A scaling of orographic precipitation for both stratiform and convective clouds

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Motivation

- A number of analytical models have been proposed to quantify stratiform orographic precipitation
  - Jiang and Smith (2003)

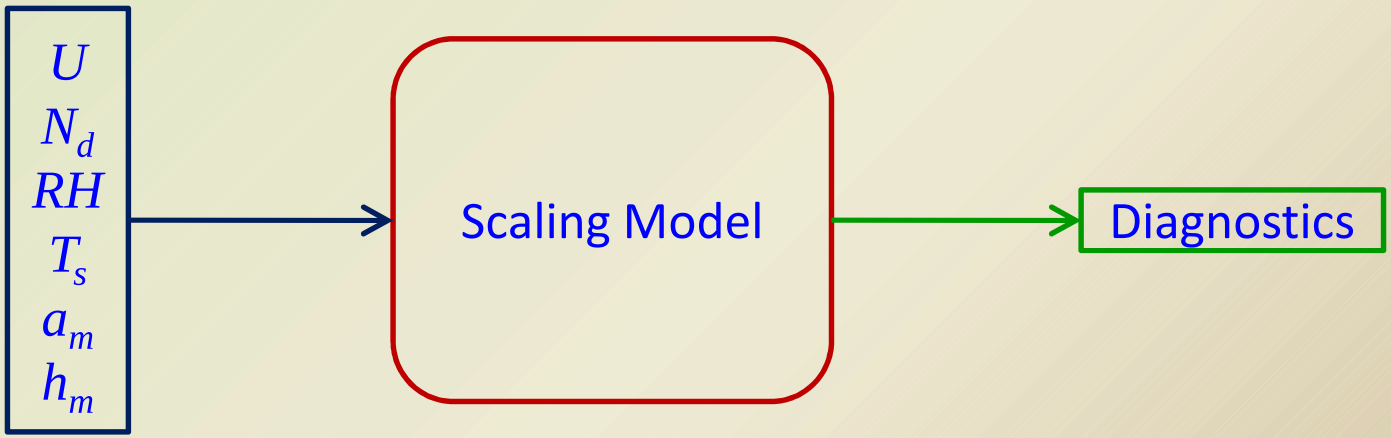
    Box model for precipitation efficiency including linear and non-linear accretion
  - Smith and Barstad (2004)

    Linear theory predicting condensation, precipitation and downslope evaporation for complex terrain
  - Kunz and Kottmeier (2006)

    Diagnostic model with linear dynamics and simple parameterisations for hydrometeor drifting, evaporation and repeated uplift

Objective

- Currently no analytical model exists to quantify the impact of embedded convection on orographic precipitation
  - Complex dynamics, microphysics and the effects of mixing
- Create a simple scaling for orographic precipitation, valid for both laminar and (mountain-forced) convective flow



Diagnostics

- Quantify in terms of:
  - Incident water flux (I)
  - Condensation rate (C)
  - Precipitate formation rate (F)
  - Surface precipitation rate (P)

- Condensation Ratio $CR = C / I$

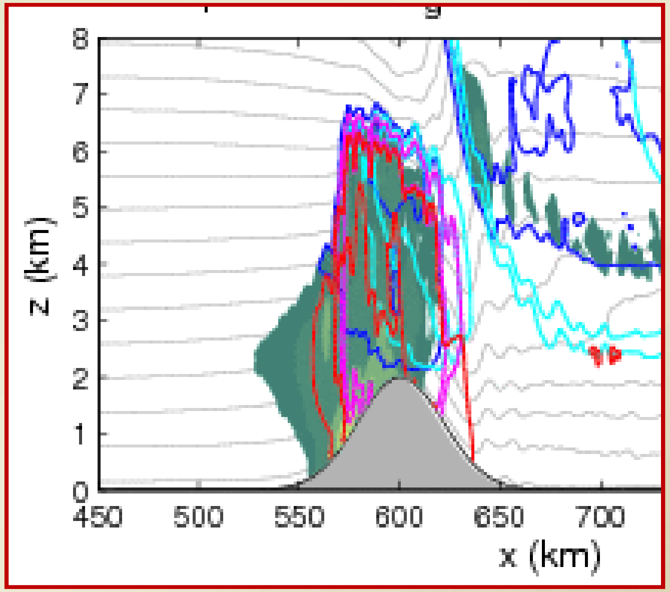
- Precipitation Efficiency $PE = P / C$

- Drying Ratio $DR = P / I \quad = CR \times PE$

Simulations

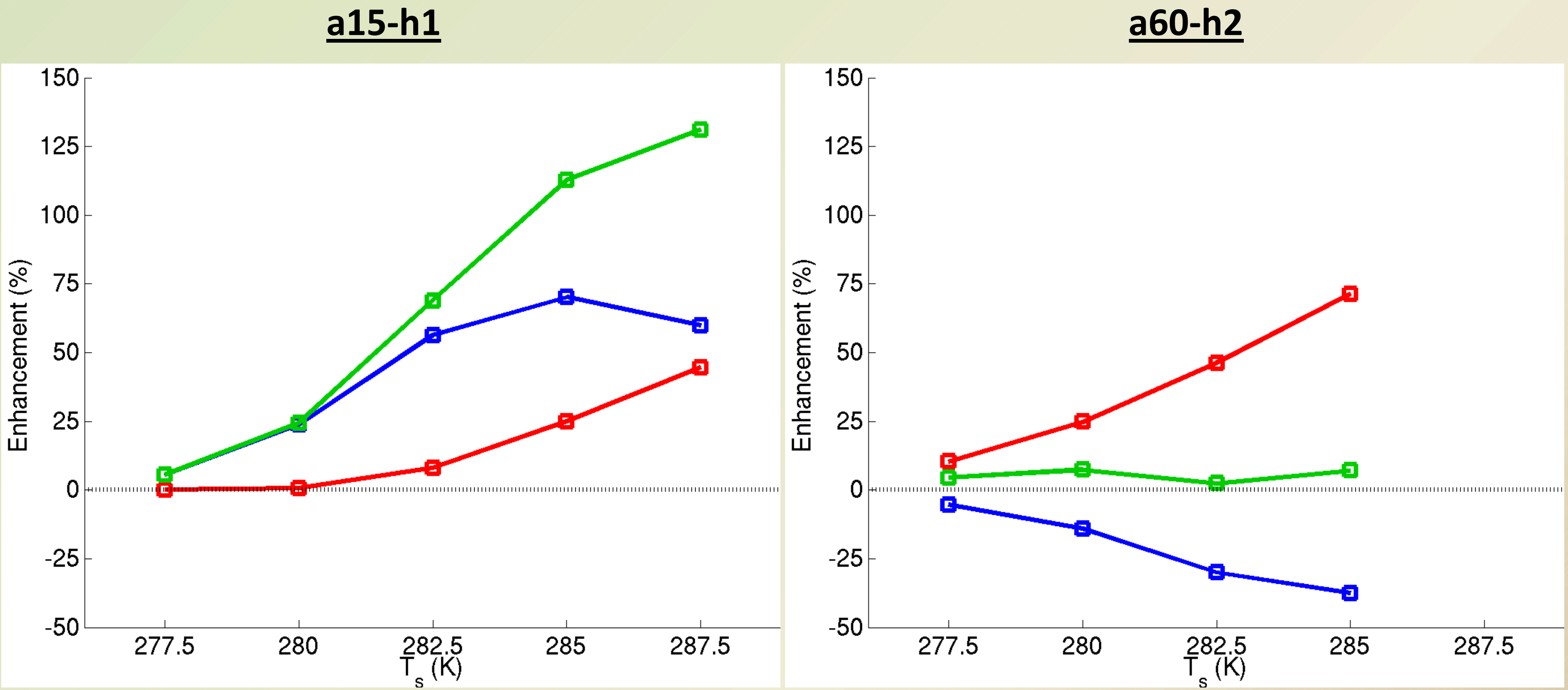
- Performed idealised simulations using WRF (Cannon *et. al.,* 2011, submitted)

  – Stability varied via surface temperature
  T_s = 277.5 – 287.5 K
  – 2D Gaussian orography ("infinite ridge")
  h_m = (1, 2) km
  a_m = (15, 30, 60) km



- 2 simulation suites:
  – 3D "Convection-permitting" simulations with 1 km horizontal grid
  – 2D "Laminar" simulations with suppressed convection

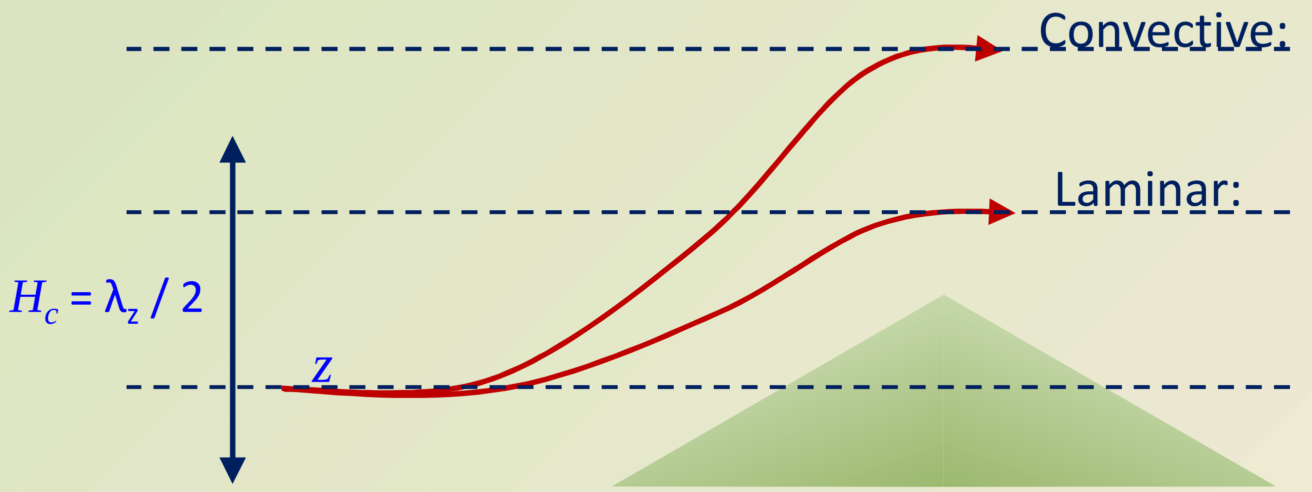
Relative enhancement



Condensation ratio ($CR = C/I$) Precipitation Efficiency ($PE = P/C$)

Drying Ratio ($DR = P/I = CR \times PE$)

Scaling: Condensation Ratio



$z_{lift} = LNB(z) + f(h_m)$

$z_{lift} = z + f(h_m)$

$$C = U \int_0^{H_c} [\Delta \rho_v]_z^{z_{lift}} \, dz$$

$$CR = \mu_{lam} CR_{lam} + \mu_{conv} CR_{conv}$$

$$\tau_{adv} = \frac{a_c}{U} \qquad \tau_{conv} = \frac{LNB(0)}{0.2\sqrt{CAPE(0)}}$$

$$\mu_{lam} = \frac{1}{1 + \frac{\tau_{adv}}{\tau_{conv}}} \qquad \mu_{conv} = \frac{1}{1 + \frac{\tau_{conv}}{\tau_{adv}}}$$

Scaling: Precipitation Efficiency

- General formulation based on a steady state cloud (e.g. Jiang and Smith, 2003)

$$\frac{d\rho_c}{dt} = C - F - \frac{\rho_c}{\tau_{adv}} \approx 0$$

$$\frac{d\rho_p}{dt} = F - \rho_p \left(\frac{1}{\tau_{adv}} + \frac{1}{\tau_{sed}} \right) \approx 0$$

- Solved to find,

$$PE = \left(\frac{F}{C} \right) \left(\frac{1}{1 + \frac{\tau_{sed}}{\tau_{adv}}} \right) = \underbrace{FE}_{\text{Formation efficiency } (F/C)} \times \underbrace{SE}_{\text{Sedimentation efficiency } (P/F)}$$

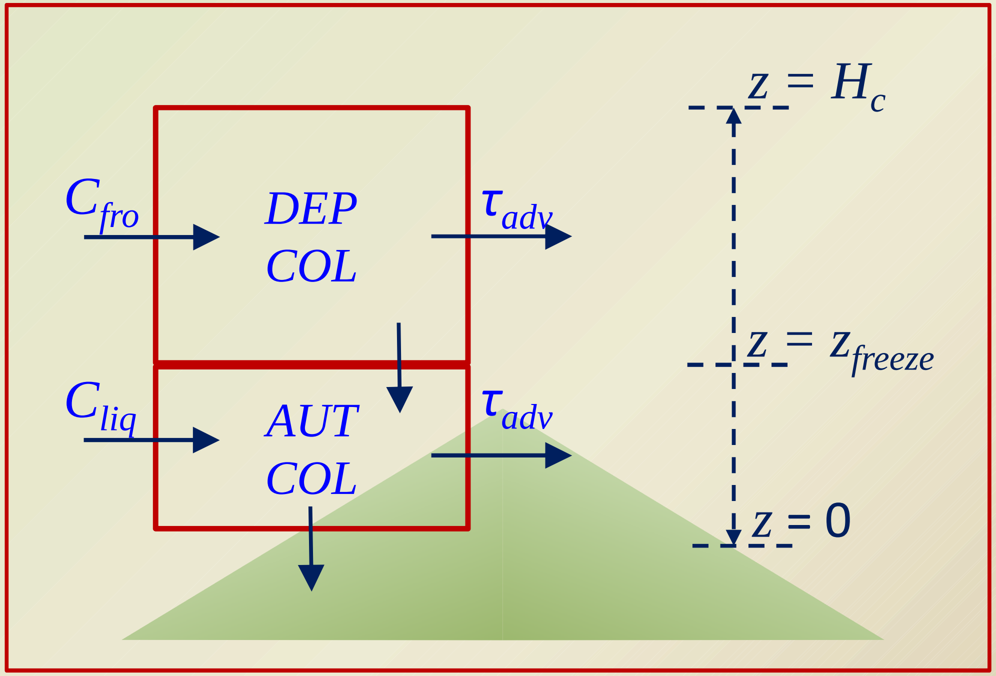
Formation efficiency (F/C)

Sedimentation efficiency (P/F)

Scaling: Precipitation Efficiency

Laminar flow

$$FE_{lam} = \frac{AUT + COL + DEP}{C_{lam}}$$



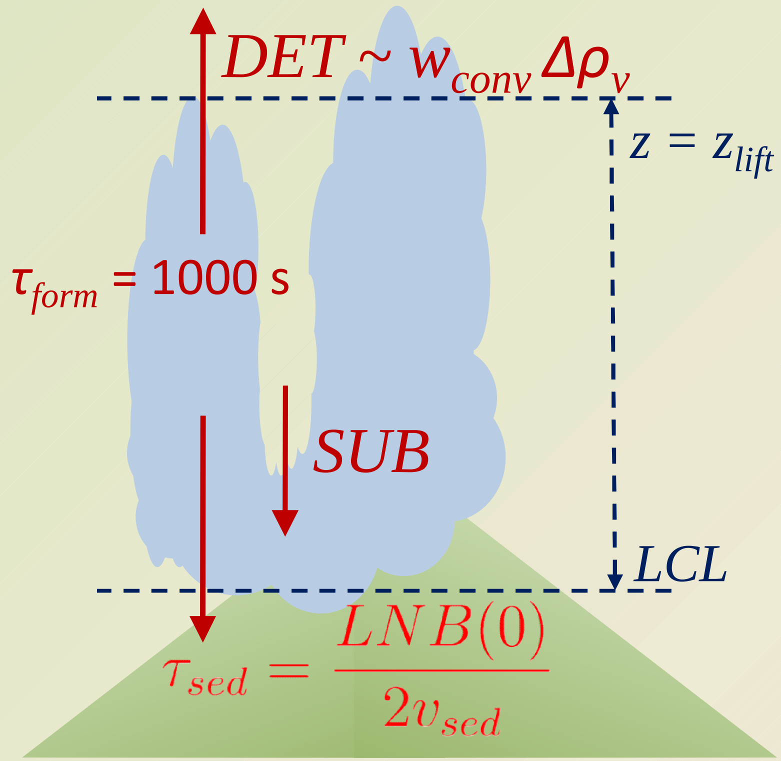
- $\tau_{sed} = \frac{H_{\rho_v}}{\overline{v}_{sed}}$

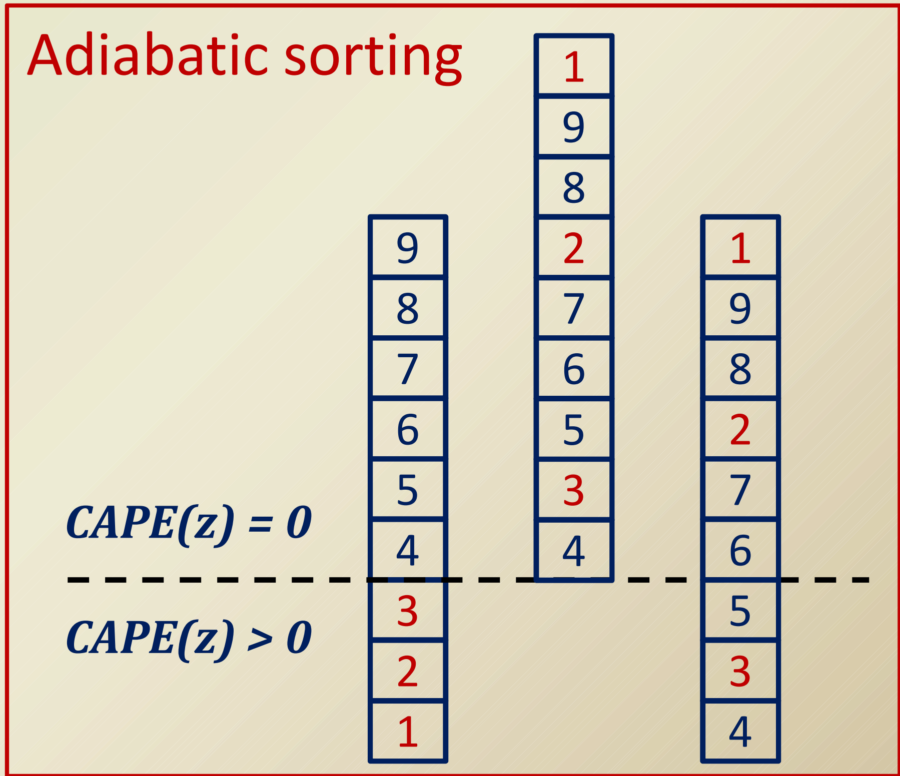
- Formation rates calculated using simple microphysical relations (e.g. Rogers and Yau, 1989)
  - "Collection efficiency" of 25 % used to tune the collection rate
- Marshall-Palmer size distribution assumed for snow (upper layer) and rain (lower layer)

Scaling: Precipitation Efficiency

Convective flow

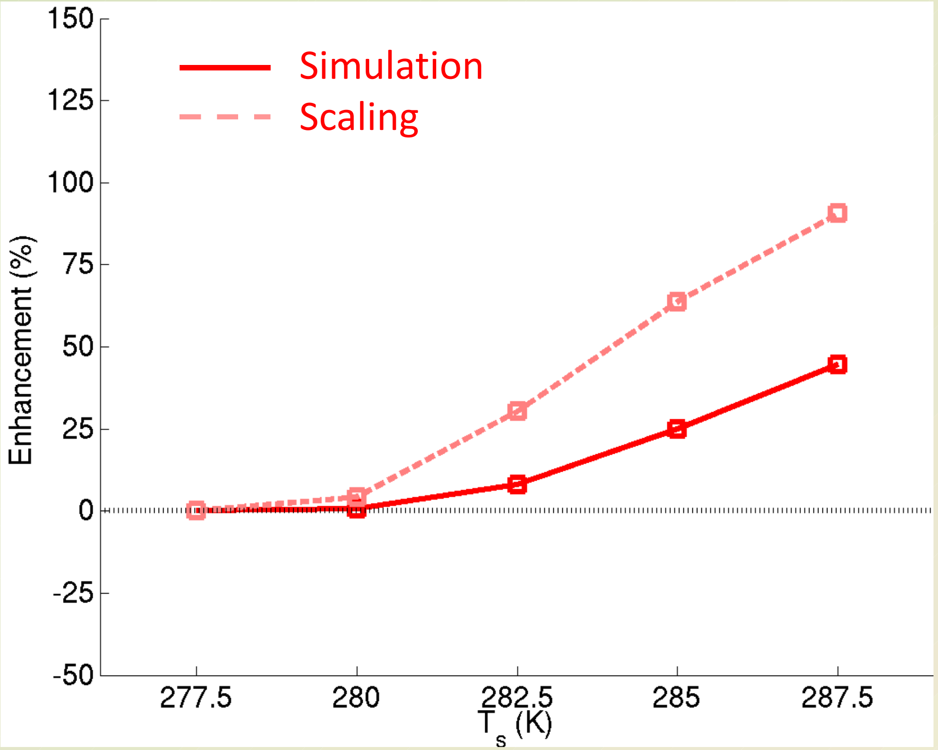
$$PE_{conv} = \left(1 - \frac{DET}{C_{conv}} - \frac{SUB}{C_{conv}}\right)\left(1 + \frac{\tau_{form}}{\tau_{adv}}\right)^{-1}\left(1 + \frac{\tau_{sed}}{\tau_{adv}}\right)^{-1}$$



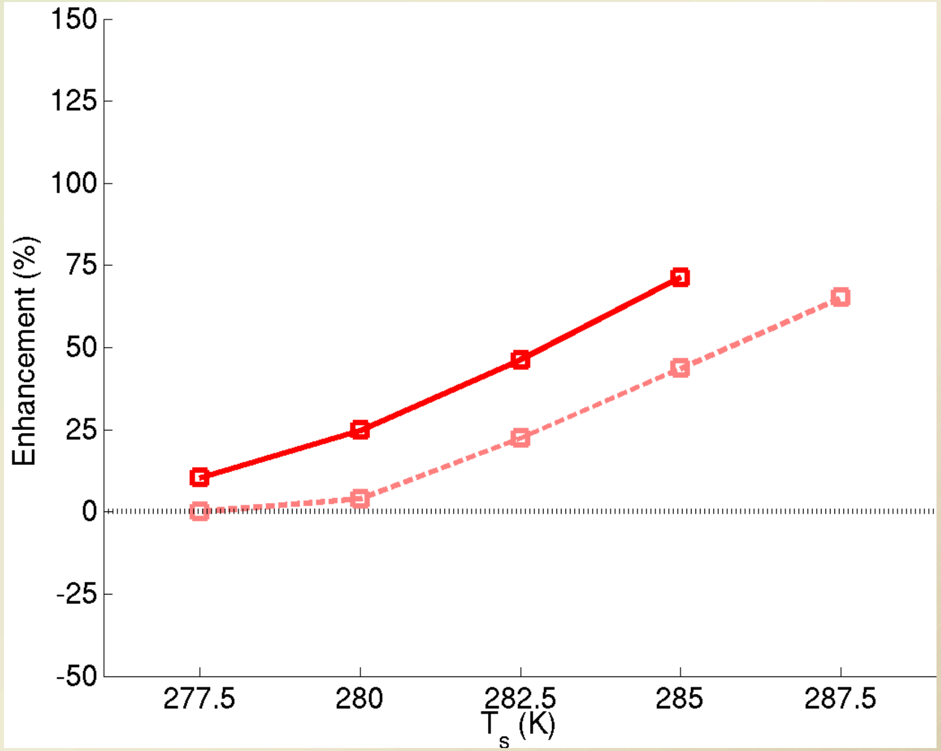


Relative enhancement

a15-h1



a60-h2



Condensation ratio ($CR = C/I$)   Precipitation Efficiency ($PE = P/C$)

Drying Ratio ($DR = P/I = CR \times PE$)

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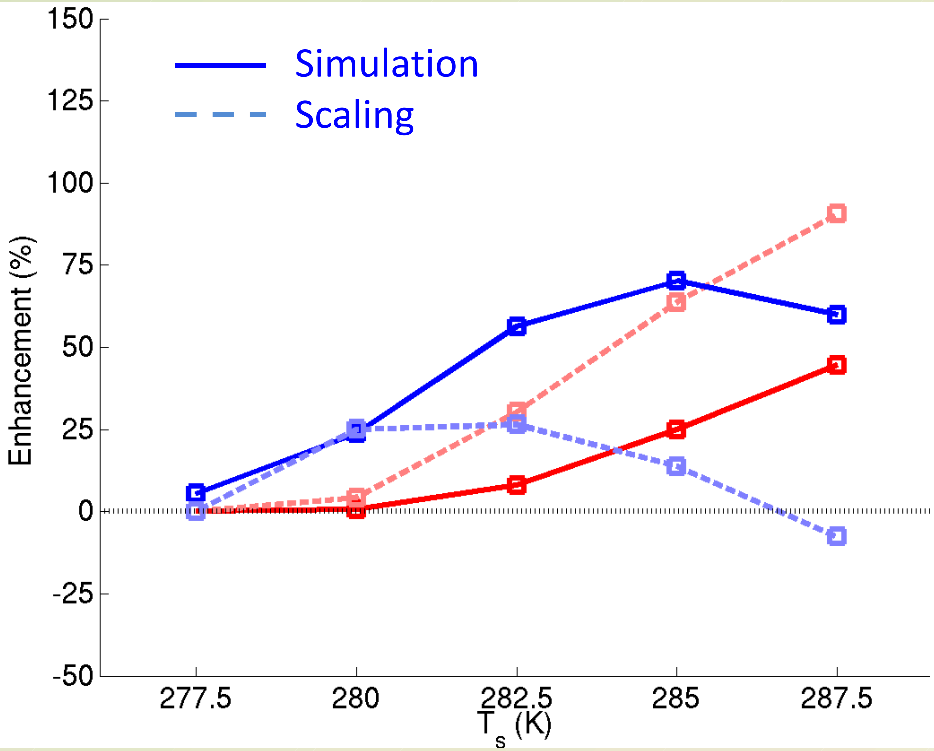

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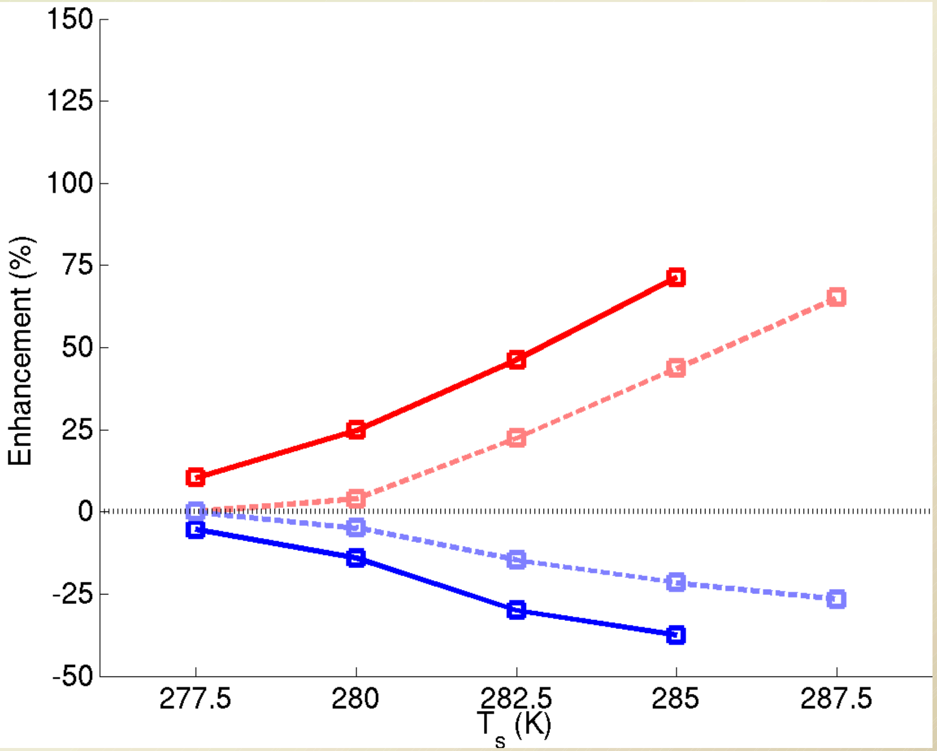

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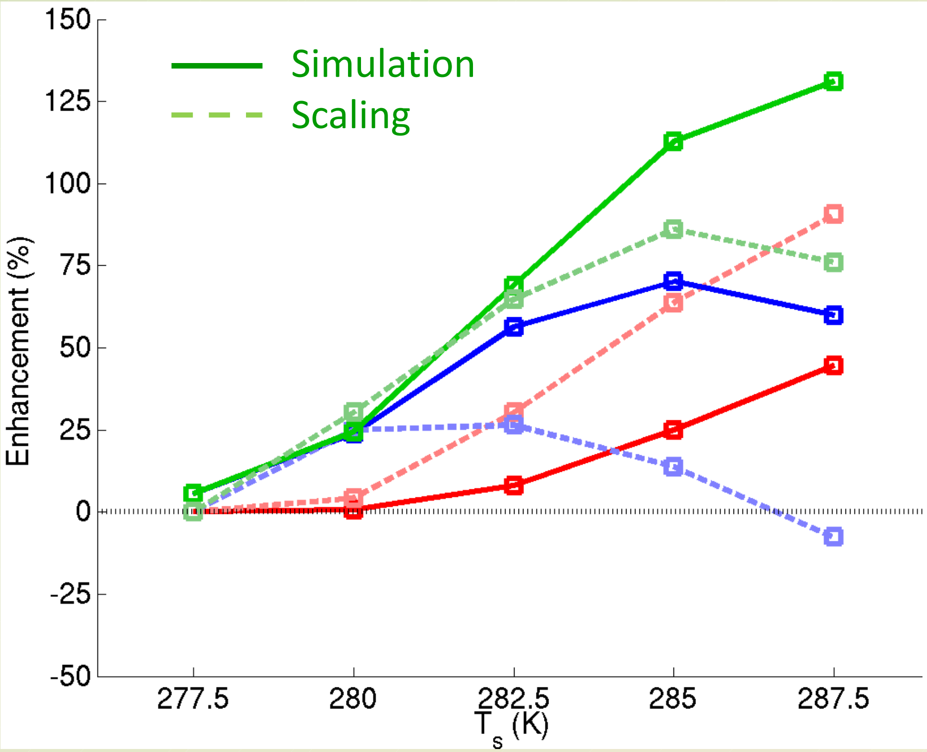

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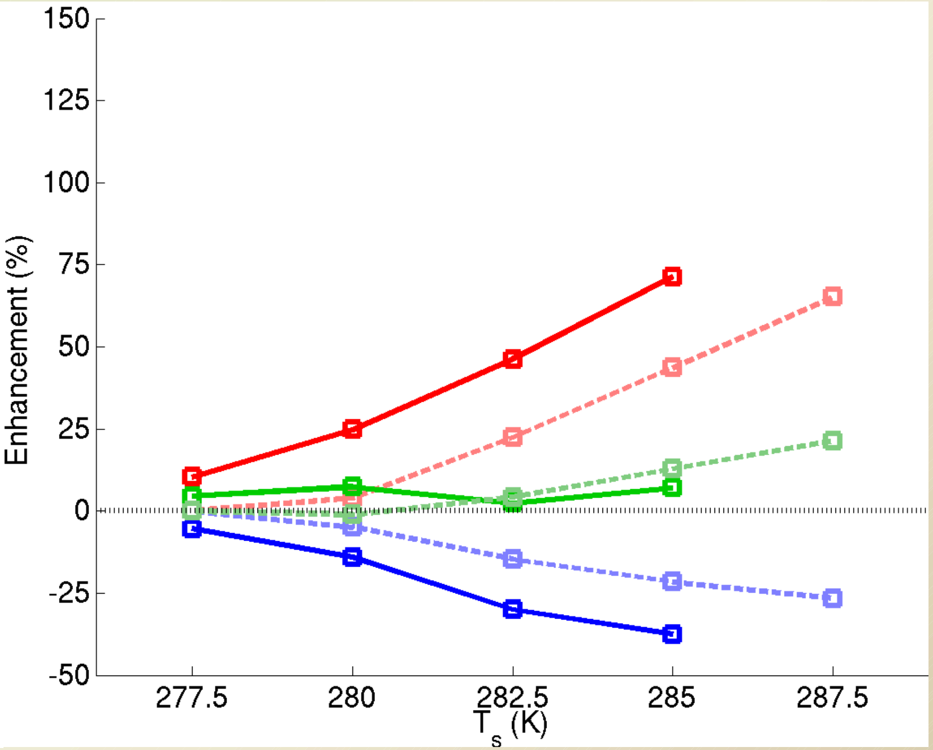

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Conclusions

- We have developed a simple scaling for orographic precipitation, for both stable and conditionally unstable incident flow
- The scaling results were tested against the simulations of Cannon *et. al.* (2011, submitted)
  - Dependencies of CR reproduced
  - Dependence of PE on stability and mountain height reproduced
  - Fails to reproduce the lack of PE enhancement over low and wide mountains
- We seek to further develop this model through
  - Comparison to real cases
  - Increased sophistication of microphysics