# Orographic Effects and Lake Geometry in Idealized Simulations of Banded and Cellular Lake- and Sea-Effect Precipitation Systems

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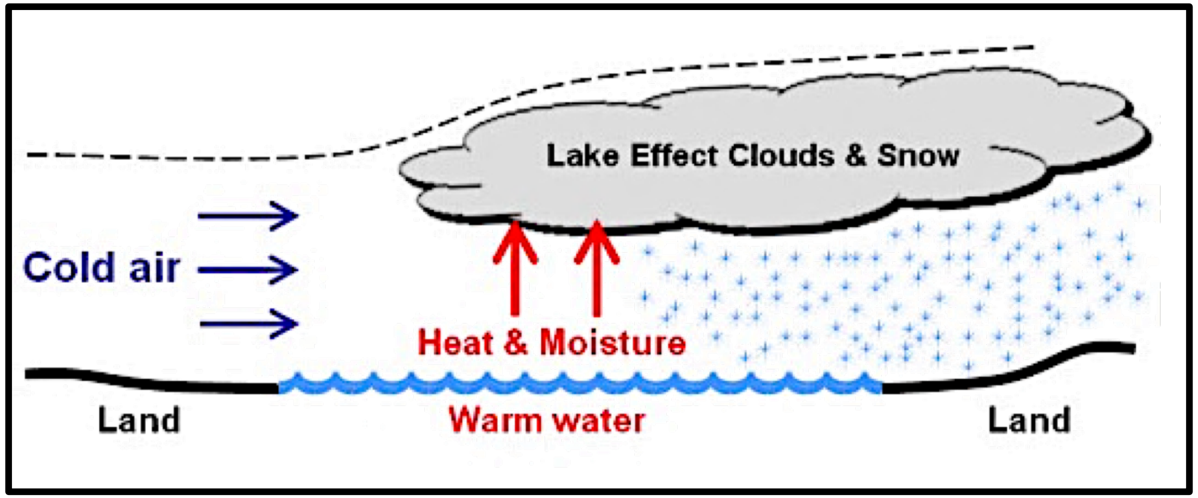
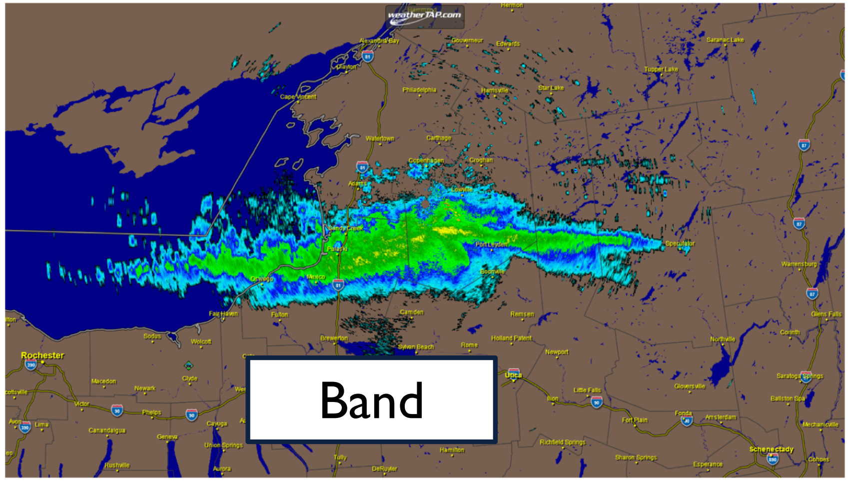
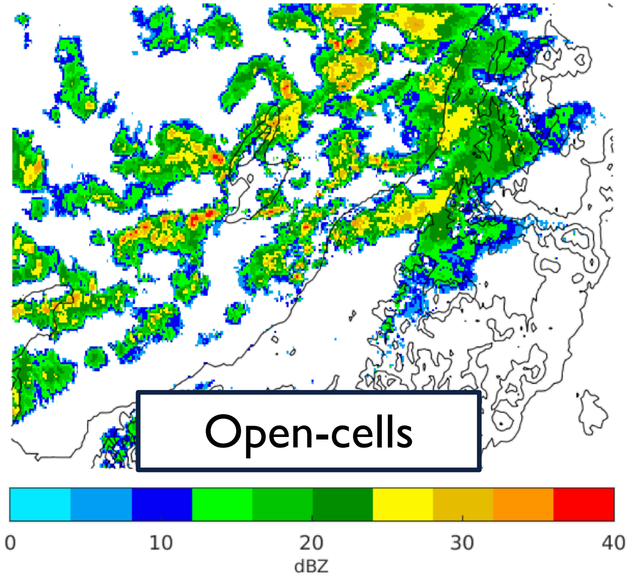


Lake Effect Clouds & Snow
Cold air
Heat & Moisture
Land
Warm water
Land

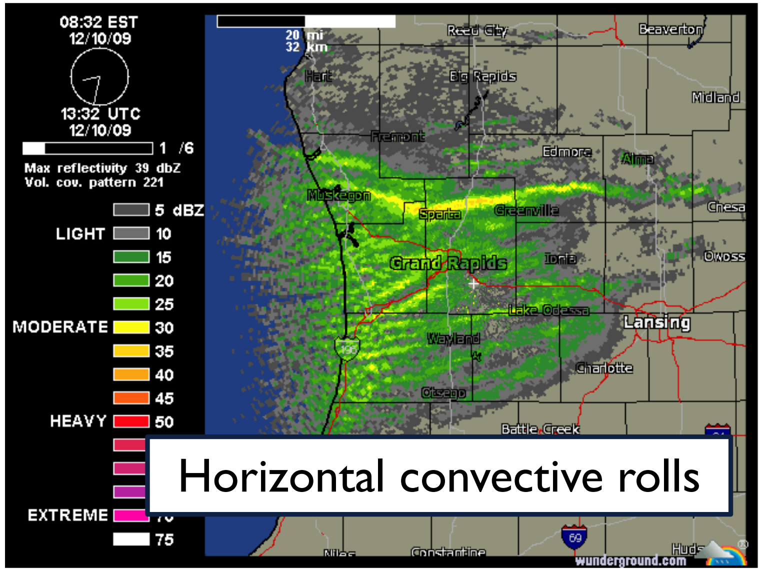

Credit: NWS



Band

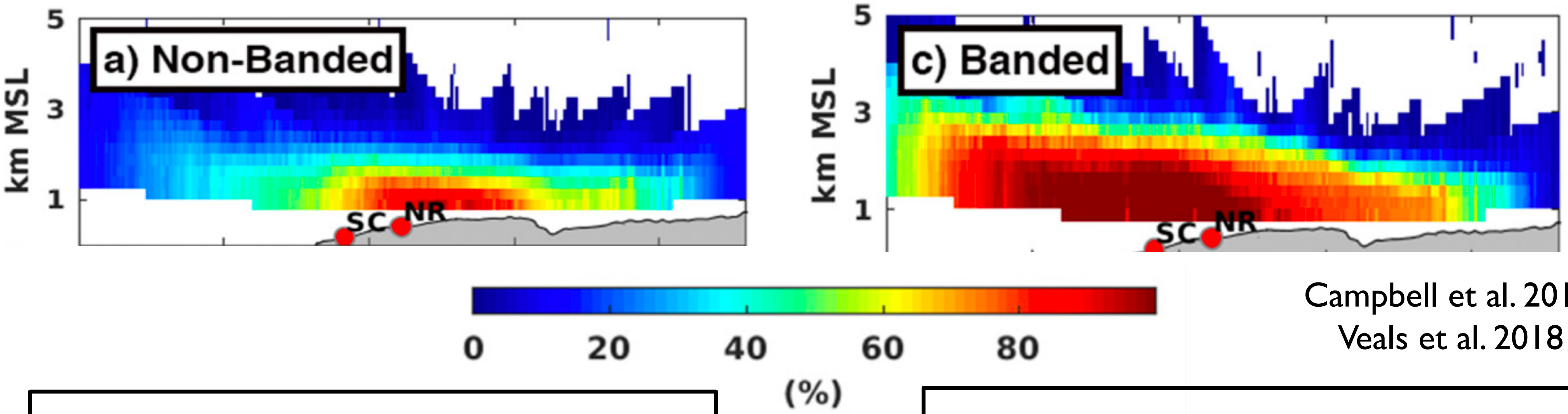



Open-cells
0
10
20
30
40
dBZ

08:32 EST
12/10/09
13:32 UTC
12/10/09
Max reflectivity 39 dbZ
Vol. cov. pattern 221
5 dBZ
LIGHT
MODERATE
HEAVY
EXTREME
Muskegon
Grand Rapids
Lansing
Horizontal convective rolls
wunderground.com

# Mode and Orographic Enhancement




Campbell et al. 2016;
Veals et al. 2018

Strong orographic enhancement

Weak orographic enhancement

**Operational models poorly resolve mode**
**→ understanding mechanisms important to improve predictions**

Why is orographic enhancement **weak during banded** periods and **strong during cellular** periods under similar conditions?

↓

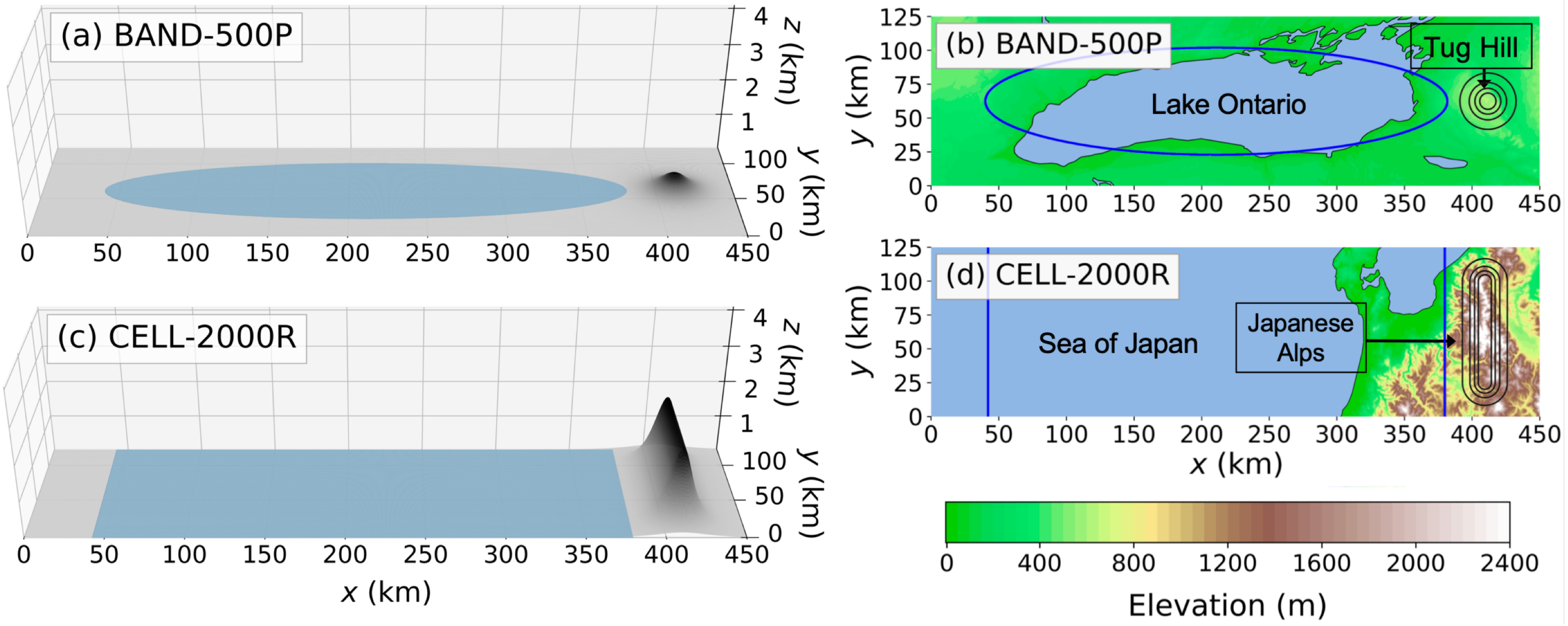
Run idealized LESs of **banded** and **cellular** lake-effect systems with terrain representative of **Tug Hill** and **Japanese Alps**

# Numerical Set-up

Model: CM1 (George Bryan)

To form band:

To form cells:




**6 unique domains:**

- **2 lake shapes:** oval, open
- **3 terrain:** no terrain, 500m peak, and 2000m range

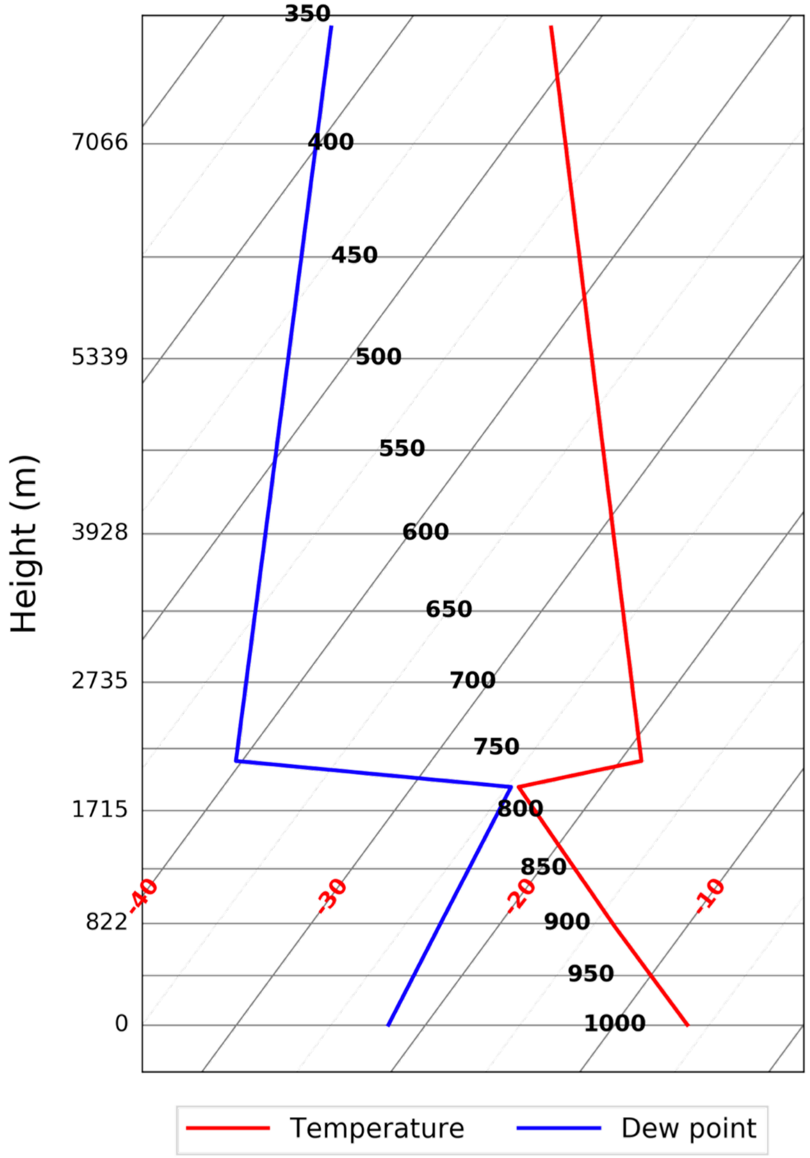
- △x, △y = 125m, △z = 100m
- **Parameterizations:** ThompsonMP, WRF LSM

# Environment

Same sounding used in all 6 runs

| Thermodynamics |
| --- |
| • Typical upstream sounding<br>• Well-mixed boundary layer<br>• Stable layer between 800-750 mb |

| Wind |
| --- |
| • 12.5 $ms^{-1}$ in positive x-direction (60$^{th}$ percentile)<br>• Maintained at inlet using Rayleigh damping |

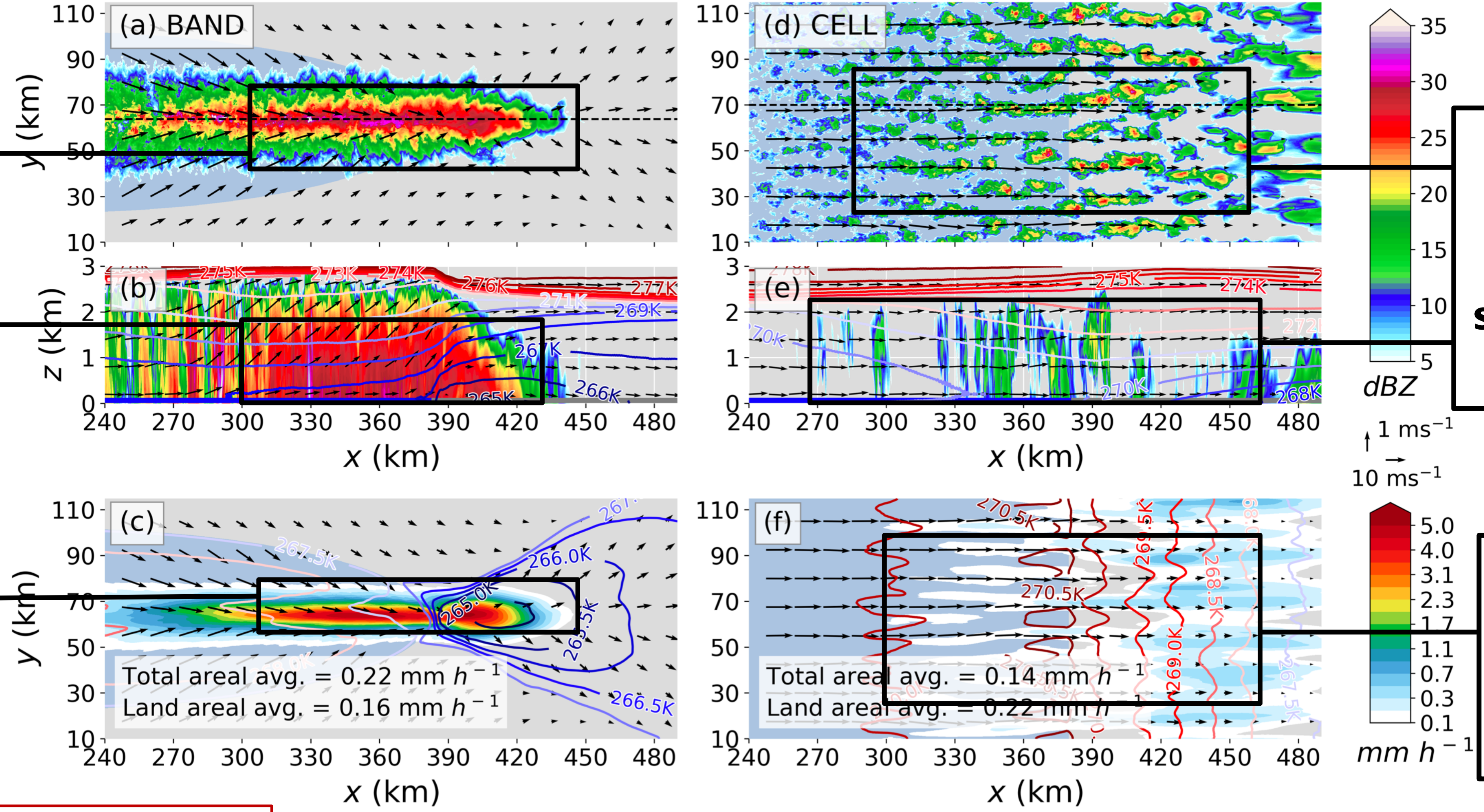


# No-Terrain “Control” Simulations

# Overview

Convergence → **strong band forms**

Heavy, narrow band of precip.

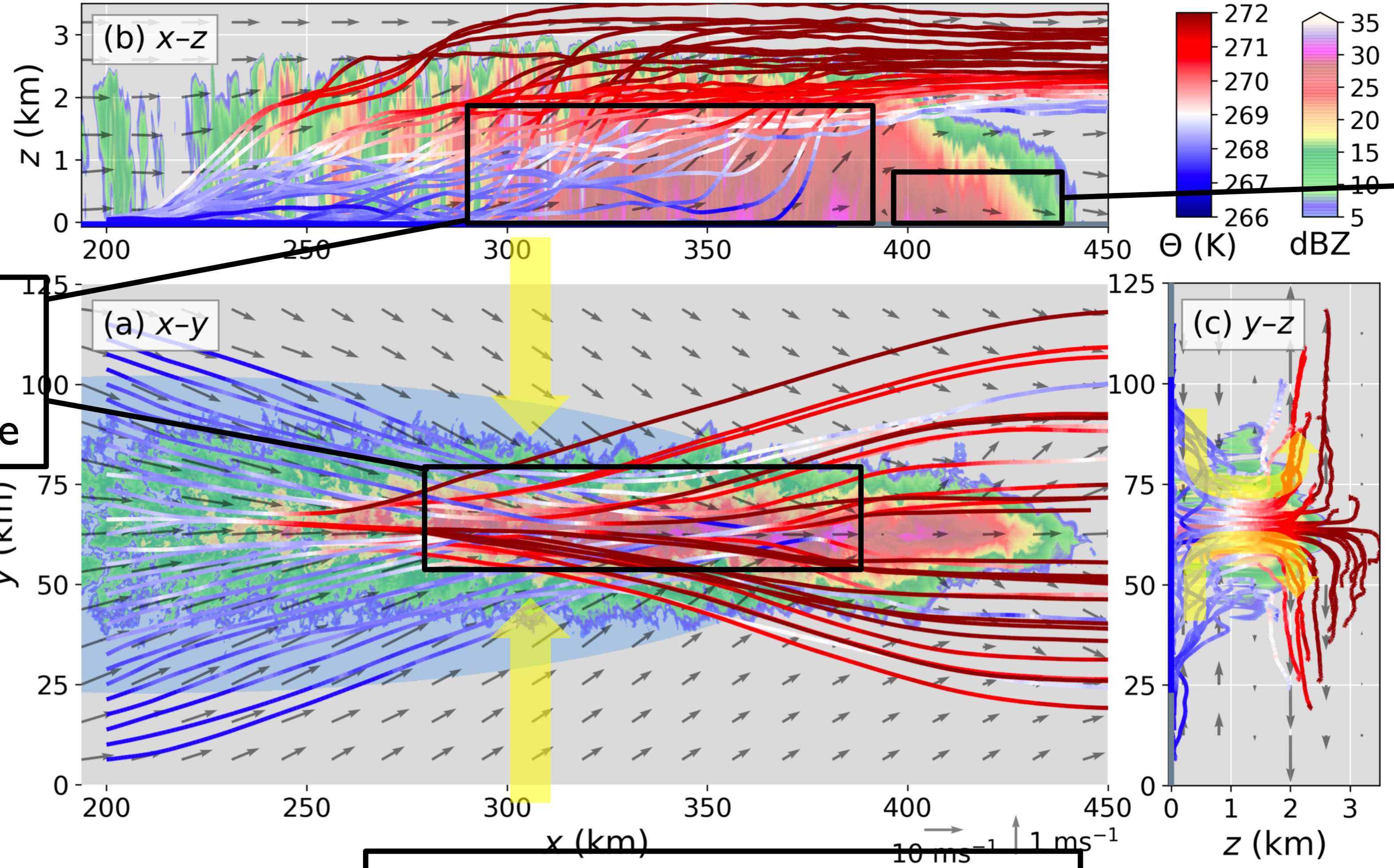



Cells grow **bigger, stronger, deeper**

Minimal precip., more inland

**BAND CTL** = oval lake, no terrain
**CELL CTL** = open lake, no terrain

# Band: Cross-band Circulation



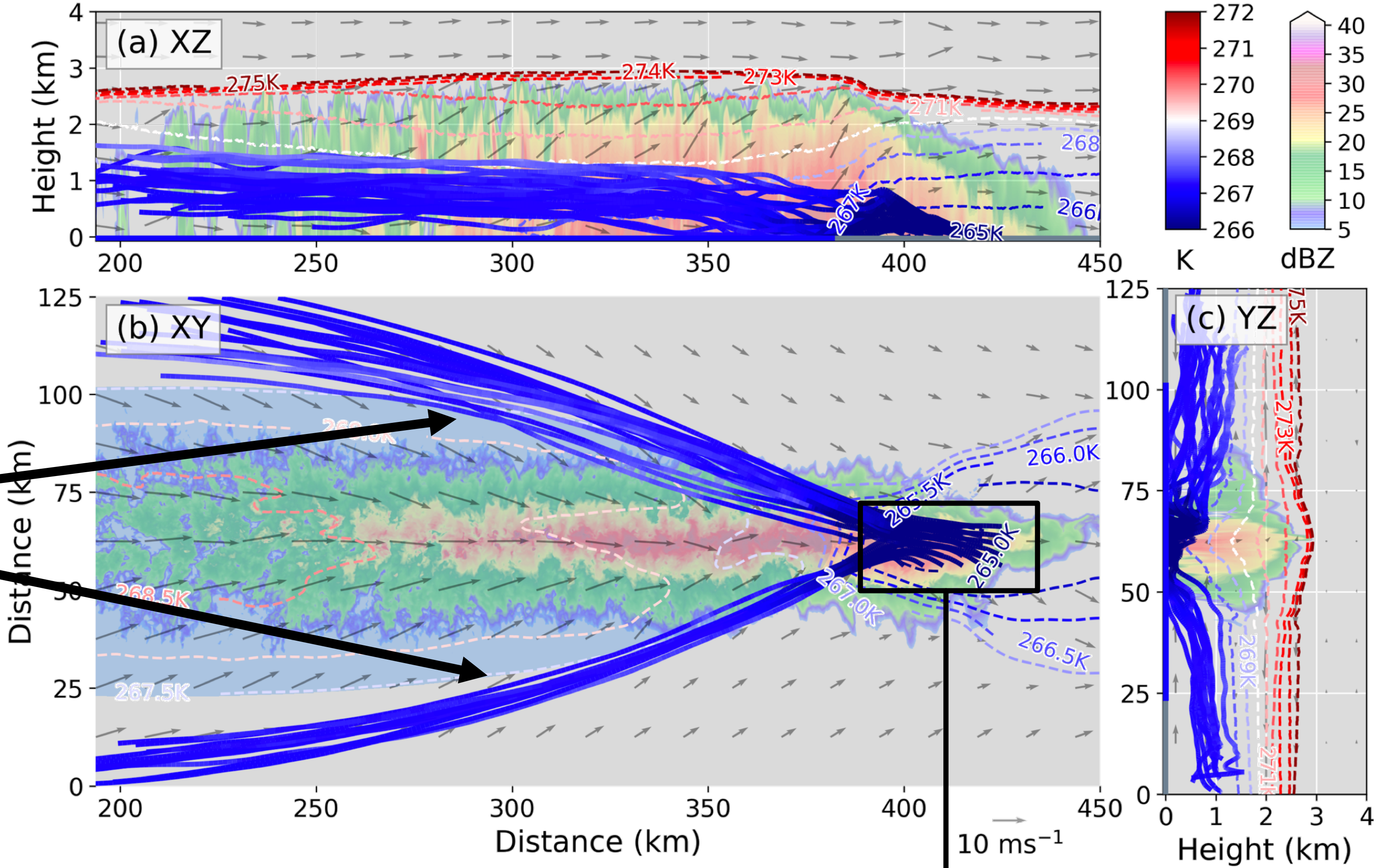

**Why are there no parcels downstream of lake?**

2) Intense band where land breezes converge

3) Cross-band circulation forms

1) Land breezes form due to land/water temp differences

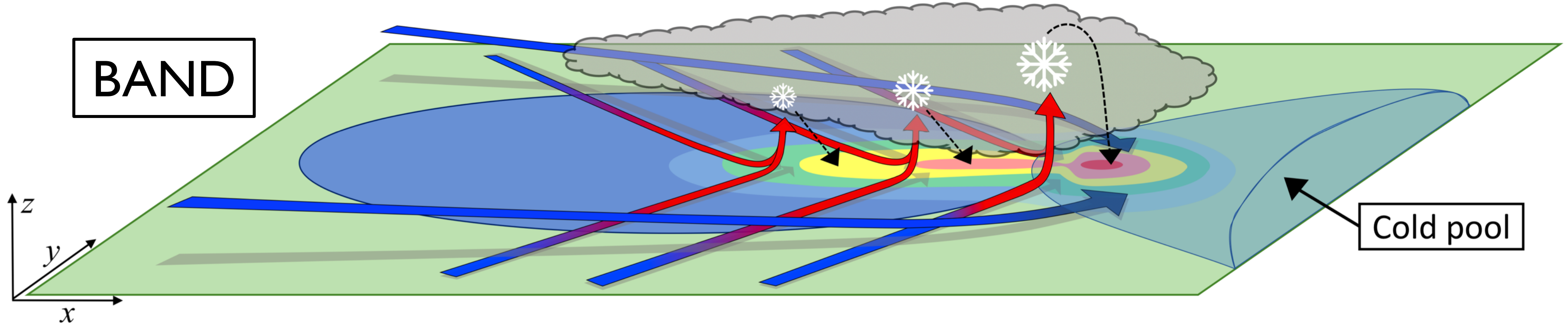
# Band: Cold Pool

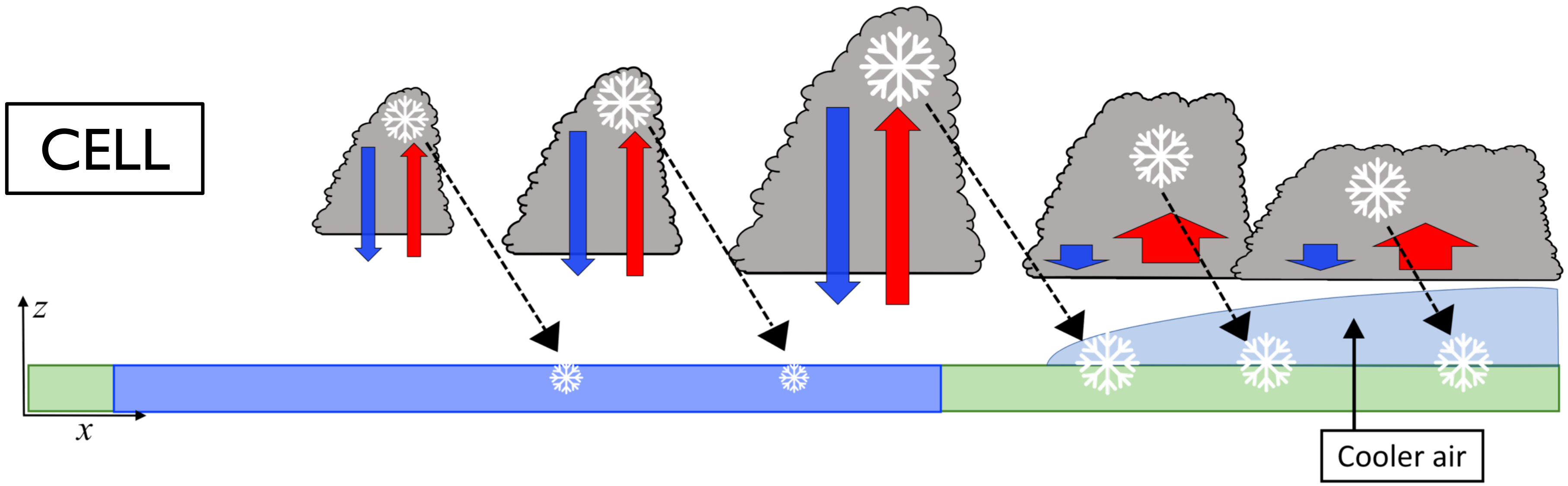



Cool, continental air flanks the lake due to land breezes. Avoids lake modification

Air is further cooled by sublimation

# Summary Schematics



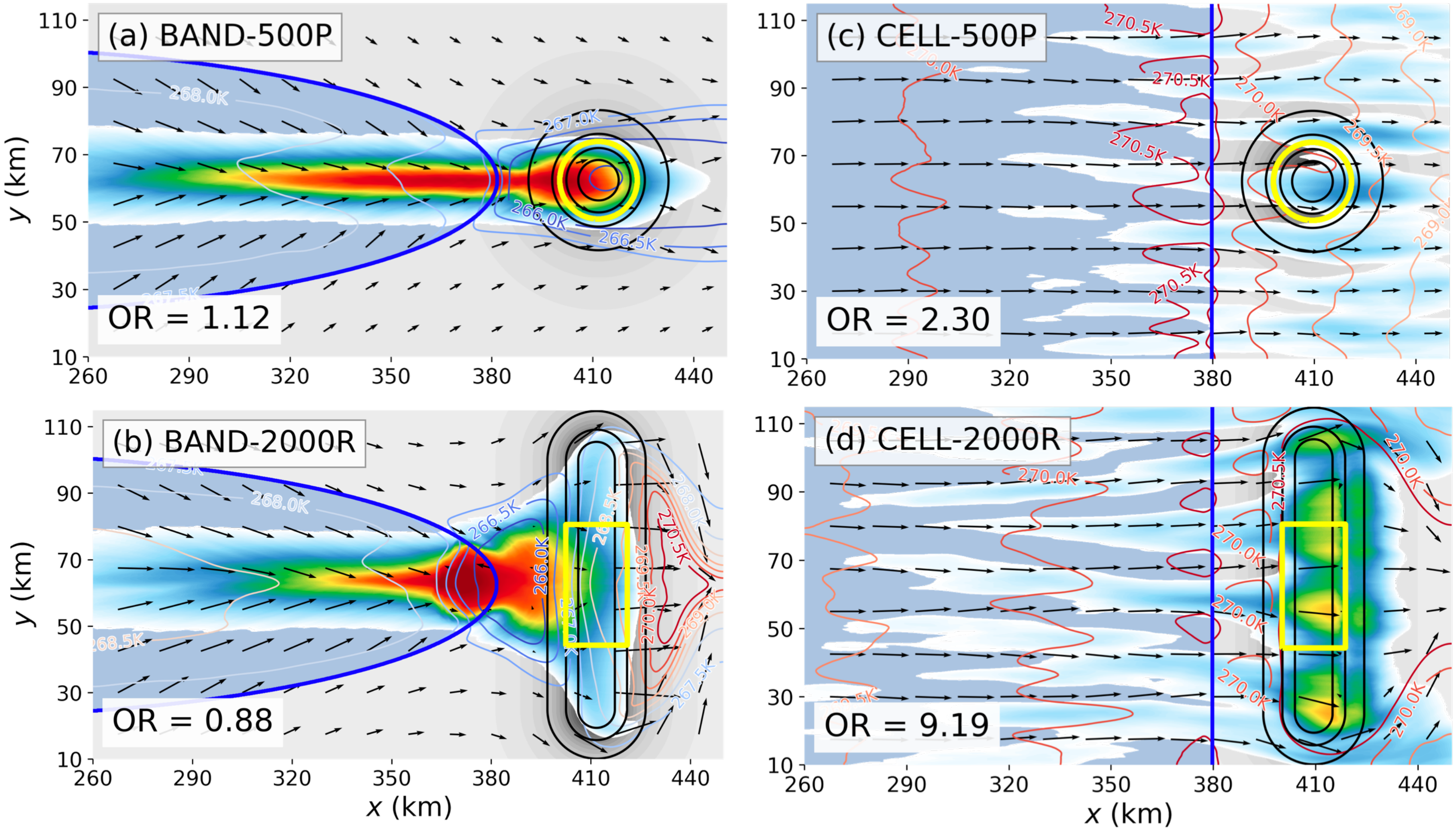



# Terrain Simulations

# Terrain Impacts

**BAND-500P**
Weak orographic enhancement

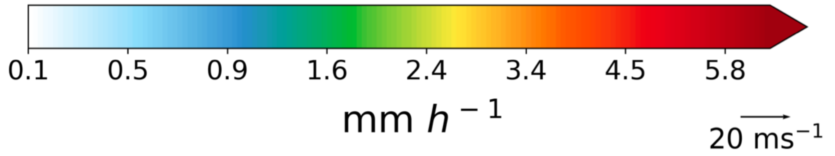
**BAND-2000R**
Blocking → max shifts upstream




**CELL-500P**
Moderate orographic enhancement

**CELL-2000R**
Significant orographic enhancement

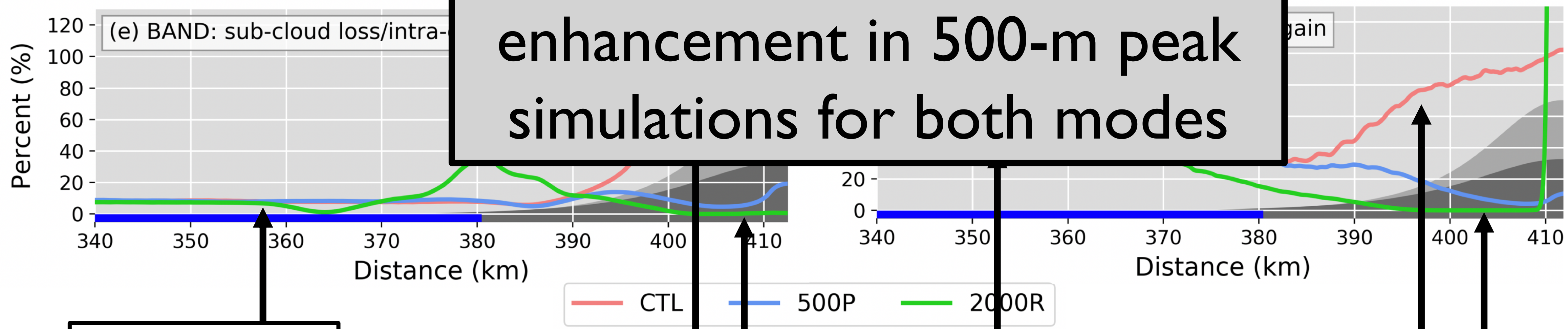
**BAND-500P** = oval lake, 500-m peak
**BAND-2000R** = oval lake, 2000-m ridge




**CELL-500P** = open lake, 500-m peak
**CELL-2000R** = open lake, 2000-m ridge

# Sub-cloud Sublimation

$$\frac{-\int_{surface}^{cloud\ bottom} hydrometeor\ tendency}{\int_{cloud\ bottom}^{cloud\ top} hydrometeor\ ten\ldots} = \frac{\textbf{Hydrometeor loss (sublimation)}}{\textbf{Hydrometeor growth}} = \text{Percent sublimated}$$




Accounts for most of enhancement in 500-m peak simulations for both modes

~10% loss all simulations

>50% loss in CTL
< 10% in 500P and 2000R

~50% loss all simulations

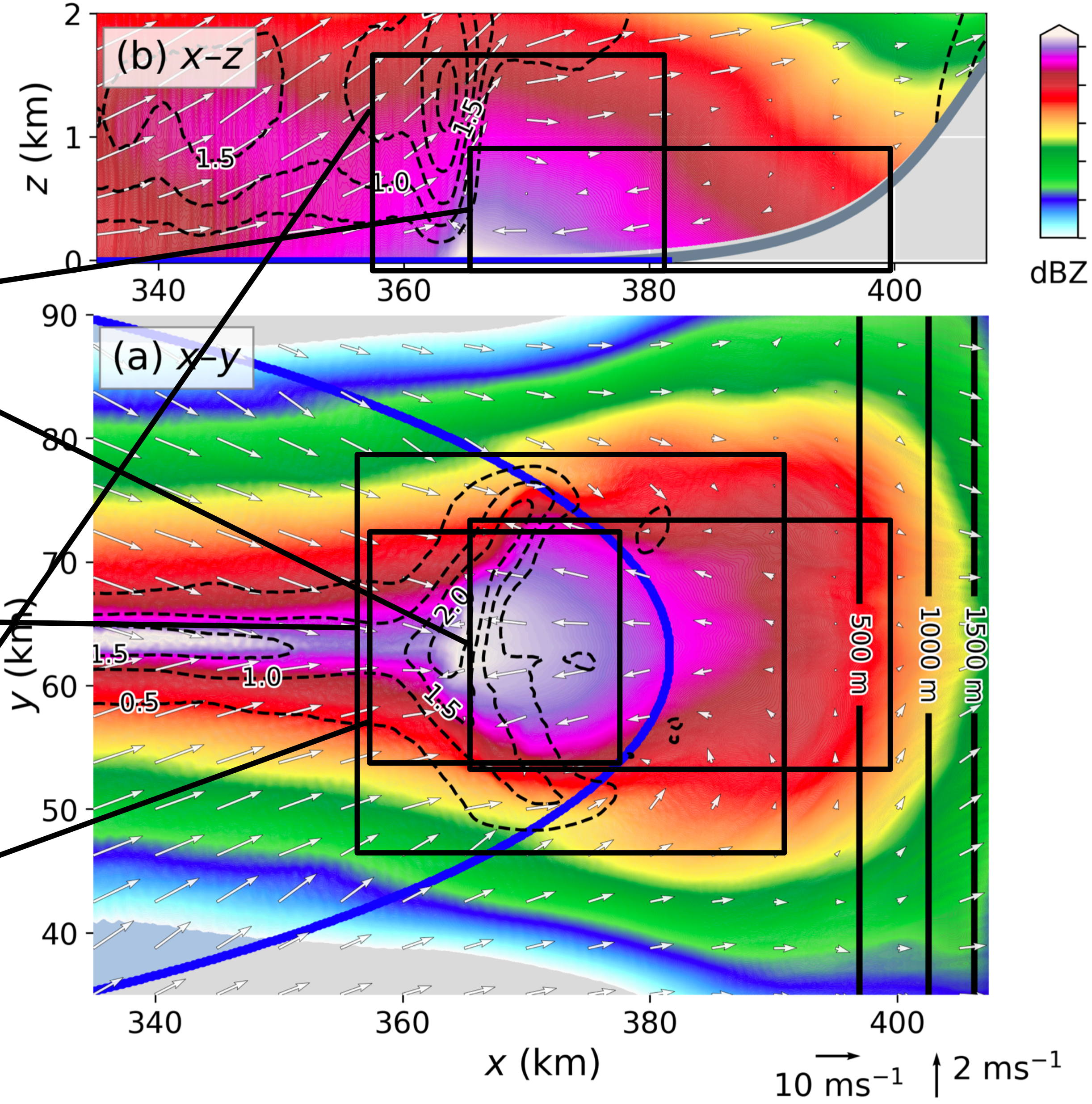
> 50% loss in CTL
< 10% in 500P and 2000R

# Mechanisms in BAND-2000R

1. Cold, stable air + large mountain = blocking

2. Flow reversal → land breeze front

3. Max ascent over water → precip. max



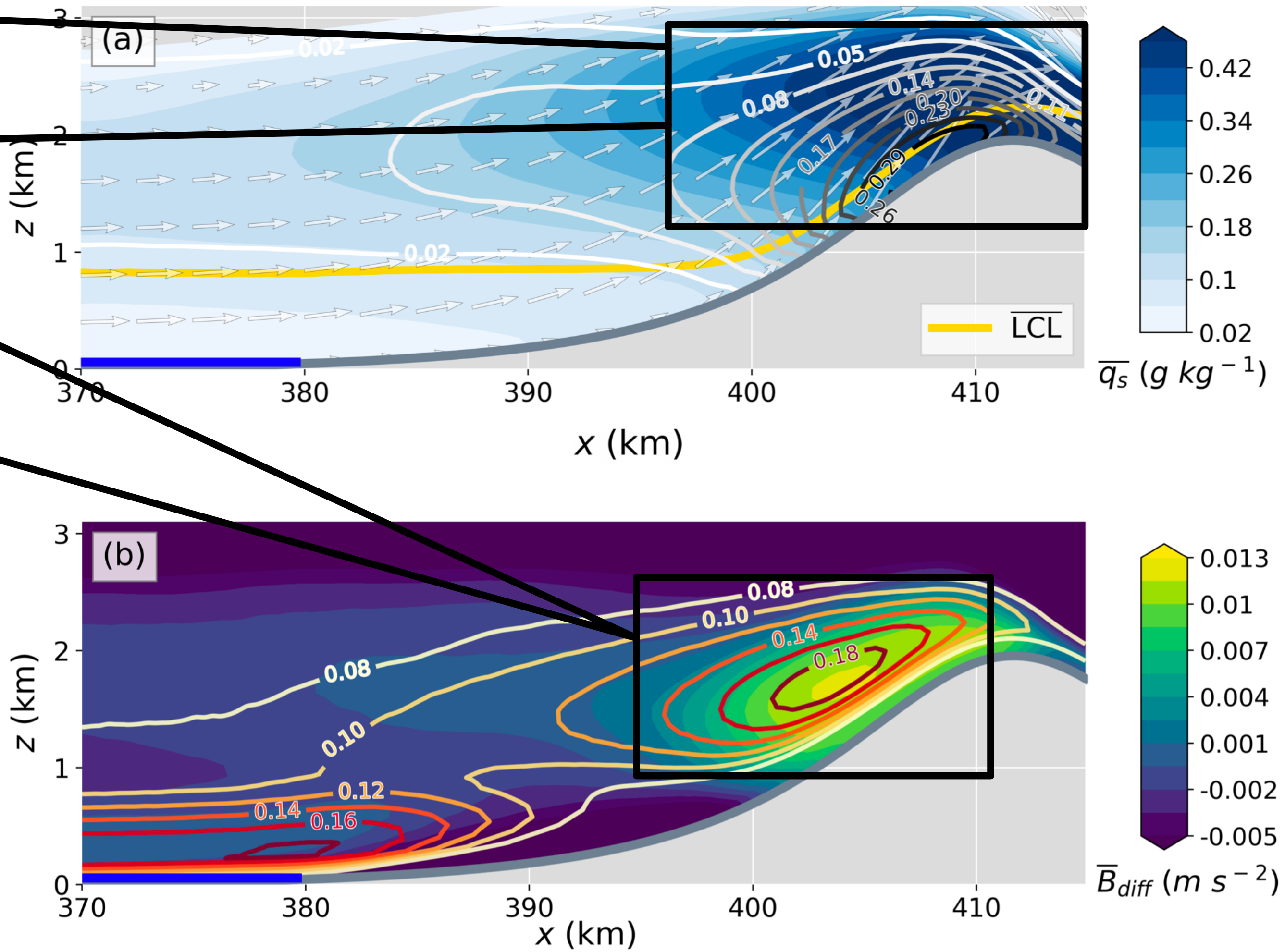
# Mechanism in CELL-2000R

Unblocked flow - air forced above LCL

Generates dense cap cloud and intense snow growth. Why?

Rapid growth of buoyant updrafts (> 0.5 $ms^{-1}$)

Large increase in difference in buoyancy between moist and dry parcels ($\overline{B}_{diff}$)




## Lapse-Rate Mechanism?

(Kirshbaum and Smith 2009)

1) Moist anomalies (clouds, precip.) cools moist-adiabatically and dry air cools dry-adiabatically

2) Moist air gains buoyancy relative to dry air = **rapid growth in snow-producing updrafts**

# CONCLUSIONS

## No-Terrain

- **Band**: land breezes → convergence → cold-pool
  - Intense, localized precipitation
- **Cellular**: grow in size, strength, and height
  - Widespread, light precipitation. Enhancement inland

Gowan, T.M., W.J. Steenburgh, and J.R. Minder, 2020: Downstream Evolution and Coastal-to-Inland Transition of Landfalling Lake-Effect Systems. *Mon. Wea. Rev.* **(in prep).**

## Terrain

- **500-m peak:** enhancement largely explained by decrease in sub-cloud sublimation
- **2000-m ridgeline:**
  - **Band:** strong cold-pool induced blocking (OR = 0.88)
  - **Cellular:** strong enhancement (OR = 9.19) possibly due to lapse-rate mechanism