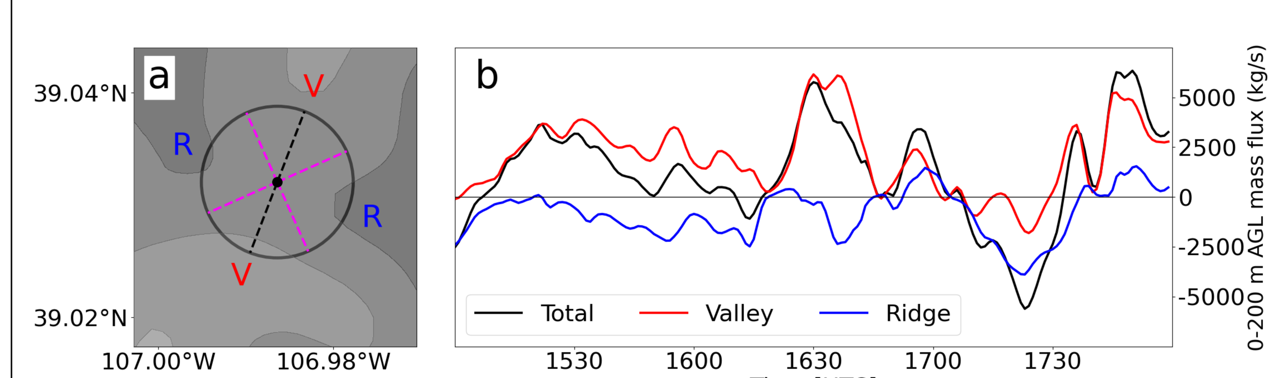

Fig. 6: Time series of 0-200 m above ground level (AGL) net mass flux at the pass. In (a), black circle denotes the area of mass flux calculation, black dotted line denotes the valley axis. Magenta dotted lines indicate the boundaries of valley and ridge sectors used for total flux decomposition.

⇒ DCI at MP owes to low-level convergence (Fig. 6) over the pass. This convergence is caused by two branches of thermally-driven up-valley flows.

4b: DCI over SBM

At SBM, DCI manifested over the entire mountain after cycles of convection development (Fig. 7).

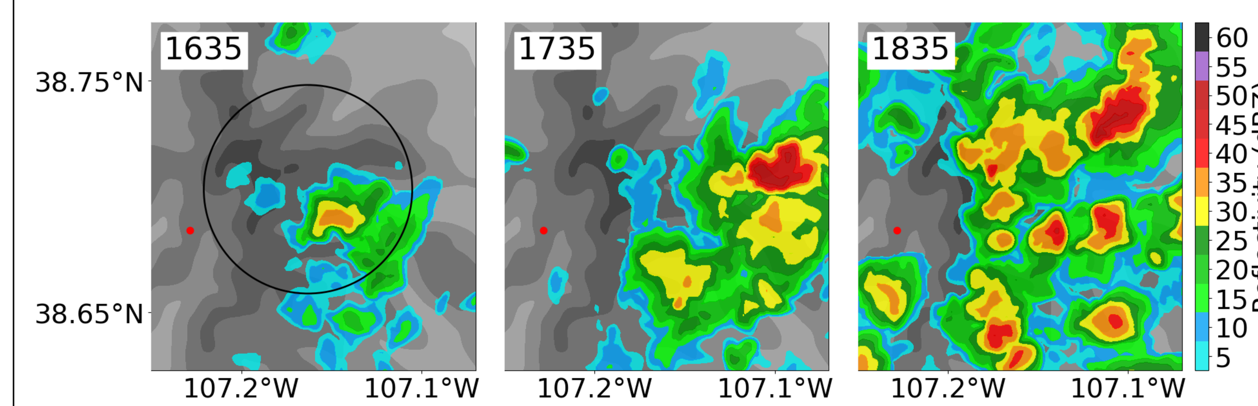

Fig. 7: Same as Fig. 5 but for SBM. Red dot indicates the "cloud-free" profiling location; local profiling is done in the black circle.

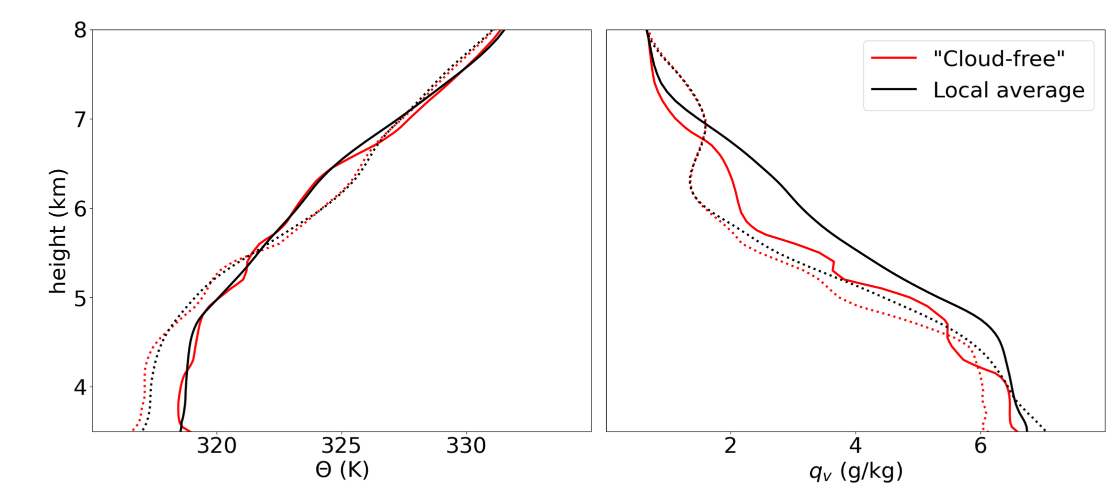

Fig. 8: Evolution of "cloud-free" and local θ and q_v profile between 1600 (dotted) and 1800 UTC (solid).

⇒ Along with diurnal PBL preconditioning, cloud growth at SBM requires the moistening and cooling in mid-to-upper-level through evaporation of earlier clouds (Fig. 8).

4c: DCI over RM

Located downstream of SBM, convection over RM also deepens progressively, but slightly later than that over SBM (Fig. 9).

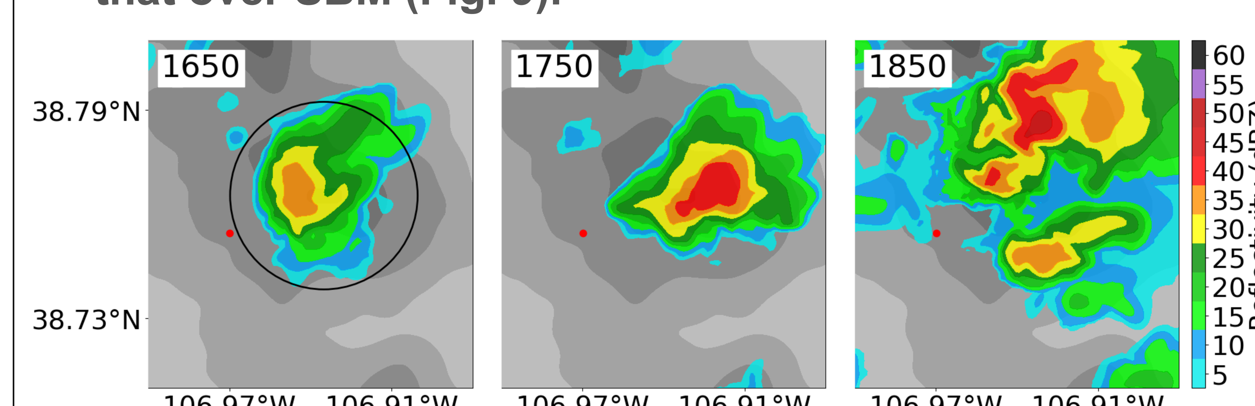

Fig. 9: Same as Fig. 5 but for RM. Red dot indicates the upstream profiling location.

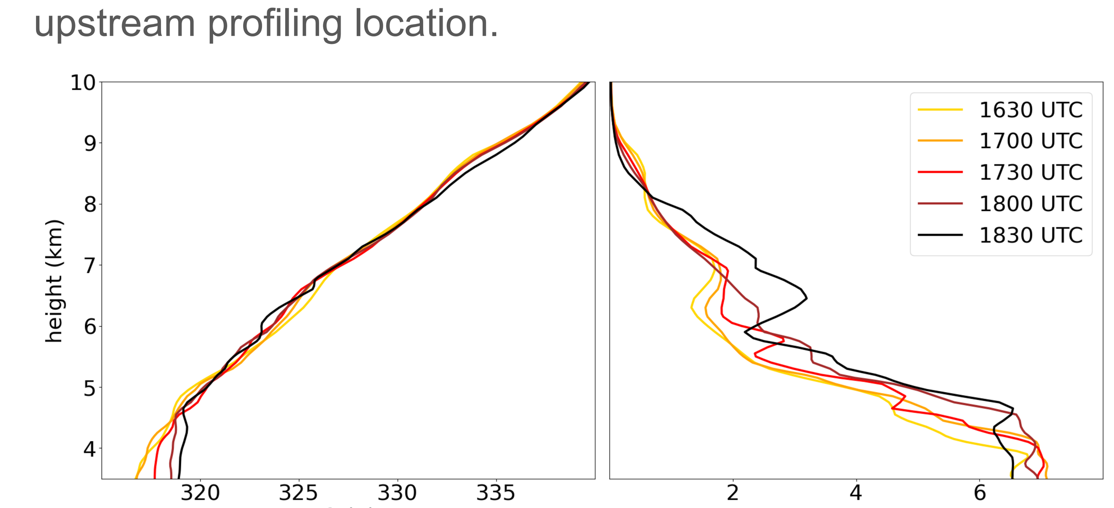

Fig. 10: Evolution of upstream θ and q_v profile between 1630 and 1830 UTC.

⇒ DCI at RM is promoted by local PBL heating and upstream upper-level preconditioning (moistening and cooling). The latter is associated with DCI from SBM.

Further sensitivity tests (not shown) suggest that:

1. **Upstream upper-level preconditioning is more important compared to PBL processes.**
2. **Changes in upper-level θ and q_v are equally important.**

4d: DCI over GM

Vigorous convection developed amidst several storms, reaching 60 dBZ within 20-min (Fig. 11).

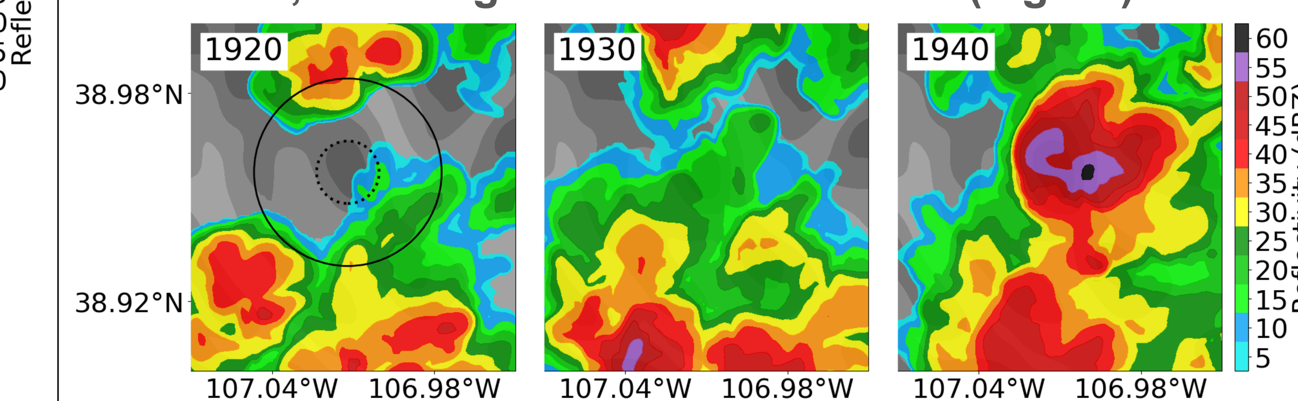

Fig. 11: Same as Fig. 5 but for GM.

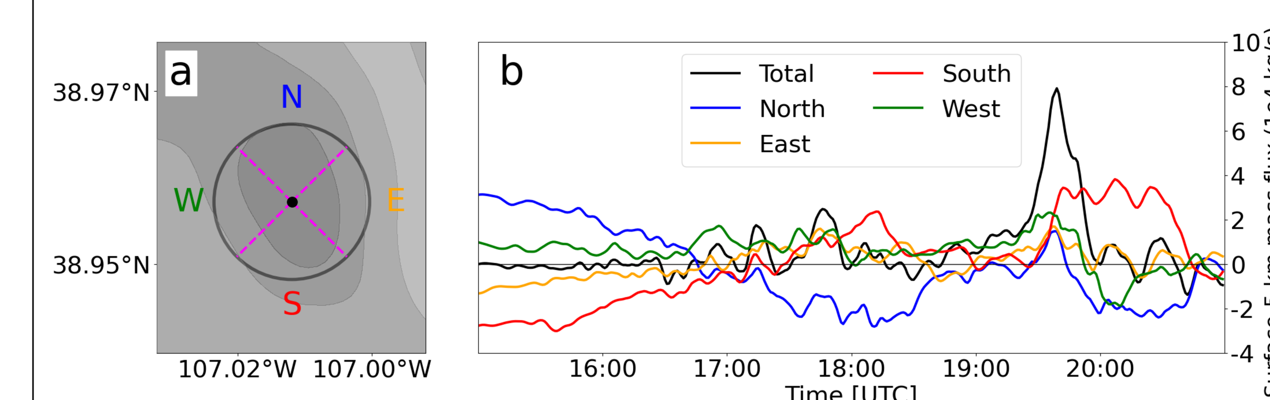

Fig. 12: Same as Fig. 6 except that mass flux is calculated below 5 km above sea level over GM and decomposition is made into four sectors (i.e., north, east, south, and west).

⇒ DCI over GM owes to the convergence of :

1. **Two cold pools, one from north, one from south.**
2. **Thermally-driven upslope flow over the eastern slope.**
3. **Western branch of plain-to-mountain circulation over the larger mountain scale.**

This convergence locally lifts thermal anomalies into cloud-base, leading to DCI.

5: Conclusions

1. A WRF-LES simulation reasonably reproduces observed convective cells during a SAIL event.
2. Simulated DCI occurs in multiple locations, four of which were analyzed in detail (Fig. 4).
   - MP: formation of thermally forced valley flows strengthen low-level convergence over the pass. The convergence initiates/deepens clouds, some forming heavy precipitation.
   - SBM: clouds gradually deepen owing to 1) local PBL heating and 2) mid-to-upper-level moistening and cooling. The latter is associated with the evaporation of earlier clouds.
   - RM: upstream convection moistens and cools the flow aloft. This cloud preconditioning, together with local PBL diurnal heating, facilitates DCI.
   - GM: cold pools collide with local orographic flows. The convergence lifts thermal anomalies over the mountain top into cloud-base.

We acknowledge the support of the Natural Sciences and Engineering Research Council of Canada (NSERC).
Nous remercions le Conseil de recherches en sciences naturelles et en génie du Canada (CRSNG) de son soutien.