Impact of transported dust aerosols on precipitation over the central Himalayas using convection permitting WRF-Chem Simulation

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Abstract

A substantial amount of dust aerosol was transported to the central Himalayas during the multiple dust storm event that occurred from 12 to 15 June 2018 in the Thar desert, northwestern India. In this study, we implemented a cloud-resolving Weather Research and Forecasting model coupled with chemistry (WRF-Chem) to assess the impact of transported Thar-related dust aerosols on precipitation processes over the central Himalayas. We isolated the effect of the transported dust on the precipitation distribution by zeroing out dust aerosols from lateral boundary condition and keeping other species of aerosols. Results show the noticeable impacts of transported dust aerosols on regional precipitation and cloud properties over the central Himalayas. When transported dust is included, spatially averaged (25°N-31°N and 78°E-89°E) AOD increases by 0.36. Over the Himalayas foothills with the dust, precipitation is enhanced by 7.5% (0.63mm), while surface temperature is reduced. The presence of mineral dust aerosols increased the cloud droplets and ice crystal number concentration, which is further facilitated by the mountainous terrain by orographic lifting, leading to enhanced precipitation. We diagnosed the role of cloud microphysics and that of the cloud dynamics in the simulated precipitation sensitivity. This study highlights the effect of remote dust aerosol on the perturbation of cloud microphysical properties, which can significantly influence precipitation over the Himalayas and impact the regional hydrology.

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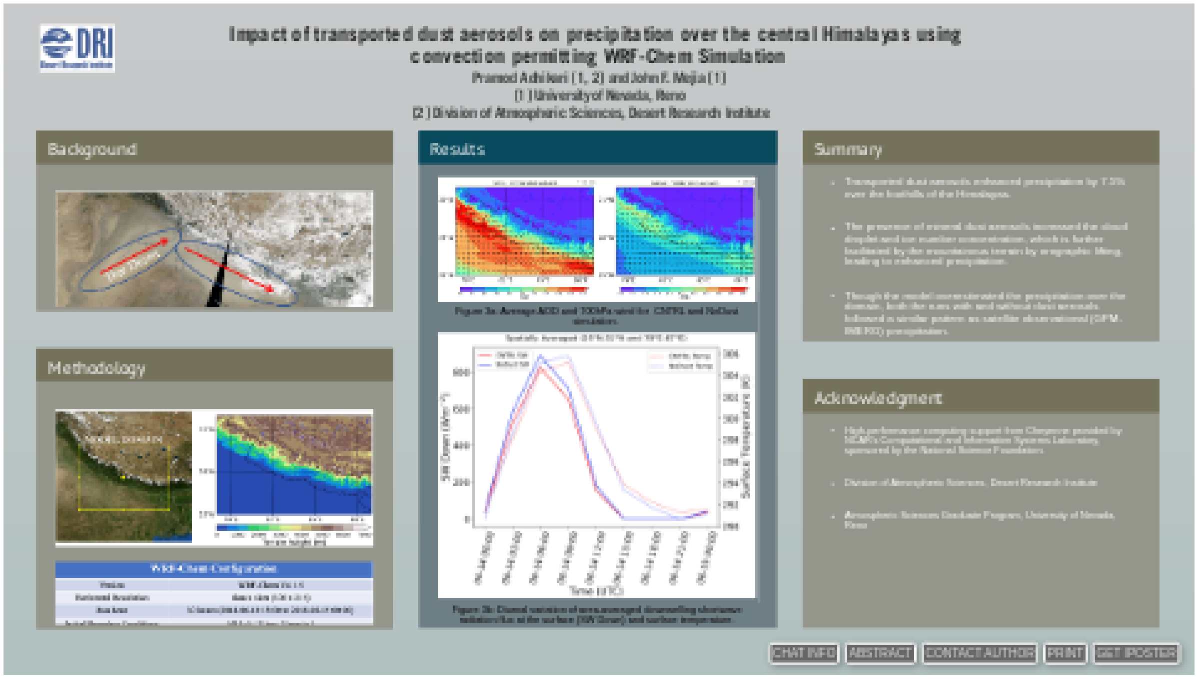

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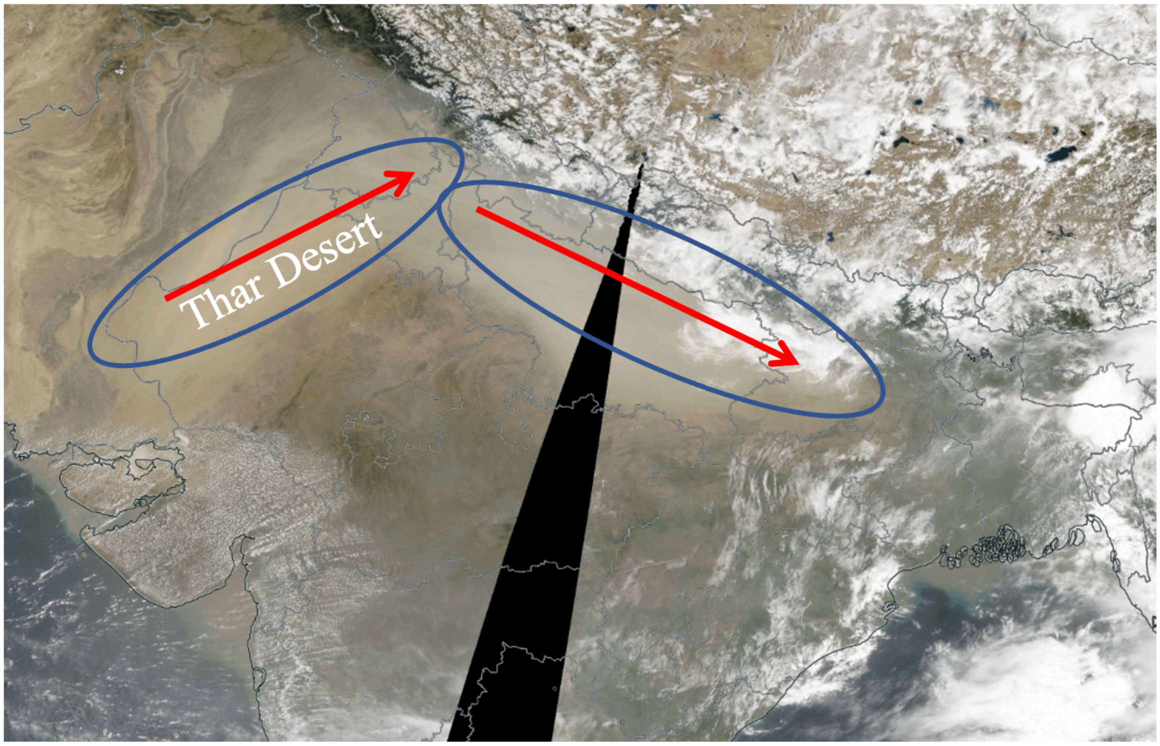
BACKGROUND



Dust plume observed from MODIS-Terra on 14th June 2018

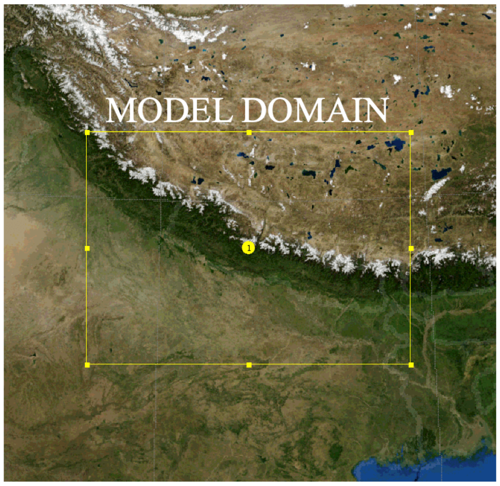
- Dust storm event peaks during the pre-and early monsoon season over the Arabian peninsula and northwestern India and transport a large amount of dust towards Himalayan foothills impacting the air quality and human health.

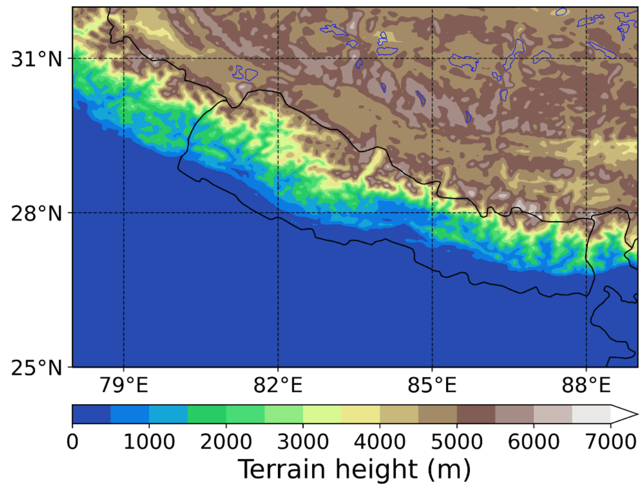
- Also, remote dust aerosols act both as cloud condensation nuclei and ice nucleating particles and influence the cloud microphysical process and hence the monsoonal precipitation [1].

- A substantial amount of dust aerosol was transported to the central Himalayas during the dust storm outbreak that occurred from 12 to 15 June 2018 in the Thar desert, northwestern India [2].

- What is the simulated impact of this Thar Desert dust outbreak on the precipitating processes over the central Himalayas?

METHODOLOGY





WRF-Chem Configuration	
Version	WRF-Chem V4.1.5
Horizontal Resolution	4km x 4km (300 x 216)
Run hour	30 hours (2018-06-13:18:00 to 2018-06-15:00:00)
Initial/Boundary Conditions	ERA-5 (31km; 3 hourly)
Cloud Microphysics	Morrison 2-moment
Cumulus Scheme	Turned Off (Cloud-Resolving)
Dust Emission	GOCART
Anthropogenic and Biogenic Emissions	Not Included
Chemistry/Aerosol Mechanism	CBM-Z/MOSAIC 8-bin
Chemistry Boundary Condition	Community Atmosphere Model with Chemistry (CAM-Chem; 0.9°x1.25° horizontal resolution, 6 hourly)

CNTRL = Simulation with transported dust aerosols

Dust concentration included from the CAM-Chem

NoDust = Simulation without transported dust aerosols

Dust concentration excluded from the CAM-Chem

RESULTS

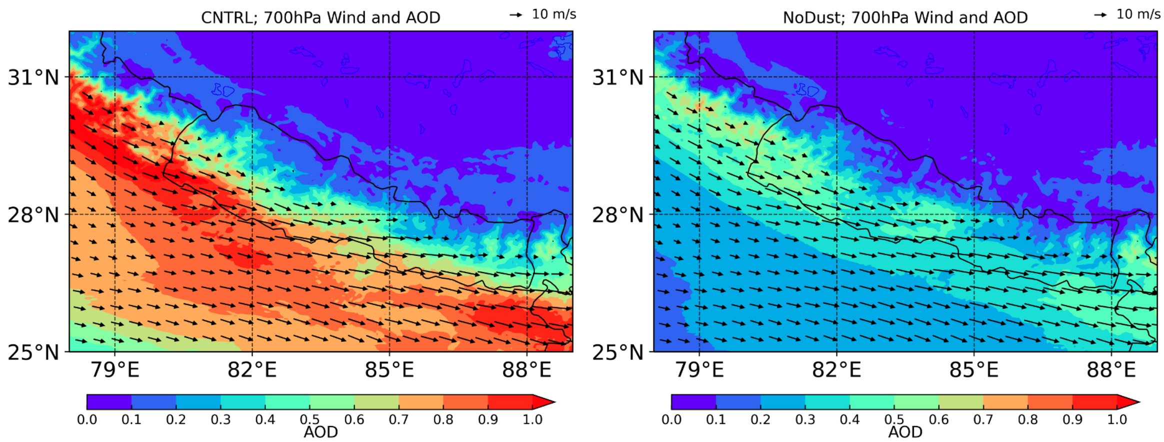


Figure 3a: Average AOD and 700hPa wind for CNTRL and NoDust simulation.

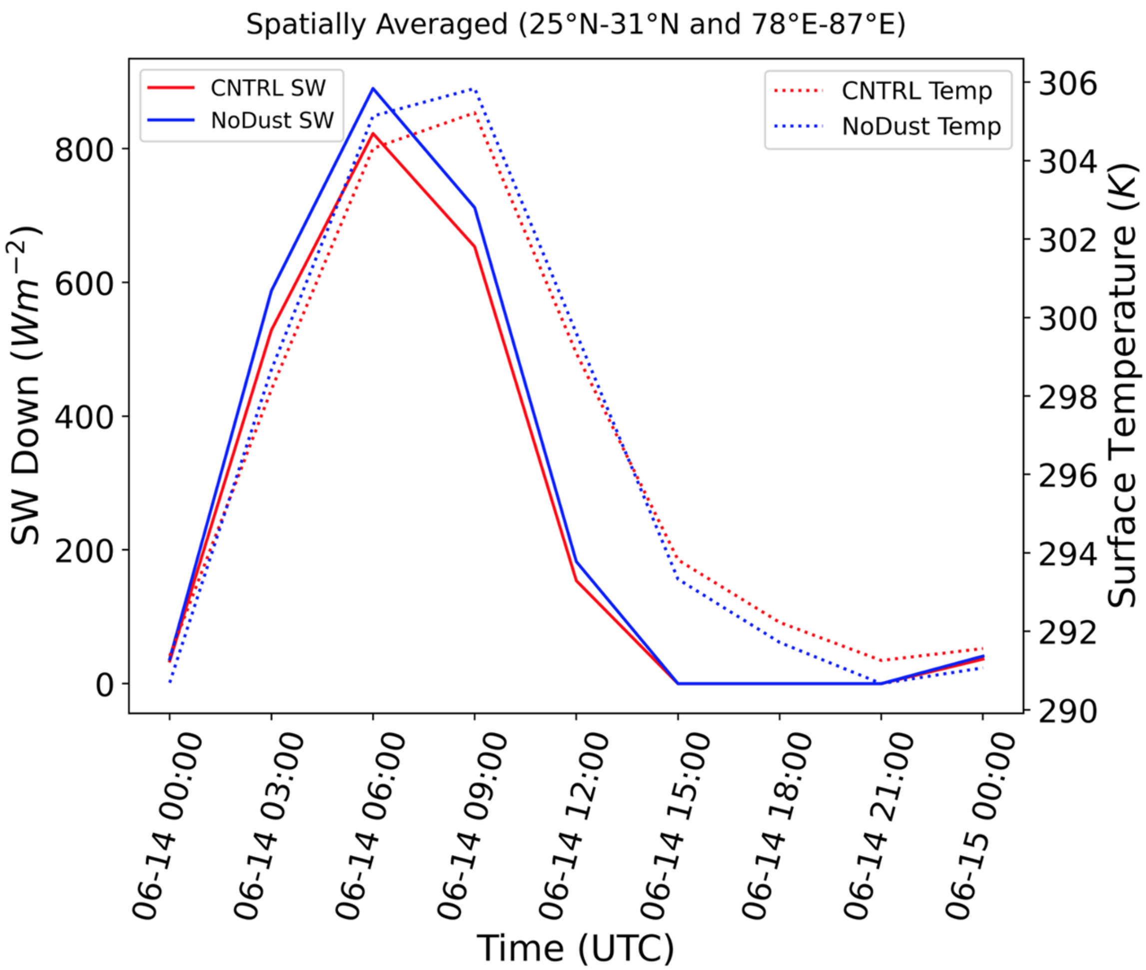


Figure 3b: Diurnal variation of area-averaged downwelling shortwave radiation flux at the surface (SW Down) and surface temperature.

- Westerly/ South-westerly wind transported dust aerosols from the remote desert to the foothills of the central Himalayas.

- Dust aerosol mostly contributed to the aerosol optical depth (AOD) differences.

- The area-averaged simulated downwelling shortwave radiation flux at the surface was reduced by 10% during the CNTRL run with dust aerosols than the run without dust, reducing the daytime surface temperature by 0.35°C.

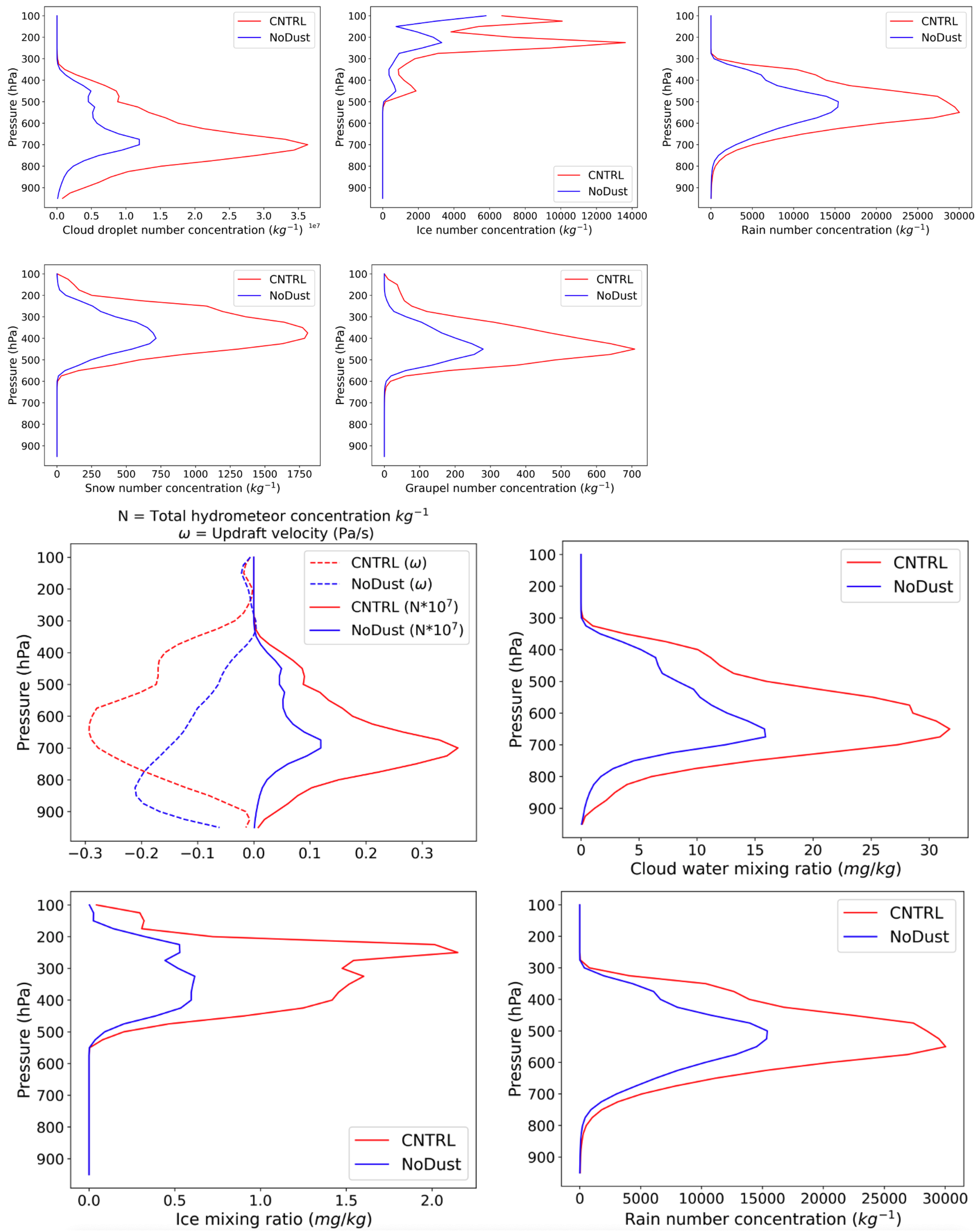


Figure 4: Vertical structure of the spatially averaged (78-87° E and 25-31°N) number concentration of cloud hydrometeors and mixing ratio at precipitating pixels.

An increase in dust aerosols enhanced the CCN activation and updraft velocity, resulting in a higher number concentration of the hydrometeors.

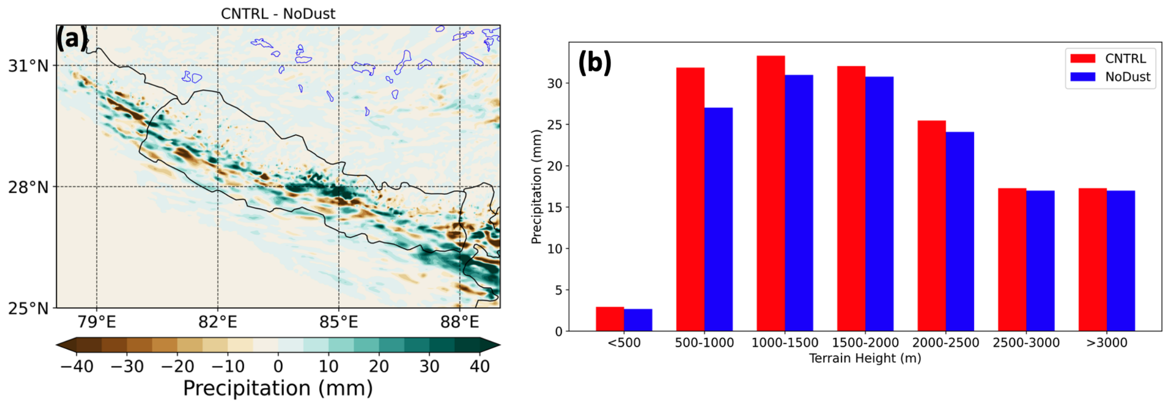


Figure 5: (a) Mean simulated precipitation differences between CNTRL and NoDust run, and (b) the spatially averaged precipitation of CNTRL and NoDust simulation for different elevations.

An increase in dust aerosols enhanced precipitation regardless of the terrain elevation. The differences in precipitation between the CNTRL and NoDust run is higher at an elevation below 2000 meters, where the dust concentration is higher. The observed precipitation pattern above 500 meters suggests orographic lifting resulted in higher precipitation.

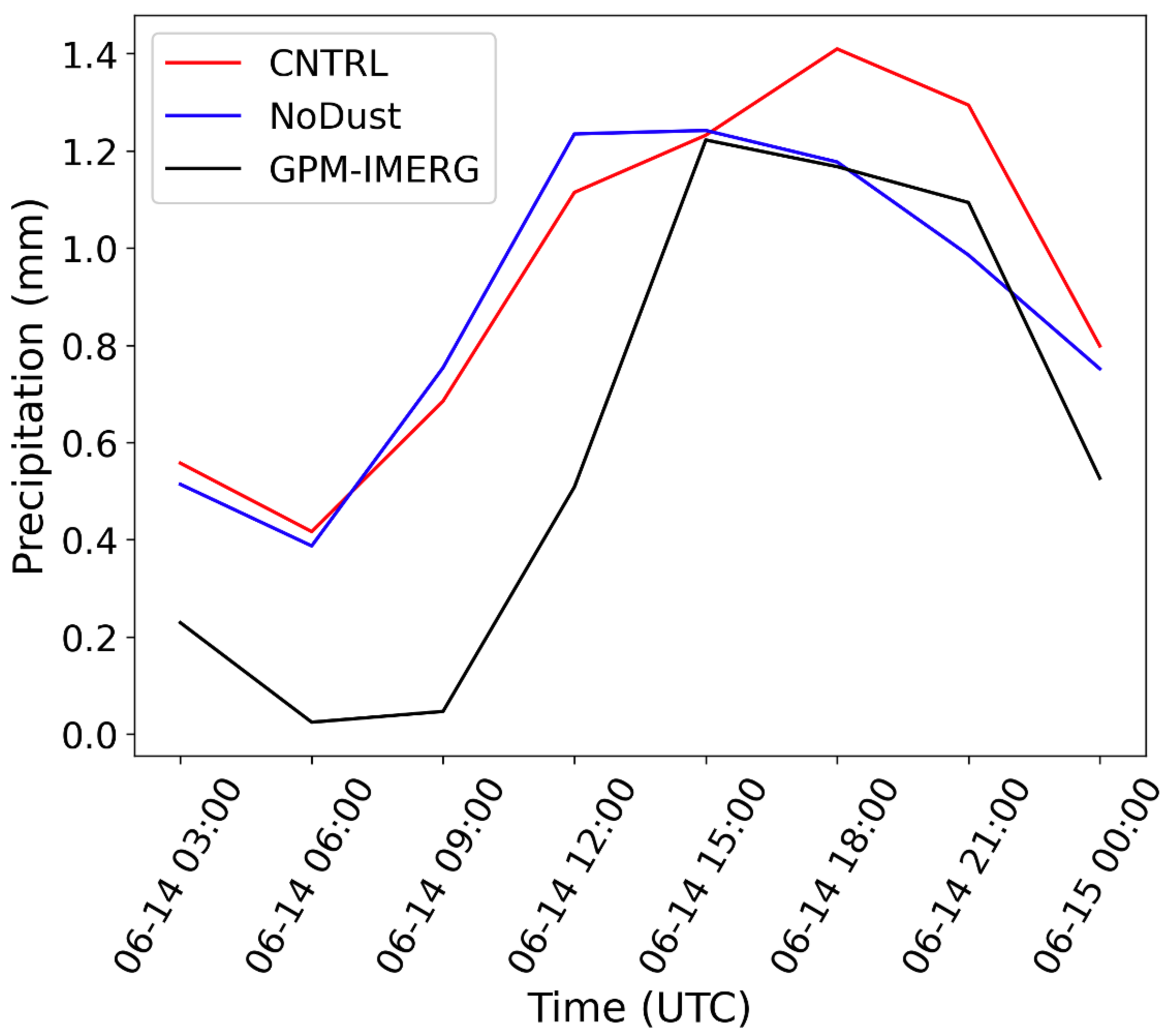


Figure 6: Comparison of model accumulated precipitation with GPM–IMERG (level 3; version 06, 30 minutes, 0.1° x 0.1°).

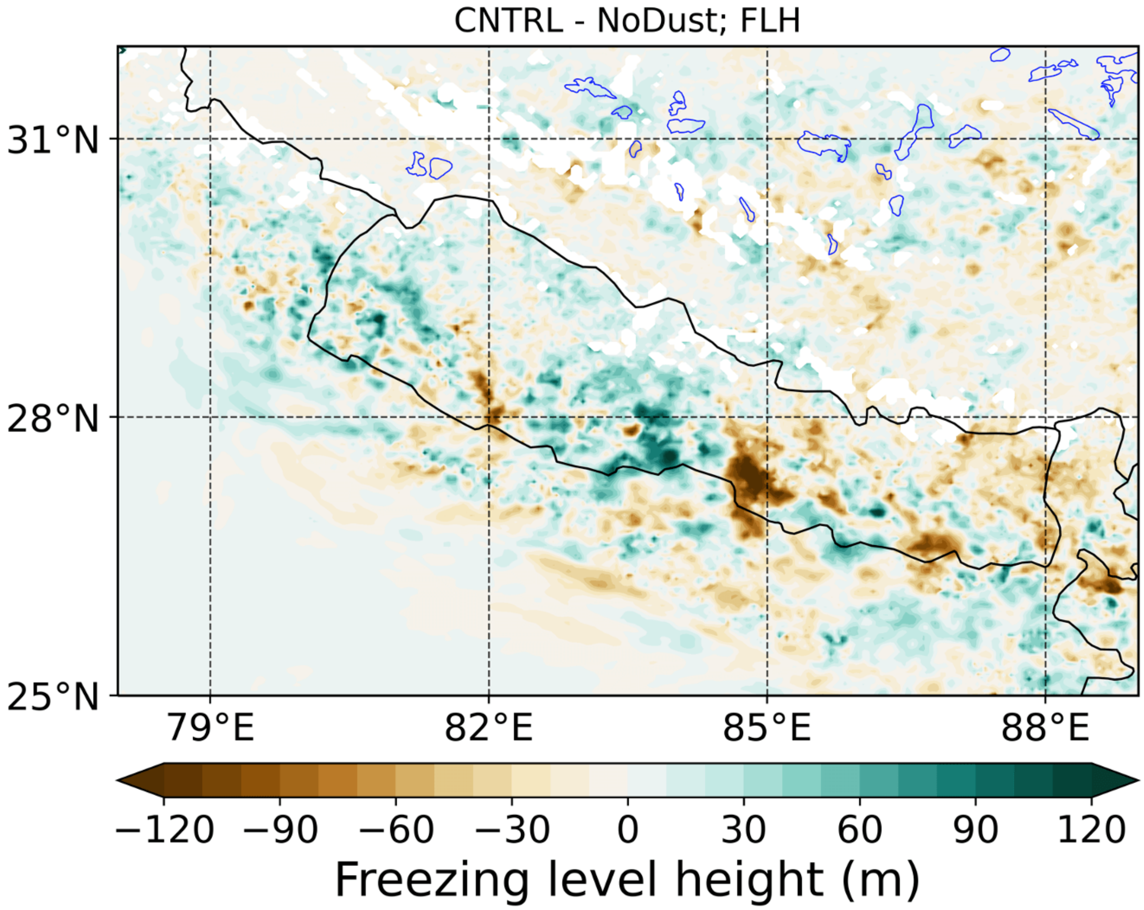


Figure 7: Comparison of Freezing Level Height between the CNTRL and NoDust run.

SUMMARY

- Transported dust aerosols enhanced precipitation by 7.5% over the foothills of the Himalayas.
- The presence of mineral dust aerosols increased the cloud droplet and ice number concentration, which is further facilitated by the mountainous terrain by orographic lifting, leading to enhanced precipitation.
- Though the model overestimated the precipitation over the domain, both the runs with and without dust aerosols followed a similar pattern as satellite observational (GPM-IMERG) precipitation.
- This study highlights the effect of remote dust aerosols on modulating the cloud microphysical properties, which can significantly influence precipitation processes over the foothills of the Himalayas.
- Simulating more number of similar case studies and isolating the radiative and microphysical interaction of dust will provide better insight in understanding the role of dust modulating the precipitation processes over the central Himalayas.

ACKNOWLEDGMENT

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- Atmospheric Sciences Graduate Program, University of Nevada, Reno

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[1] Vinoj, V., Rasch, P. J., Wang, H., Yoon, J. H., Ma, P. L., Landu, K., & Singh, B. (2014). Short-term modulation of Indian summer monsoon rainfall by West Asian dust. Nature Geoscience, 7(4), 308-313.

[2] Pokharel, A. K., Xu, T., Liu, X., & Dawadi, B. (2020). Dynamics of Muddy Rain of 15 June 2018 in Nepal. Atmosphere, 11(5), 529.