Pseudo Seeder-feeder Mechanism in Orographic Precipitation in a Typhoon Environment and its Response to Global Warming

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Introduction

- A tropical cyclone (TC) can produce heavy rainfall indirectly through the interaction between its circulation with mountain ranges (Wang et al. 2009).
- When a steep mountain range intersects with TC circulation, the environmental conditions featuring strong surface wind, moist air, and low static stability are consistent with empirical conditions favoring the occurrence of intense orographic precipitation (Lin et al. 1998).
- Few studies investigated how this orographic precipitation might respond to global warming because it computationally expensive to simulate the entire TC with high resolution Large eddy simulation method while it is intrinsically uncertain using low resolution simulations with cumulus parameterization.
- In this study, instead of simulating an entire TC, we only simulate a small patch area in outer typhoon environment by using a large-eddy simulation (LES) method.
- This aim of this study is to estimate the global warming-induced change in the precipitation near an idealized mountain in a TC environment by assuming Pseudo global warming.

Method

LES method

- Large eddy simulation (LES) of wind profiles in the boundary Layer of Tropical Cyclones developed by Bryan et. al (2017).
- Use simple inputs: radius, gradient wind, and the radial gradient of gradient wind.
- The input profiles are derived from WRF simulations of Typhoon Vicente 2012.
- An idealized bell-shaped mountain is inserted to the middle of domain with half width: 10 km, maximum Height of 1 km.

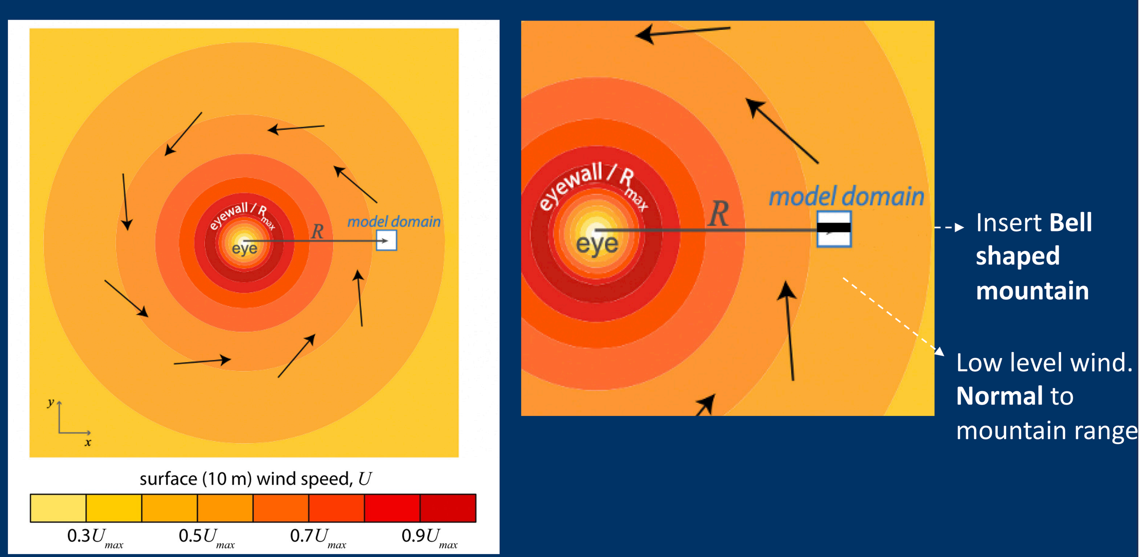


Fig. 1. The schematic plot for ideal TC adapted from Bryan et. al (2017)

Pseudo global warming

- Add on temperature changes predicted by the CMIP6 SSP 585.
- Three climate scenario are considered:
  - Present climate (no pseudo warming is applied)
  - Mid-term future (2050-2060)
  - Long-term future (2090-2100)

Model setup

- Cloud model 1
- The horizontal grid: 200 m , the vertical grid size: 150 m
- Model domain 51.2 km (x) * 102.4 km (y)* 30km(z)
- Thompson microphysics scheme
- Periodic boundary conditions in both x and y

Results

Precipitation distribution

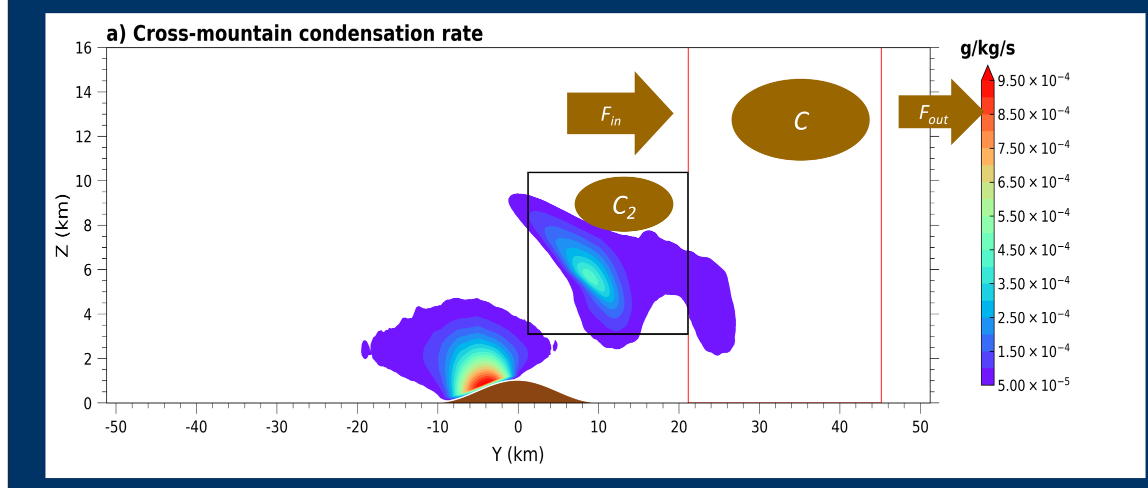


Fig. 2. The zonal and temporal mean of the sum of condensation and deposition rate

- Two cloud centers, one is over upslope of the mountain induced by the forced lifting of mountain.
- Another is the Lee cloud (induced by mountain waves)

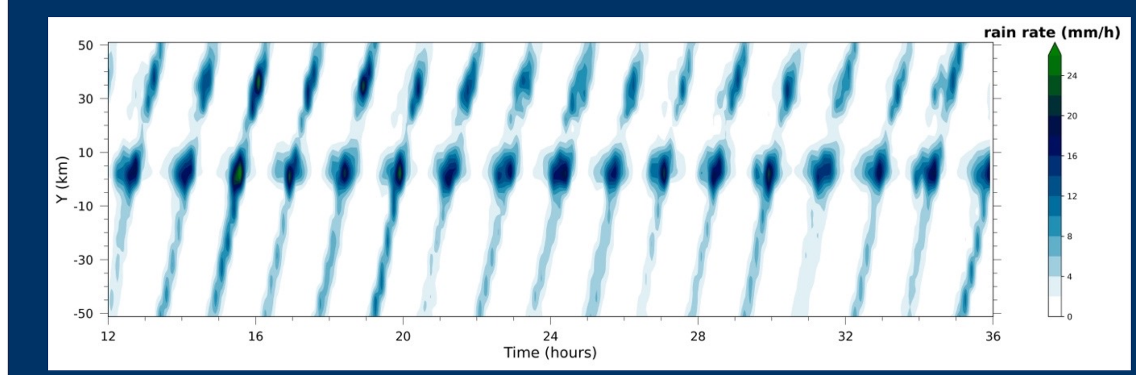


Fig. 3. Hovmöller diagram of the surface precipitation (averaged over x direction)

- The surface precipitation is mainly caused by the travelling precipitation system.
- The precipitation system is enhanced in two regions. One is over the mountain, the other is in the downstream.

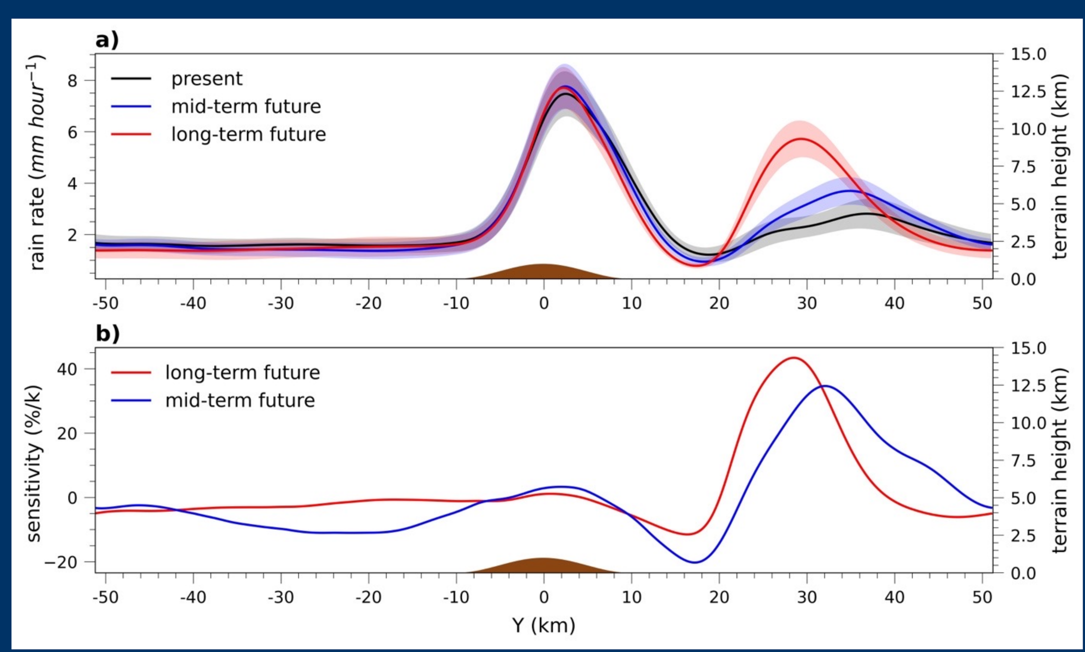


Fig. 4. a) The zonal and temporal mean precipitation distribution in the simulations of present, mid-term future, and long-term future climate. (b) the corresponding precipitation sensitivity distribution of mid-term future and long-term future climate in (a).

- First precipitation maximum is related to the traditional seeder feeder effects.
  - Seeder is the traveling convective systems
  - Feeder is the upslope cloud
- Second precipitation maximum is related to Pseudo seeder-feeder mechanism.
  - Seeder is the lee cloud.
  - Feeder is the low-level clouds in traveling convective system

- Under global warming, the first precipitation peak exhibit minimum change, while the second precipitation peak intensify and shift upwind towards mountain

High downstream precipitation sensitivity

Budget analysis in Figure 2:

$$F_{net}+C_{net}\approx \mathrm{P}$$

$$F_{net}=\mathrm{F_{out}}-\mathrm{F_{in}}$$

redefine the precipitation efficiency.

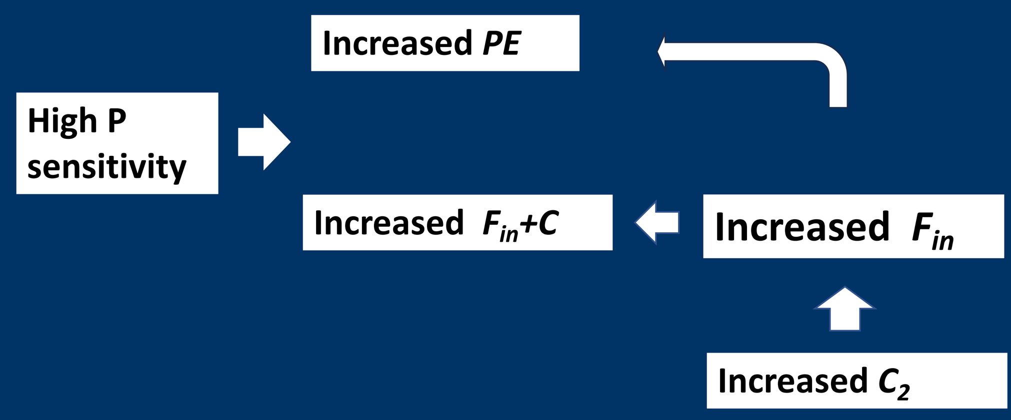
$$PE=\frac{P}{C+F_{in}}$$

Partition the high precipitation sensitivity

$$\frac{1}{P}\frac{\partial P}{\partial T_s}=\frac{\partial lnP}{\partial T_s}$$

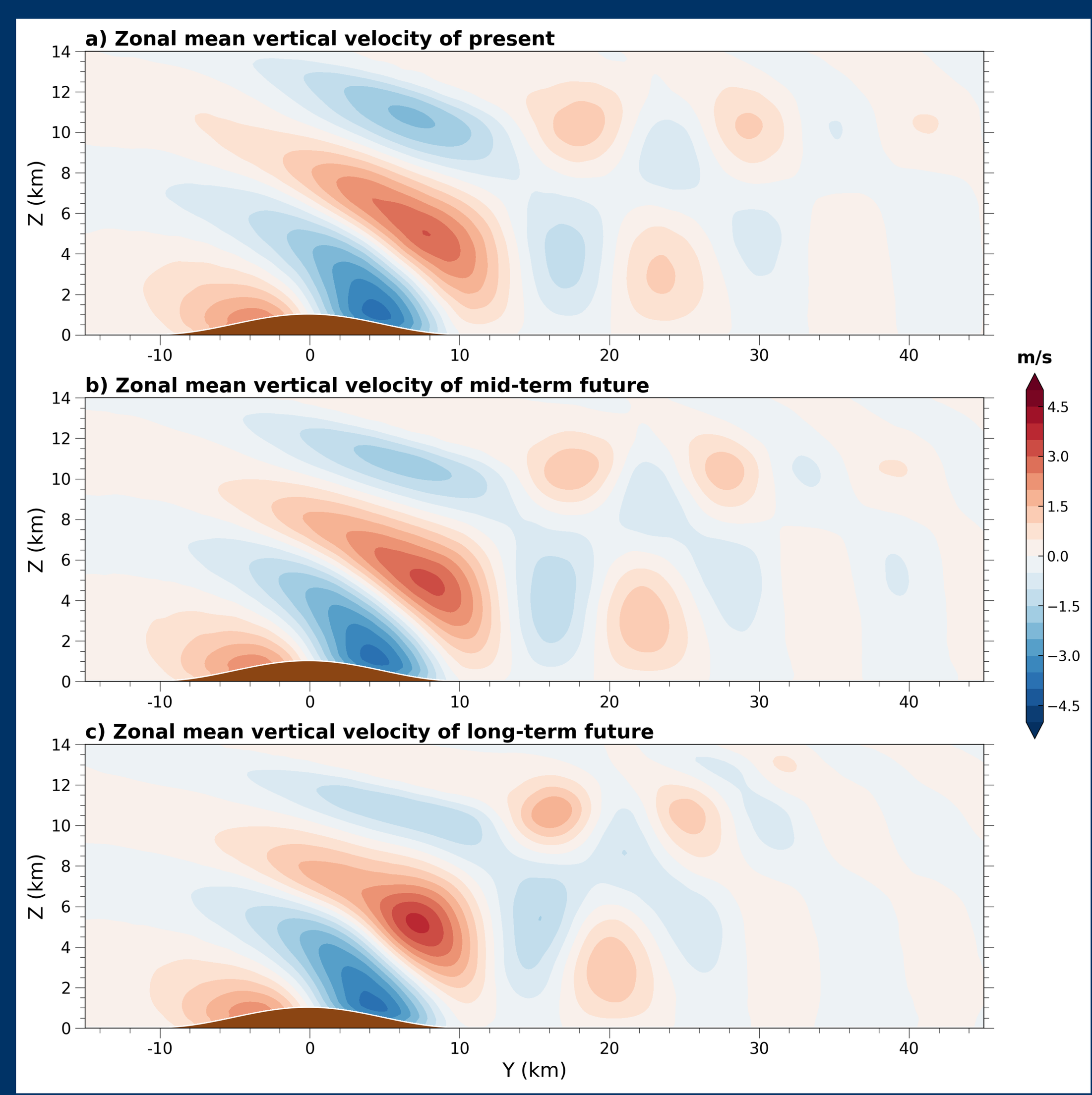
$$=\frac{\partial \ln(\mathrm{PE}\cdot(C+F_{in}))}{\partial \mathrm{T_s}}=\frac{\partial ln(C+F_{in})}{\partial T_s}+\frac{\partial \ln(\mathrm{PE})}{\partial T_s}$$

$$=\frac{\partial(\mathrm{PE})}{\mathrm{PE}\,\partial T_s}+\frac{\partial(C+F_{in})}{(C+F_{in})\,\partial T_s}$$



- Condensation change can be decomposed into the dynamic contribution related to Δw and thermodynamic contribution related to ΔT.
- The lee condensation change is further decomposed into thermodynamic contribution (~ 80%) and dynamic contribution (~ 10%)

The role of trapped lee wave



Fug. 5. The zonal and temporal mean of vertical velocities of simulations of the climate of the present (a), mid-term (b), and long-term future (c)

- The upwind shift of the second precipitation peak is related to upwind shift of the mean wave pattern, specifically, the trapped lee wave.
- The upshift of trapped lee wave is due to the wavelength decrease under global warming in which the mid-layer atmospheric stability increases and tropopause are elevated.

Conclusions

- Two regions exhibit enhanced precipitation, one over the mountain and the other in the downstream region 25 to 45 km away from the mountain.
- The enhanced precipitation in both regions is related to the seeder-feeder mechanism. The enhancement in the downstream regions is different from the conventional definition and is referred as pseudo-seeder-feeder mechanism (PSF).
- Under warming, the over-mountain precipitation maximum exhibits minimal changes, while the downstream precipitation maximum exhibits a large sensitivity of 18 % K-1.
- The large sensitivity in the downstream region is mainly due to the strengthening of mountain wave induced lee cloud which acts to amplify the PSF and supply more hydrometeors downstream.
- The upwind shift of downstream precipitation peak is related to wavelength decrease of trapped lee wave .

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