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Evaluating the Influence of Ice Microphysics on an Idealized Simulation of Orographic Precipitation

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- CM1 used to simulate idealized flow over a bell-shaped mountain for dry, warm-rain only, and ice microphysics simulations for different initial parameters
- Addition of moisture lessens wave breaking and weakens downslope winds and winds aloft where clouds develop
- Addition of ice microphysics produces similar flow structures, but less precipitation, and contributes to cloud dehydration
- Future work will involve sensitivity experiments exploring the effects of perturbing ice microphysics parameters

Project Objectives

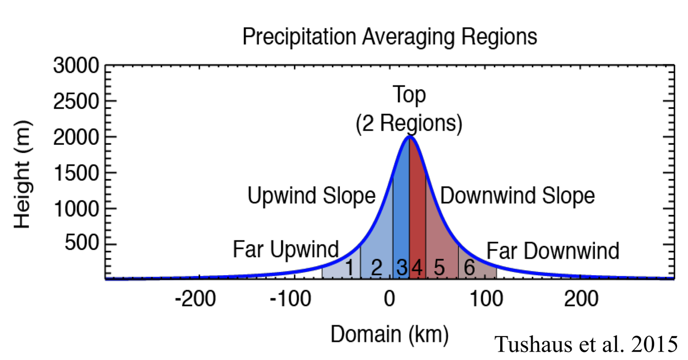
- Understanding sensitivity to ice microphysics in orographic precipitation events
  - ➢ Addition/modification of ice processes has been shown to impact surface precipitation (Colle and Zeng 2004; Stoelinga et al. 2003)
- Starting with moist neutral flow over bell-shaped mountain
  - ➢ Moist neutral conditions common in producing heavy rain during non-convective events
  - ➢ Following the work of Miglietta and Rotunno 2005, 2006
    - Found non-linear dependence of simulated rainfall to model parameters, such as mountain geometry and ice microphysics

What is the sensitivity of dynamical structures and surface precipitation to the addition of ice microphysics?

CM1 Model Configuration

CM1, release 17 (Bryan and Fritsch 2002)

- Quasi-2D 10-hr simulation
- 2-km horizontal grid spacing
- 20-km domain height
- 59 vertical levels (stretched)
- Constant wind with height

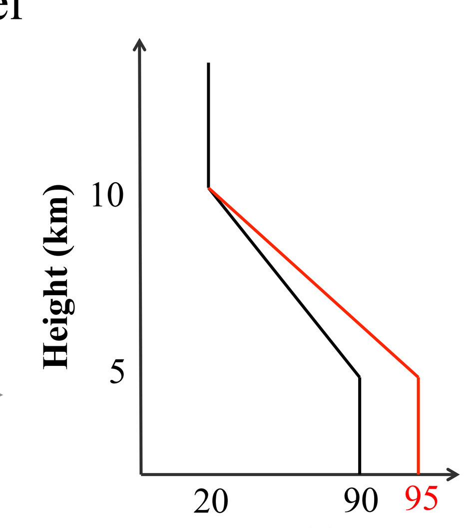


Tushaus et al. 2015

Simulations

- **Dry** – no moisture included (imoist = 0)
- **Warm-rain microphysics** – Kessler (1996) scheme
- **Ice microphysics** – NASA-Goddard version of Lin, Farley, Orville (1983; LFO) scheme
  - 3 ice species: cloud ice, snow, graupel

Initial Parameters	Case 1	Case 2
U	15 m s^{-1}	13 m s^{-1}
N^2	$1x10^{-5}$ s^{-2}	$4x10^{-5}$ s^{-2}
θ_{sfc}	288 K	292 K
$RH_{sfc-5km}$	90%	95%
H_{mtn}	2 km	2.35 km
W_{mtn}	30 km	30 km



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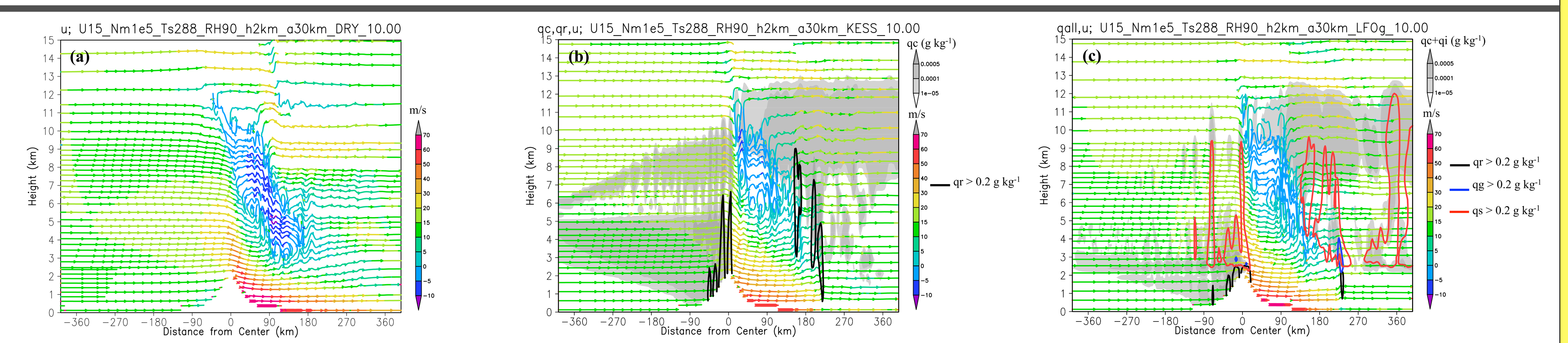
Results

Dry | **Warm-rain** | **Ice**

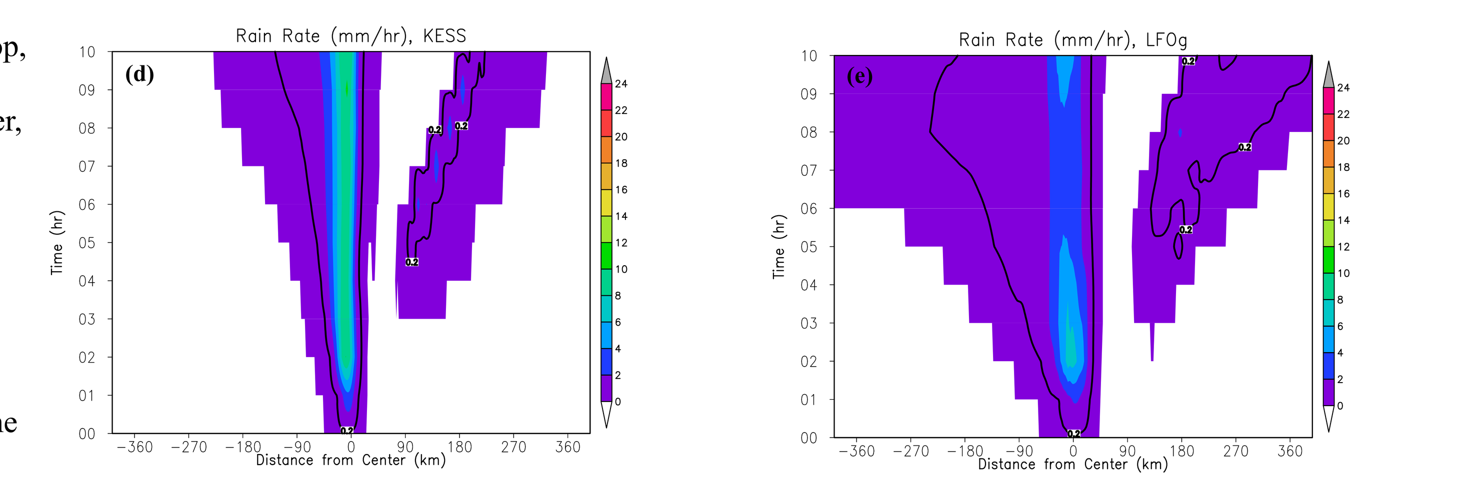
CASE 1: Strong downslope



$Fr_m = \frac{u}{Nh_m} = 2.37$ For $Fr_m > 1$, flow ascends over obstacle without upstream deceleration

(TOP) Vertical cross-sections for (a) dry run, (b) warm-rain run, and (c) ice run at hour 10: cloud water (g/kg), shaded gray contours; rain (> 0.2 g/kg), black contours; snow (> 0.2 g/kg), red contours; graupel (> 0.2 g/kg), blue contours; u- and w-direction streamlines colored by u-wind speed (m/s). All plots for Case 1 initial parameters.

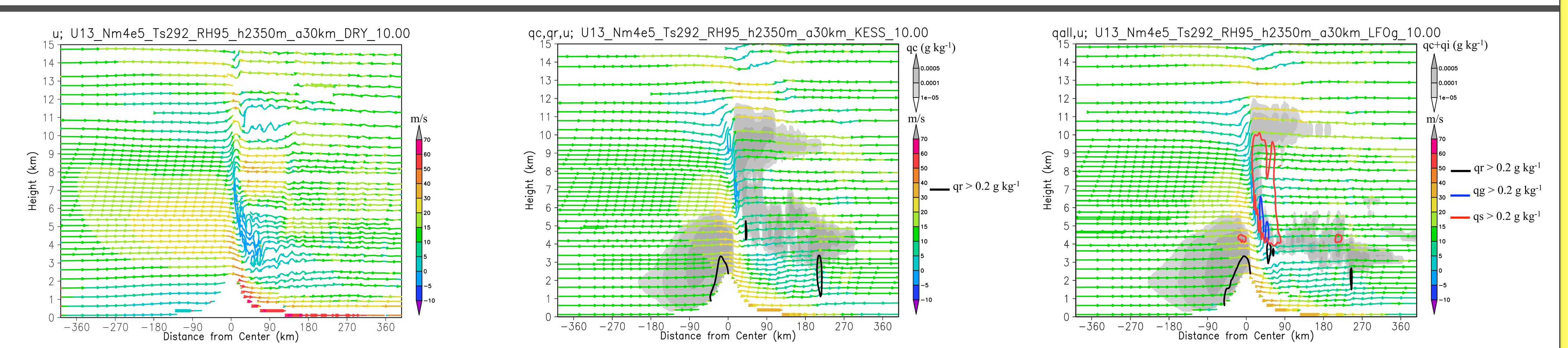
(BOTTOM) Hovmöller diagram of hourly precipitation (mm) for (d) warm-rain run, and (e) ice run. All plots for Case 1 initial parameters.



DRY to WARM-RAIN
- Downslope winds become slower above mountain top, and between 8-11 km where clouds develop
- Lee wave breaking extends farther, depth is shallower, and become weaker (less backward motions)
- Faster winds near the surface do not extend as far downstream

WARM-RAIN to ICE
- Precipitation still mainly over upwind slope
- Cloud dehydration occurs above 3 km where snow develops (especially upwind)
- Initially have similar rain rates, but weaken with time (due to cloud dehydration)

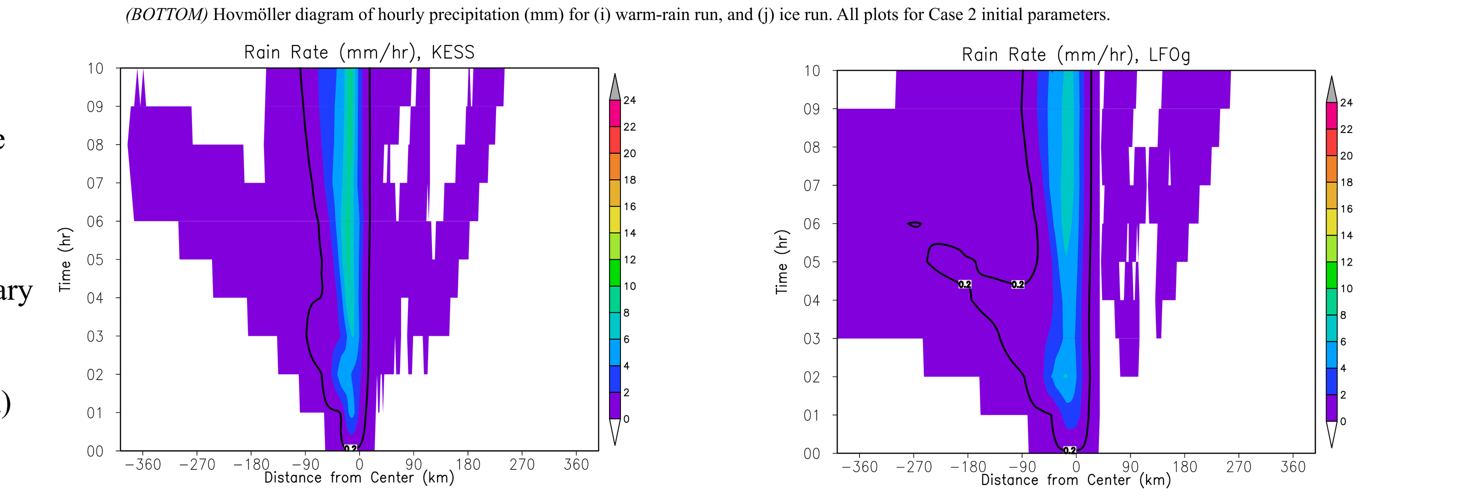
CASE 2: Weaker downslope



$Fr_m = \frac{u}{Nh_m} = 0.875$ For $Fr_m < 1$, at least some depth of flow will be blocked by obstacle

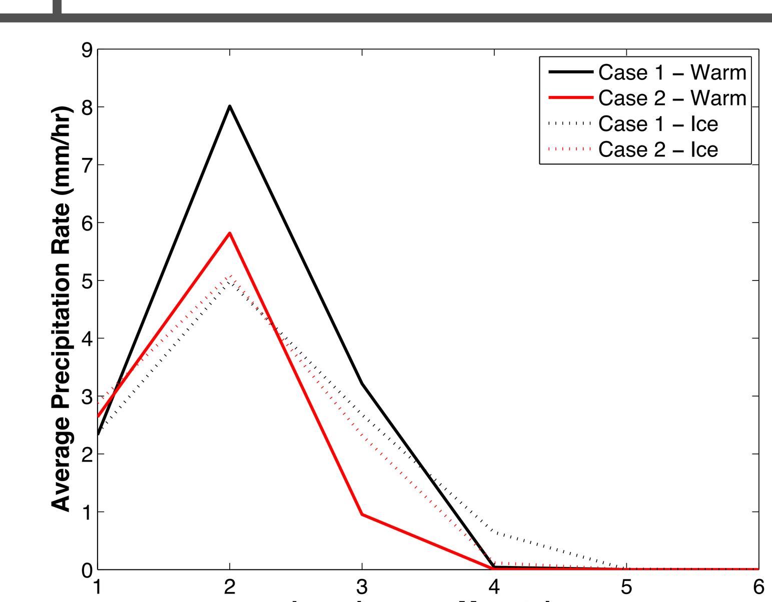
(TOP) Vertical cross-sections for (f) dry run, (g) warm-rain run, and (h) ice run at hour 10: cloud water (g/kg), shaded gray contours; rain (> 0.2 g/kg), black contours; snow (> 0.2 g/kg), red contours; graupel (> 0.2 g/kg), blue contours; u- and w-direction streamlines colored by u-wind speed (m/s). All plots for Case 2 initial parameters.

(BOTTOM) Hovmöller diagram of hourly precipitation (mm) for (i) warm-rain run, and (j) ice run. All plots for Case 2 initial parameters.



DRY to WARM-RAIN
- Much slower downslope windstorm
- Much less turbulent mid-levels, winds slowed where clouds develop 6-10 km
- Upstream winds below 2 km are slightly faster

WARM-RAIN to ICE
- Snow and graupel develop and remain fairly stationary (no downstream propagation) on lee side
- Mid-level cloud dehydrates where snow develops downwind (no impact on upwind slope precipitation)
- Rain rates are similar with time, still mainly over upwind slope



CASE 1 vs. CASE 2
- Precipitation upwind pulses with time and develops multiple narrow rain contours in Case 1
- Precipitation upwind is more steady with time and develops one main rain contour in Case 2
- Case 2 produces less precipitation in warm-rain simulation
- Average precipitation rates in ice simulations are more similar between cases
- Mid-levels are less turbulent, both upstream and downstream, in Case 2
- Case 1 snow development is substantial and propagates downstream, while in Case 2 the snow remains on lee side, above the downslope windstorm

DRY vs WARM-RAIN vs ICE
- Addition of moisture led to weaker wave breaking downwind, shallower and slower downslope windstorm, and slower winds aloft where clouds developed on the lee side
- Ice simulations produce less rain upwind than warm-rain only

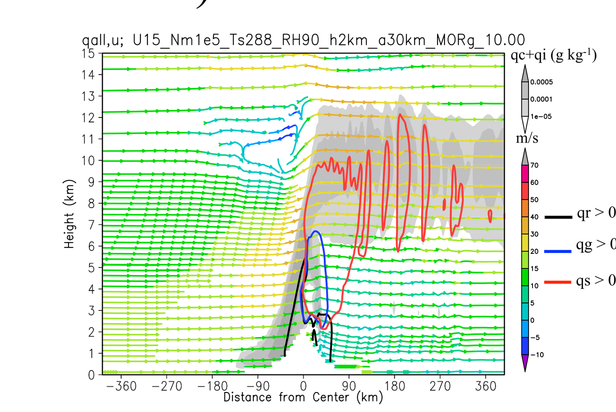
(LEFT) Average precipitation rate (mm/hr) over six locations on the mountain (1-far upwind, 2-upwind slope, 3-top upwind, 4-top downwind, 5-downwind slope, 6-far downwind) for each case (see table in Simulations section) and warm-rain (solid) vs ice simulations (dotted).

Conclusions

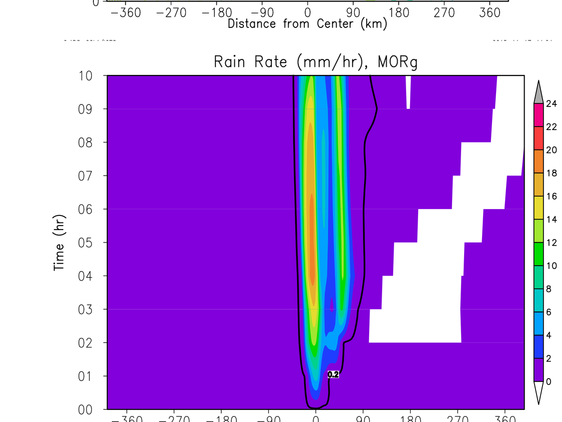
- Stronger impact on dynamics from addition of moisture (dry to warm-rain) than ice microphysics
- Addition of ice mainly acts to impact precipitation and hydrometeor development, not much impact on dynamical structures
- Bergeron-Findeisen process may be responsible for cloud dehydration in ice simulations, which can impact surface precipitation
- Similar results found when using different initial parameters

Future Work

- Use of 2-moment Morrison ice scheme (Morrison et al. 2009) produces very different results (Case 1 results shown here, similar Case 2 results not shown)



➢ Laminar flow downstream, no downslope windstorm



➢ Double-peaked precipitation spatial distribution

Future Work will include:
- Understanding substantial differences between LFO and MOR schemes
- Systematic exploration of sensitivities to ice parameter perturbation (Tushaus et al. (2015) have already looked at thermodynamic parameters and mountain geometry)
  - Will changes to microphysics have effect of similar magnitude?

Acknowledgements

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