Yamaji and Takahashi, submitted

Seasonal differences of precipitation and Microphysical Characteristics over the Asian Monsoon region using spaceborne dual-frequency precipitation radar

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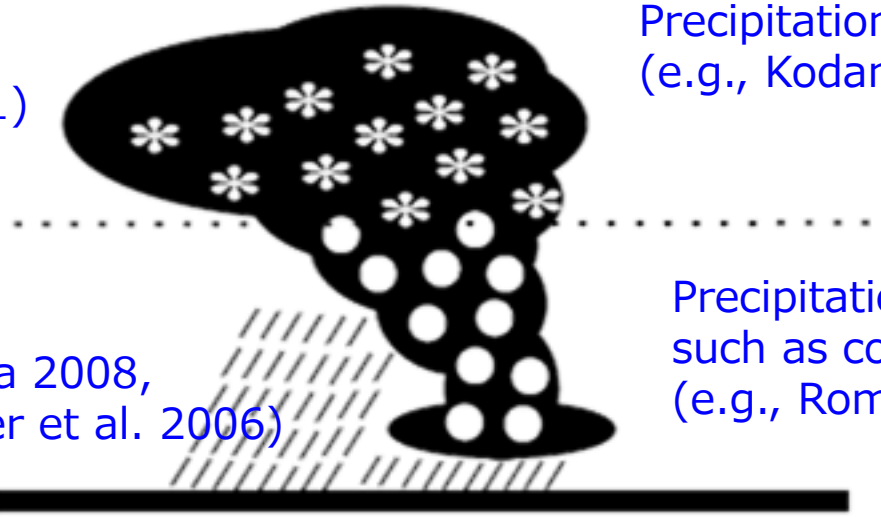
1. Introduction

- **Precipitation is one of the most essential parameters in the Earth system.**
  - Especially, the **Asian monsoon** brings abundant precipitation to densely inhabited regions, and can be a significant water resource for daily human activities.
  - The seasonal precipitation variations over the Asian monsoon region can be the most characteristic worldwide.
- **Previous studies have investigated differences in precipitation characteristics between pre-monsoon and monsoon seasons.**
  - Not only precipitation amount but also…

Size of precipitation systems
(e.g., Romatschke and Houze 2011)

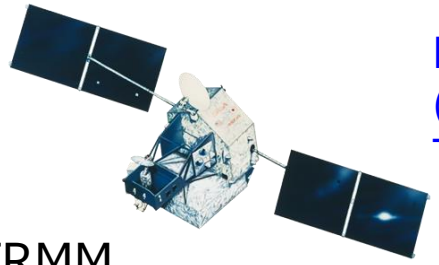
Precipitation/echo top height
(e.g., Kodama et al. 2005)



Precipitation intensity
(e.g., Islam and Uyeda 2008, Takahashi 2016, Zipser et al. 2006)

Precipitation type
such as convective or stratiform
(e.g., Romatschke et al. 2010)

(Shige et al. 2008)



TRMM
(Kumerrow et al. 1998; Kozu et al. 2001; Nakamura 2021)

1. Introduction

- In addition to such differences in the **structure of precipitation systems**, there are some studies addressing **microphysical properties** (e.g., Prabha et al. 2011, Radhakrishna et al. 2020).
  - These studies basically used in situ measurements. Differences in microphysical properties of precipitation has not yet been fully understood from a climatological and statistical perspective.
  - Recently, **GPM/DPR observation is capable of capturing precipitation microphysical quantities** (Radhakrishna et al. 2020, Yamaji et al. 2020, Ryu et al. 2020, Han et al. 2021).

Therefore, this study aims to reveal the climatological differences in precipitation microphysical characteristics between pre-monsoon and monsoon seasons over the Asian monsoon region by statistically analyzing 8 years of GPM/DPR dataset.

Size of precipitation systems
(e.g., Romatschke and Houze 2011)

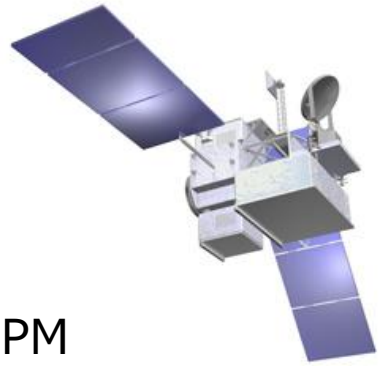
Precipitation/echo top height
(e.g., Kodama et al. 2005)

Existence of ice particles

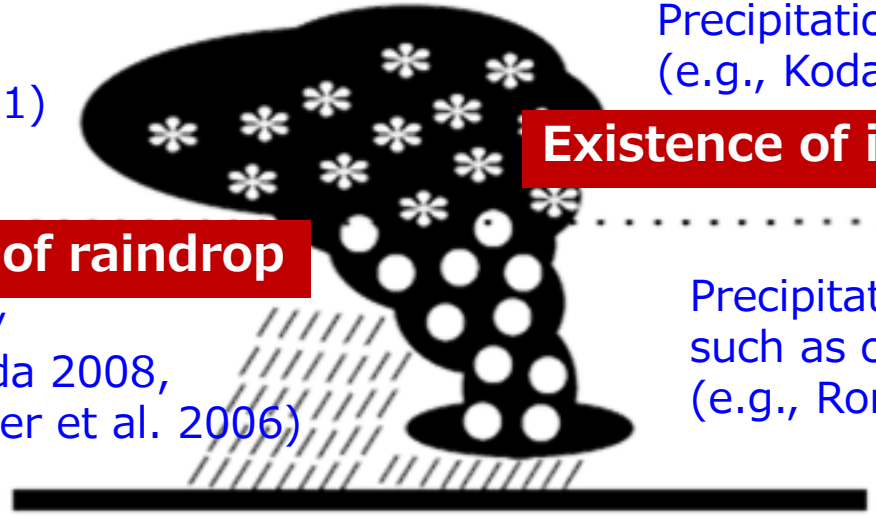
Diameter of raindrop

Precipitation intensity
(e.g., Islam and Uyeda 2008,
Takahashi 2016, Zipser et al. 2006)

Precipitation type
such as convective or stratiform
(e.g., Romatschke et al. 2010)



GPM
(Kojima et al. 2012; Hou et al. 2014; Skofronick-Jackson et al. 2017)

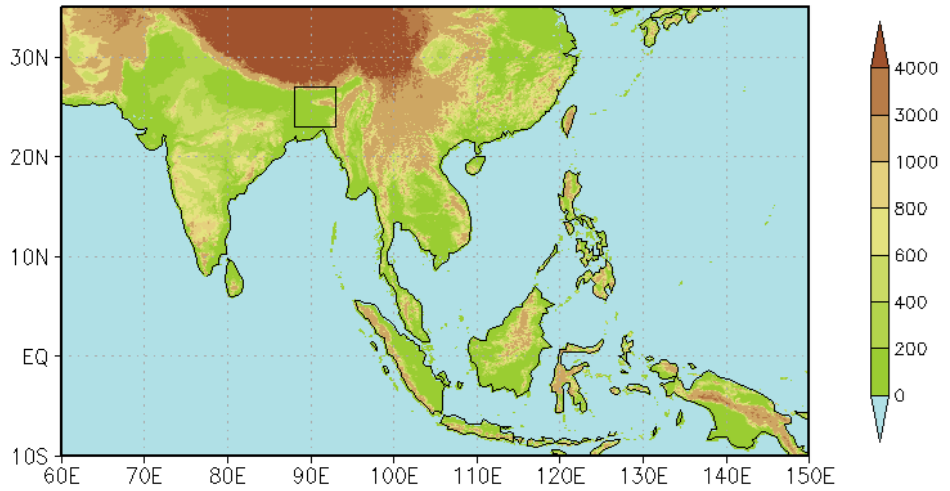


(Shige et al. 2008)

2. Data and target region

- GPM/DPR V06 Data
  - Precipitation amount: totalprecip/totalcount
  - Precipitation intensity: totalprecip/precipcount
  - Precipitation frequency: precipcount/totalcount
  - Precipitation top height [km]
  - Dm: mass-weighted mean diameter [mm]
  - Frequency of HeavyIcePrecipitation =count_flagHeavyIcePrecipitation/precipcount

Elevation [m] of the target region



- Analysis
  - Define pre-monsoon and monsoon season as APR-MAY and JUL-AUG, respectively. It should be noted that the monsoon season over the Indochina Peninsula starts at approximately mid- to late May (e.g., Matsumoto 1997), which should be taken into consideration when we discuss the results of the pre-monsoon season over the region in this study.
  - Average 8 years (2014-2021) of 2-month (AM and JA) L2 data onto 1°x1° grid box.

Figures omitted

3. Results – climatological precipitation characteristics

Precipitation amount

Generally larger in the mature monsoon season than in the pre-monsoon season; consistent with well-known seasonal changes in precipitation.

Precipitation frequency

Similar tendency to the precipitation amount

It was confirmed that well-known features related to pre-monsoon and monsoon precipitation could be captured using 8 years of GPM/DPR.

Precipitation Intensity

In some areas, the value of the precipitation intensity was higher in the pre-monsoon than in the mature monsoon season, especially over Bangladesh, the southeastern Indian subcontinent, etc.

Precip. Top Height

High around Bangladesh and the eastern Indian subcontinent during the pre-monsoon season, and in the western Himalayan indentation during the monsoon season, consistent with the results by Islam and Uyeda (2008)

Results showed that precipitation in the pre-monsoon season is more intense and highly developed compared with that in mature monsoon season, consistent with previous studies (e.g., Takahashi 2016)

Figures omitted

3. Results – Mean diameter (Dm)

- Clear land-ocean contrast was observed; Dm was larger over land than over the oceans
- In particular, Dm was large around Bangladesh and the eastern Indian subcontinent during pre-monsoon season, and over the western Himalayan indentation during the monsoon season.
- In the Arabian Sea and the Bay of Bengal, Dm tended to be larger in the monsoon season.
  - Hirose and Nakamura (2005) suggested that small precipitation systems are dominant over the Arabian Sea while the widely spread precipitation systems are prevailing over the Bay of Bengal.
  - The differences in the amplitude of the seasonal Dm changes can be related to the differences in the size of prevailing precipitation.

3. Results – frequency of heavy ice precipitation

- Kodama et al. (2005) suggested that pre-monsoon rainfall was characterized by more convective rain, consistent with the occurrence of active lightning, whereas stratiform and shallow rainfall became more common after the monsoon onset over tropical monsoon areas.
- We investigated the frequency of heavy ice precipitation (i.e., graupels or hails) which is closely related to the lightning activity.
  - It was clearly higher over land, especially in the Indian Subcontinent, during the pre-monsoon season.
  - During the monsoon season, frequent heavy ice precipitation was observed in the northwesterm Himalayam foothill.

Figures omitted

4. Analysis of Bangladesh region; R and Dm relation

Further analyses were performed to reveal the differences in the relationship among the precipitation variables in DPRL2 pixel-basis.

- **Dm could change even if R is in the same range.**
- **In other words, the relationship between R and Dm can differ among seasons, and seasonal Dm changes are not simply caused by precipitation changes, but probably induced by the changes in characteristics of precipitation.**

4. Analysis of Bangladesh region; heavy ice and Dm

- In addition to the relationship between R and Dm , we investigated the relationship among the occurrence of heavy ice precipitation, and its altitude, and Dm.
- Heavy ice precipitation in the upper atmosphere above the melting layer was observed more frequently as Dm got larger in both seasons.
- The absolute number of samples were generally almost ten times larger in the pre-monsoon season than in the monsoon season.

5. Summary

- This study reveals the climatological differences in precipitation microphysical characteristics between the pre-monsoon and monsoon seasons over the Asian monsoon region by statistically analyzing 8 years of GPM/DPR dataset.
- Dm was large over pre-monsoon land with less precipitation, corresponding to the areas where the deep convective core was dominant.
- The frequency of ice precipitation coincided with the region where Dm was large and lightning was frequently observed.
- Further analysis was performed focusing on the Bangladesh region.
  - Relationship between R and Dm can differ among seasons, and seasonal Dm changes are not simply caused by precipitation changes.
  - Heavy ice precipitation in the upper atmosphere above the melting layer was observed more frequently as Dm got larger in both seasons.