I 7 Mar. 2025: IWM8 @ IITM, Pune, Maharashtra, India



Impact of Convective Heating over the Asian Monsoon Region in Pre-monsoon and Monsoon Seasons under the Global SST Warming Event in 2023-2024

Toru Terao (Kagawa Univ.)

How is the roles of Bay of Bengal Region in the Asian monsoon onset?

An analysis showing the understanding of relationships between whole Asian monsoon system and regional processes

Heating Impact on the Asian monsoon

Response to the off-equatorial heating center



HMSEA-HDSEA view



7

HMSEA-HDSEA view



This is HMSEA!



Apparent Mass (HDSEA) Source

- Conservation law for HDSEA ($\theta_0 < \theta < 375$ K) mass, μ $\frac{\partial \mu}{\partial t} = -\nabla \cdot (\mu v) + R$
- R: the apparent mass source term (radiation, conv., others)



HMSEA(θ_e >360K, p>400hPa) amount

HMSEA strongly concentrates on Asian monsoon region especially in South Asia in boreal summer.



Terao et al. (in prep.)

HMSEA increase / BoB & Bengal Plain



Terao et al. (in prep.)

|3

Diabatic HDSEA Source Term

14



Terao et al. (in prep.)

Rainfall extremes and HMSEA peaks



Acc. Process of HMSEA over landmass

Large uncertainty in ERA5 is found around Assam Brahmaputra basin and Bengal Plain

16



How was HMSEA/HDSEA during SST warming event in 2023-24?

Recent acceleration of global warming?

Anomalous warming of global mean sea surface temperatures has been observed from May 2023



Inflation of HMSEA and HDSEA in July





Terao et al. (in prep.)

Intraseasonal Variability

20

Precip./Westerly corresponds with HMSEA/HDSEA Peaks



Terao et al. (in prep.)

Interannual Variatility



	Cor. Coef. Jul.	HMSEA	HDSEA	GSMaP			
	HMSEA	-	0.90	0.69			
	HDSEA	0.90	-	0.70			
	GSMaP	0.69	0.70	-			
precipitation (Gt)	GSMa	Ρ	2000-2024				
			m03 m04 m05 m06 m07 m08	-			
	6			-			
	4	\sim		-			
	2						

year

Terao et al. (in prep.)

Interannual Variatility

Correlation from 2000 to 2024(23)

					2000-2024			2000-2023
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
HMSEA HDSEA	0.29	0.29	0.58	0.72	0.90	0.93	0.79	0.62
HMSEA GSMaP _{v8}	₃ 0.08	0.37	0.23	0.32	0.69	0.55	0.57	0.37
HDSEA GSMaP _V 8	₃ -0.04	0.33	0.53	0.41	0.70	0.51	0.71	0.63
HMSEA Westerly	-0.18	-0.33	-0.14	-0.03	0.09	0.11	0.16	-0.20

Summary

- To diagnose the Asian monsoon variability including the onset process and impact of the global change in sea surface temperature, the lower tropospheric HMSEA (High Moist Static Energy Airmass) and upper tropospheric HDSEA (High Dry Static Energy Airmass) is useful.
- In the period from 2023 to 2024, the global sea surface temperature was higher than normal. HMSEA and HDSEA over the Asian monsoon region were also extremely higher than normal especially in 2024 summer. Although precipitation was also higher than normal, monsoon westerly over the Indian Ocean did not match on interannual time scales.
- HMSEA and HDSEA has strong correlation indicating the HMSEA controls HDSEA simultaneously.
- In 2024 summer, several peaks in HMSEA and HDSEA were found in the intraseasonal time scales. Precipitation and westerly has peaks at the similar timings.

24

- -

Sohnon Intensive Obs. In 2024

- Acc. process of HMSEA over NE-Indian subcontinent
 - Focus: May-Jun, monsoon onset process

Observation plan in 2024 around monsoon onset season

- Dhaka, Sylhet (with BMD), Guwahati (with IMD)
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 - Land surface modeling
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- Other observational platforms?



test obs. Aug. 2023



Sohnon Automatic Weather Station





Driven by Observed SR, LR, Temp, RHum, Rain, Wind

Summary

- AsiaPEX-SOHMON-LivingSpaces Projects
 - Interdisciplinary research collaboration framework on Asian Climate Change Impacts on nature and humanity.
- Studied HDSEA source term to investigate roles of regional convections in the Asian monsoon circulation.
 - Lower/Upper tropospheric High Moist/Dry Static Energy Airmass (HMSEA/HDSEA) is utilized to analyze roles in different regions in the onset and maintenance of Asian monsoon circulation.
 - BoB to Bengal Plain region drives the Asian monsoon onset.
 - Extreme rainfall over the Bengal Plain corresponds with the HMSEA accumulation
 - New observational activity over NE Indian Subcontinent.

We invite you to:

- AsiaPEX-AMY-II: Discussion on field campaign to understand Asian Hydroclimatological system.
 - A session in JpGU
 - 25-30 May 2025 in Makuhari, Chiba, Japan
- First Conference of Asian Association for Environmental History (AAEH 2025)
 - The Ist Conference of AAEH
 - 19-23 September 2025 in Takamatsu, Japan
- Hydroclimatological-Geological view of South Asian Climate and Climate Change Impact:
 - A session in IAEG ARC
 - November 2025 in Kathmandu, Nepal

"Altered Earth" in Asia:

Strategy for

Hydroclimatological Field

Observation

Ocean, Atmosphere, and Landscape

oint Discussion between Hydroclimatological and **Geological Time Scales**

Local Condition over the T. P.

30-35N / 80-100E



Underestimation of TRMM/PR

- Bias Ratio: Meghalaya: -51.3%, Sylhet-Barak: -35.2%
 - Significant at 99% Confidence Level
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- We calculate the correlation coefficient between Rg and Rt with different lags.

Terao et al. (2017)





Rainfall estimated by HDSEA source

Rainfall P estimated by diabatic HDSEA source vs GSMaP $P = Rq \quad P \text{ from GSMaP}$

- Bay of Bengal: Peaks correspond in onset phase 80-100E, 10-25N
- Tibetan Plateau: Peaks correspond after July 80.

80-100E, 30-35N



Terao et al. (in prep.)

Apparent HDSEA Source

- Apparent HDSEA source over the Tibetan Plateau appears before the beginning of July
- If we combine with that over the southern slope just to the south of the Plateau, it played crucial roles.



Local Condition over the T. P.

30-35N / 80-100E



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Global Partnership for Asian Hydroclimatological Research

International collaboration framewoks and research projects in near future



From slides of Prof. Matsumoto
GHP under GEWEX



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BAMS review paper was published!

Based on discussion of SSG of AsiaPEX.

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	DOI: https://doi.org/10.1175/BAMS-D-20-0220.1 Article History Download PDF © Get Permissions	

AsiaPEX as an umbrella

- Coordination of individual research activities
 - Project design / funding source / interaction with GEWEX



Approach-Oriented Research Strategy

- Discussion on Science Plan of AsiaPEX
 - Project initiation and kick off Conference in Sapporo
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Hirose and Okada (2018)

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Multiple scale interactions: Diurnal to S2S scales



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Mass balances of representative glaciers in Mongolia

Estimation of mass balances and meteorological condition



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Field Campaign: Asian Monsoon Year-II

Two Strategic Approaches:

5

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Water

Climate

水

気候

Register yourself to get updated

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- Source of the high θ airmass must come from high θ_e airmass in the lower troposphere.



Terao (1999)

Fig. 5. Time-pressure cross section of potential temperature averaged over 30–120°E and 20–40°N. Contour interval is 5 K. The layer between 350 K and 360 K isentropic surfaces is hatched.

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The Shillong Times \equiv

Home > MEGHALAYA >

Mawsynram sets new record with 1003.6 mm rain in 24 hours

MEGHALAYA

By By Our Reporter - On Jun 18, 2022



Source : Internet.

Another record for Cherrapunji: 972 mm rainfall in a day, 3rd highest in 122 years

(https://www.addtoany.com/share#url=https%3A%2F%2Fwww.morungexpress.com%2Fanother-record-for-cherrapunji-972-mm-rainfa

years&title=Another%20record%20for%20Cherrapunji%3A%20972%20mm%20rainfall%20in%20a%20day%2C%203rd%20highest%20m%20 (/#facebook) (/#twitter) (/#email) (/#linkedin) (/#whatsapp)



Image Source: Views_Indian @views_indian

3days rainfall:2457.2 mm during 14-16 June 2022

TRMM PR rainfall climatology

3000



15

18

(mm/day)

21

24

27

30

12

9

Flush flood in Sylhet, Bangladesh TRMM PR rainfall climatology



#Sylhet #Bangladesh #floods The Catastrophic Flood! 59 dead, millions stranded as floods hit Bangladesh and India! June 18, 2022





(mm/day)

2022 premonsoon - monsoon

NE India+Bangladesh Flood & Drought

- In the first three weeks of June, Assam recorded 528.5 mm of rainfall more than 109 per cent. Meghalaya recorded 1215.5mm an excess of 185 per cent.
- Flooding has been reported in 33 of the 35 district, Close to half a million people have been affected while almost 300,000 people have been relocated according to the Assam



By courtecy of Dr.A. Mannan, BMD and Dr. R. Mahanta, Cotton Univ.

Change in seasonality of rainfall?

- I heard same story in Bangladesh and NE India
 - Apr.-Jun. rain is increasing? / Flush floods in Assam / Bangla.
 - Jul.-Sep. rain is decreasing? / Special irrigation in Bangladesh



Observation and Future Projection of Rainfall around Bangladesh

How accurate is our knowledge about the current and future rainfall distribution and variability?

Rainfall Observation and Projection

Observation

Raingauge Observation and Analysis

- SOHMON NE-India raingauge network (Direct raingauge observation using 0.5mm tipping backet raingauges with automatic loggers)
- APHRODITE (Analysis using many raingauge data / daily)
- Satellite Observation and Analysis
 - TRMM PR, GPM DPR (Satellite-borne precipitation radar)
 - GSMaP (Analysis using microwave passive sensors on satellites)
- Future Projection
 - d4PDF (present vs. +4K / Ultra-long integration with AGCM forced by SST derived from AOGCMs (CMIP5))
 - CMIP5/6 (AOGCM)

Raingauge Observation

SOHMON RG Network and APHRODITE



March to October

Daily / 0.05deg resolution for 30yr climatology (1981-2010). Yatagai et al. (2012/2017)

~40 tipping bucket type automatic RGs in Bangladesh & NE India installed from 2004~2007 and maintained up to now and continuing

SOHMON vs APHRODITE





Satellite Observation: TRMM

TRMM Climatology (Observation)

I998-2011, TRMM Climatology

Rainfall peak over the Meghalaya Plateau



RG network in NE Indian subcontinent

- We conducted direct
 TRMM validation using
 37 raingauges.
- They are Installed from^{26°} 2004 and continued up to now. (10yr obs.)
- We obtained 29,172
 matchups including
 2,245 rainy cases.

Only once in several days! And many no rain cases!

Terao et al. (2017)



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Satellite Observation: GSMaP

GSMaP: Hourly, 0.1deg Resolution



APHRODITE vs. GSMaP



APHRODITE vs. GSMaP



APHRODITE vs. GSMaP



Climate model output: d4PDF

MRIAGCM3.2, 60km resolution (Mizuta et al. 2017)



What is d4PDF?


APHRODITE vs d4PDF-present



APHRODITE vs d4PDF-present (NE India)



Too much Meghalaya rain in May

Too strong rain over a big region surrounding Meghalaya

This is much larger than monsoon rain (Unrealistic!)



Lacking Meghalaya rain in July

- No Meghalaya rain was found!
- Monsoon rainfall in Bengal Plain is very week



APHRODITE vs. d4PDF (Mar.-Oct.)



Future Projection of d4PDF



Future Projection of d4PDF



Regional Difference / 30yr Return Period



Precipitation observation and projection

- Direct observation
 - Low spatial density of rainfall observation
 - Subdaily rainfall / rainfall observation before 1950s
 - How can we use radar data in multiple countries?
- Satellite products (TRMM+GPM, GSMaP, ...)
 - High spatio-temporal resolution (ex. GSMaP, 1h, 0.1deg)
 - Large underestimation in PR products around Meghalaya region was detected by SOHMON raingauge network
 - ► GSMaP seriously underestimates mountain monsoon rain
- Climate projection (d4PDF-present / +4K)
 - Large BIAS over Meghalaya and Bengal Plain
 - Premonsoon: huge overestimation, Monsoon: no Cherrapunjee, underest.
 - Overall increase rainfall and delay in monsoon.
 - Extremes are expected to increase in many regions.

Consistent with Ashfaq et al. (2020)

Inconsistencies in Observation / model



MRI-AGCM3.2S, 20km resolution



Rahman et al. (2012)

MRI-AGCM3.2S, 20km resolution



Rahman et al. (2012)

+Bias Correction

Climate projection (MRI-AGCM3.2S)



Masood and Takeuchi (2016)

Is the Brahmaputra Basin a key of the Asian monsoon onset?

A proposal of an observational campaign for the monsoon onset processes over the Brahmaputra Basin

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Annual Precipitation in Climate Models

Sperber et al. (2013)



Seasonal march in climate models



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HMSEA-HDSEA view



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Asian monsoon-SA Moist Static Energy

Abrupt Monsoon SW jet onset is strongly correlated with increase in Moist Static Energy (MSE) over South Asia



Data

ERA5 (2017 / Mar-Oct Asia)

- Hourly 0.25 x 0.25 deg Lon-Lat Grid data at pressure levels from 1000 to 70 hPa and ground surface.
 - Temperature, specific humidity, zonal and meridional wind speed, geopotential height, and surface pressure.
- Airmass for 5K isentropic layers and their horizontal flux are calculated for each horizontal grid and hour.

Hershbach et al. (2020)

Meridional section of θ and θ_{e} .



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Terao et al. (in prep.)

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test obs. Aug. 2023



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Society	Precipitation Research Toru Terao, Shinjiro Kanae, Hatsuki Fujinami, Someshwar Das,	R.
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AsiaPEX South Asia

I-2 Mar 2020, CURAJ, India



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Timeline of AsiaPEX

Organizing AMY-II field campaign combined with modeling initiative and satellite observations.



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Climate

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気候

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New Generation in South Asia

- We shall think about involving new generations in our projects.
- Capacity building for new generations
 - Computer literacy including model and big data manipulation
 - Capacity to design observation and fieldwork Nepal
 India



Summary

- We do not know precipitation process over NE India
 - Inconsistencies in observations and model outputs.
- NE Indian subcontinent including Bangladesh will be one of the key regions of the Asian monsoon onset.
 - Observation project focusing on High Moist Static Energy Airmass (HMSEA) production in NE India is now running under JSPS Kakenhi Project by SOHMON targeting 2024.
- International collaboration frameworks
 - AsiaPEX was launched as a project under the WCRP/GEWEX perspective.
 - AsiaPEX will call for AMY-II coordinated field campaign to explore complex hydroclimatological system (2025-2028).
 - It will provide us a convincing climate projections.
