Distinct impacts of short- and long-time fluctuations of Indian Ocean surface wind fields on Indian summer monsoon rainfall at regional scales

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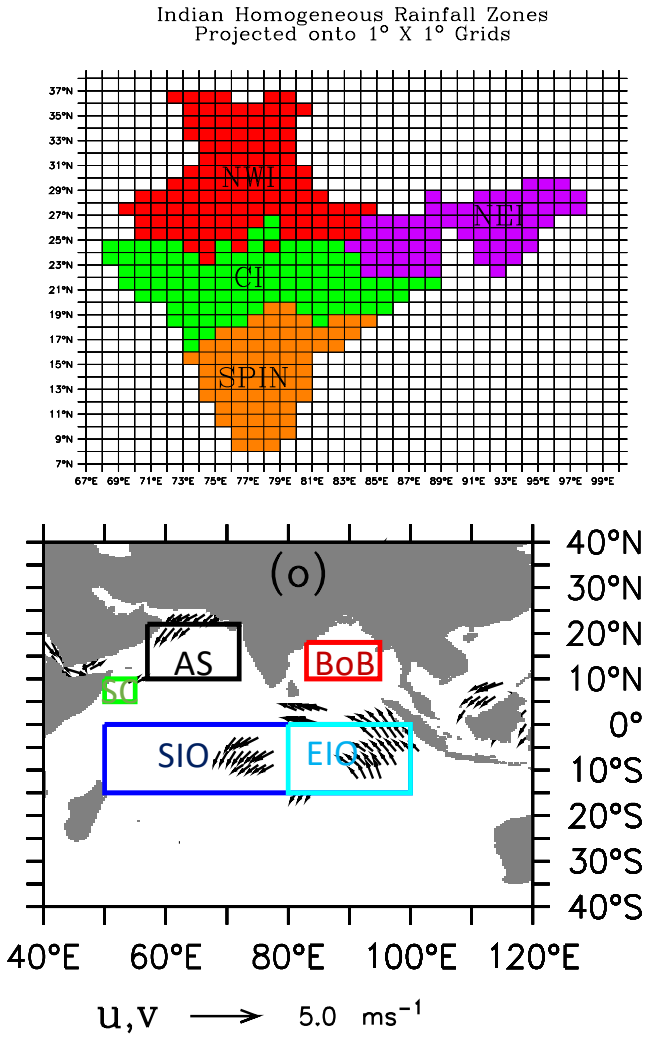
Motivations

- To better understand the salient features of ocean surface winds relevant to the strength of Indian summer monsoon rainfall (ISMR) at a better temporal and spatial scales by taking advantage of the high-quality high resolution wind products from satellite measurement;
- To better understand how ocean surface winds in different parts of Indian Ocean are associated with ISMR over four homogeneous rainfall zones of India.

Study Domain

- Rainfall over the four homogeneous rainfall zones of India: Northwest India (NWI), Central India (CI), south peninsula India (SPIN), and northeast India (NEI).

- Winds over the Arabian Sea (AS; 57°E–72°E, 10°N–22°E), the Bay of Bengal (BoB; 83°E–95°E, 10°N–18°N), Somali Coast (SC; 50°E–55°E, 5°N–10°N), South Indian Ocean (SIO; 50°E–100°E, 15°S–0°N), East Indian Ocean (EIO; 80°E–100°E, 15°S–0°N)



Methods

- Composite analysis: Group ISMR for strong, weak, and normal ISMRs;
- Lag linear correlation analysis: Examine the relationship between surface winds and rainfall during strong, weak, and normal ISMs;
- Probability Density Function (PDF) analysis: Identify Indian Ocean surface winds features during strong, weak, and normal ISMs;
- Multiple Linear Regression (MLR) analysis: Explore the contributions of ocean wind fields over AS, BoB, SIO to rainfall in all-India and in NWI, CI, SPIN, and NEI:

MLR model: $Y = a_0 + \sum_{i=1}^{9} a_i X_i + \varepsilon$

where Y is the anomalous monthly rainfall in all-India and the four IMD regions, X_i is the ith component (i.e., wind speed, wind convergence, curl in the AS, BoB, and SIO), a_i is the regression coefficient for the ith component, a_0 is intercept, and ε is the estimated error due to linear regression

Data

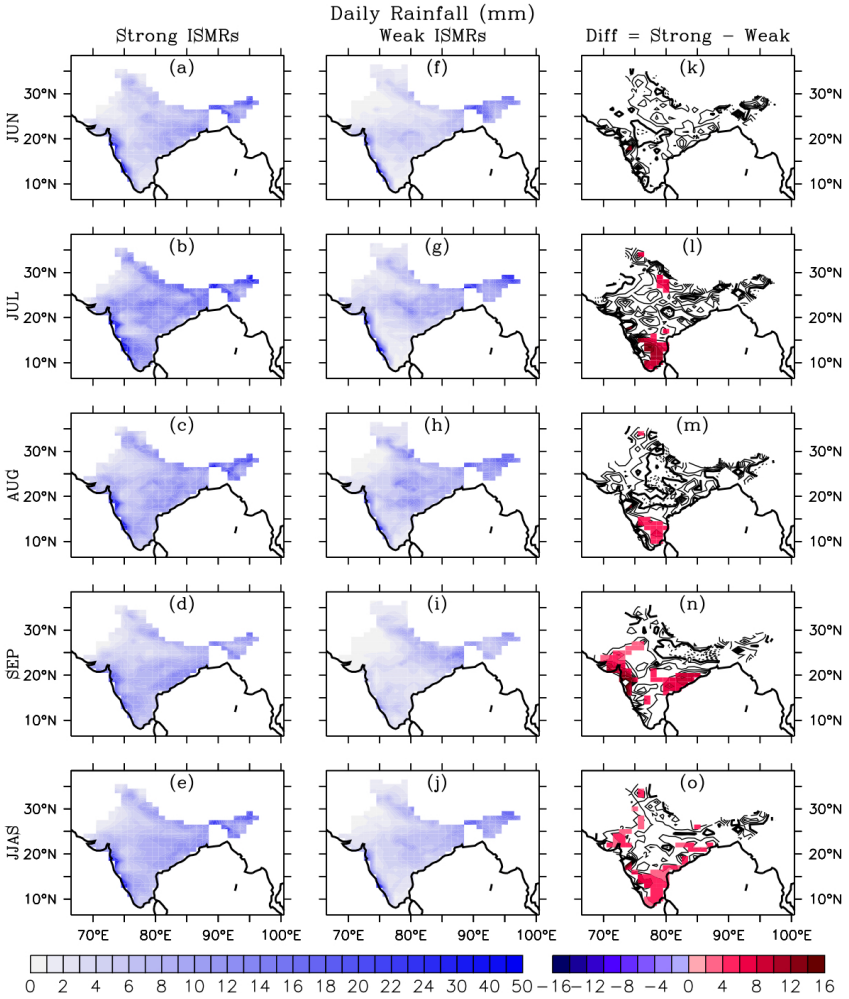
- Daily gridded rainfall prepared by Indian Meteorological Department (daily mean, 1^{o} by 1^{o}, Jan 1991–Dec 2014;

  Strong ISMR years: 2005, 2007, 2008

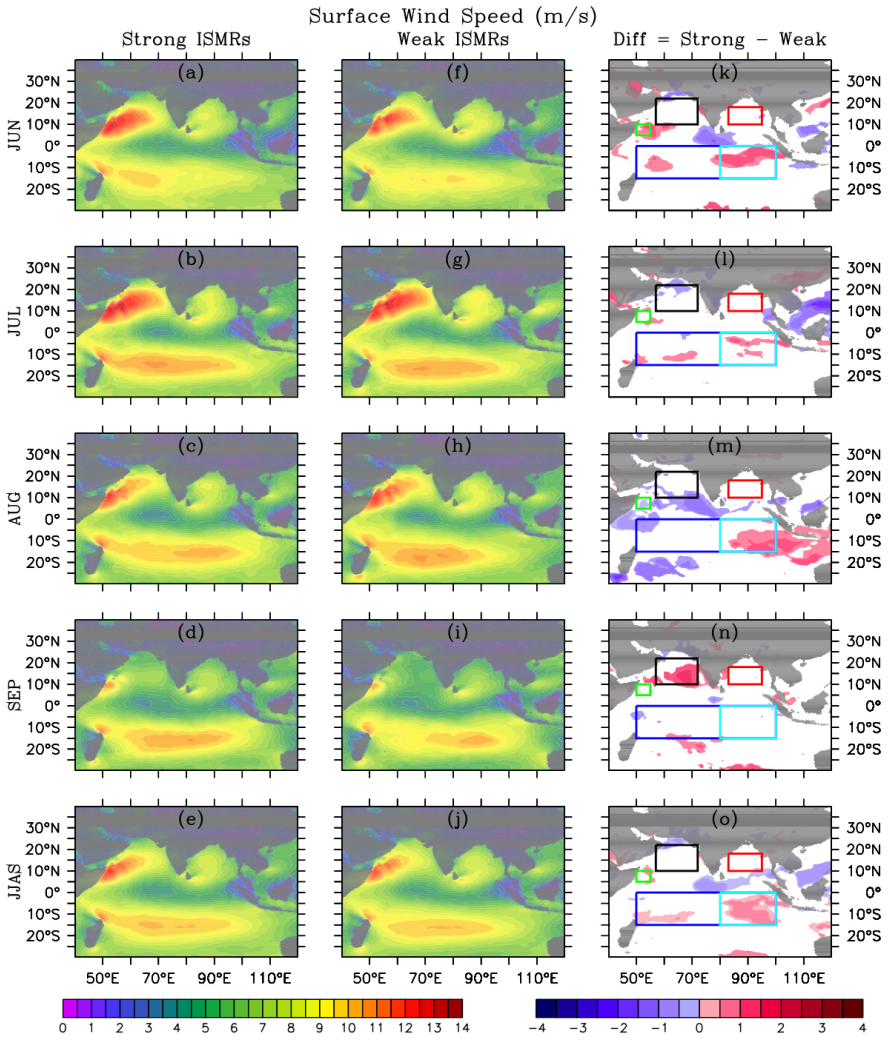
  Weak ISMR years: 2000, 2002, 2009

- CCMP (Cross-Calibrated Multi-Platform) wind vector analysis product version 2.0 Level 3 (daily mean, 0.25^{o} by 0.25^{o}, Jan 1991–Dec 2014)

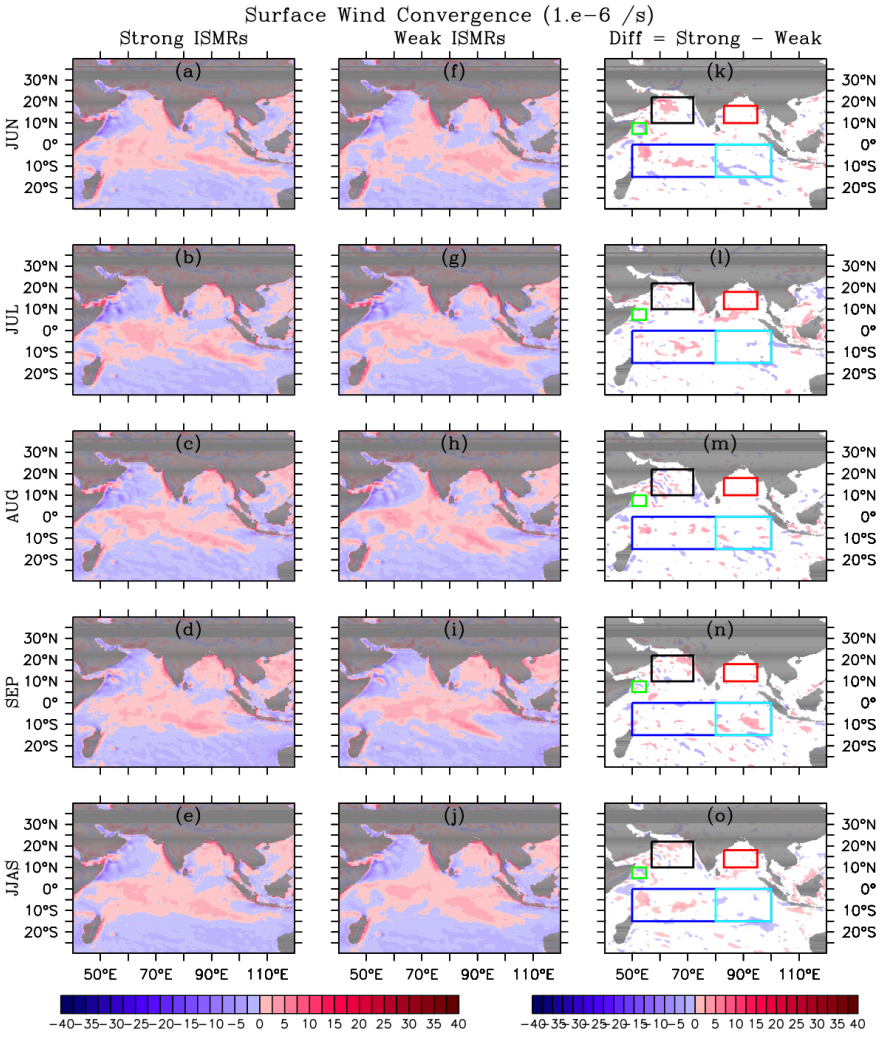
Result #1: Rainfall shows different in space and time Jun through September between strong and weak ISMRs.



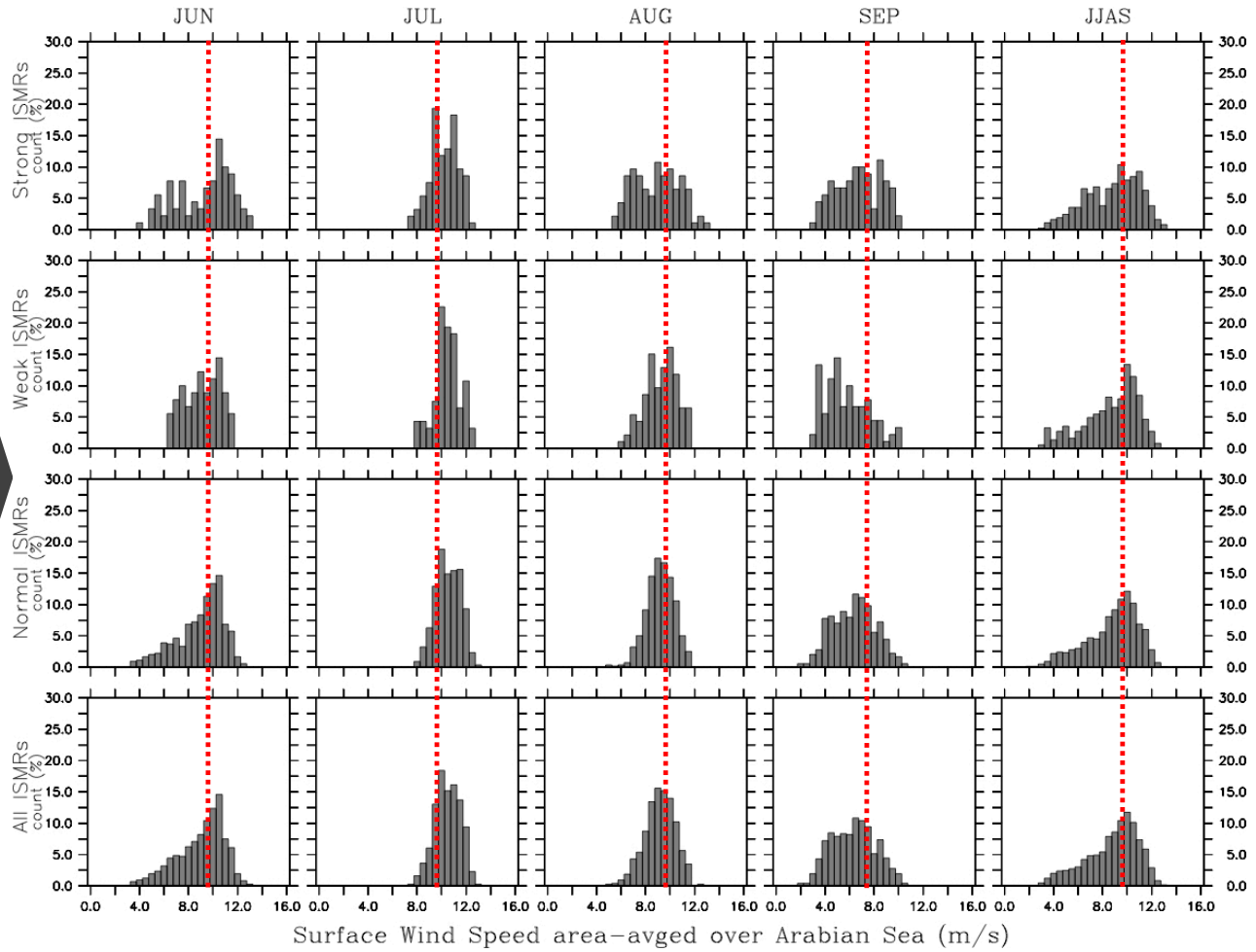
Result #2: Wind speed shows different in space and time Jun through September between strong and weak ISMRs.



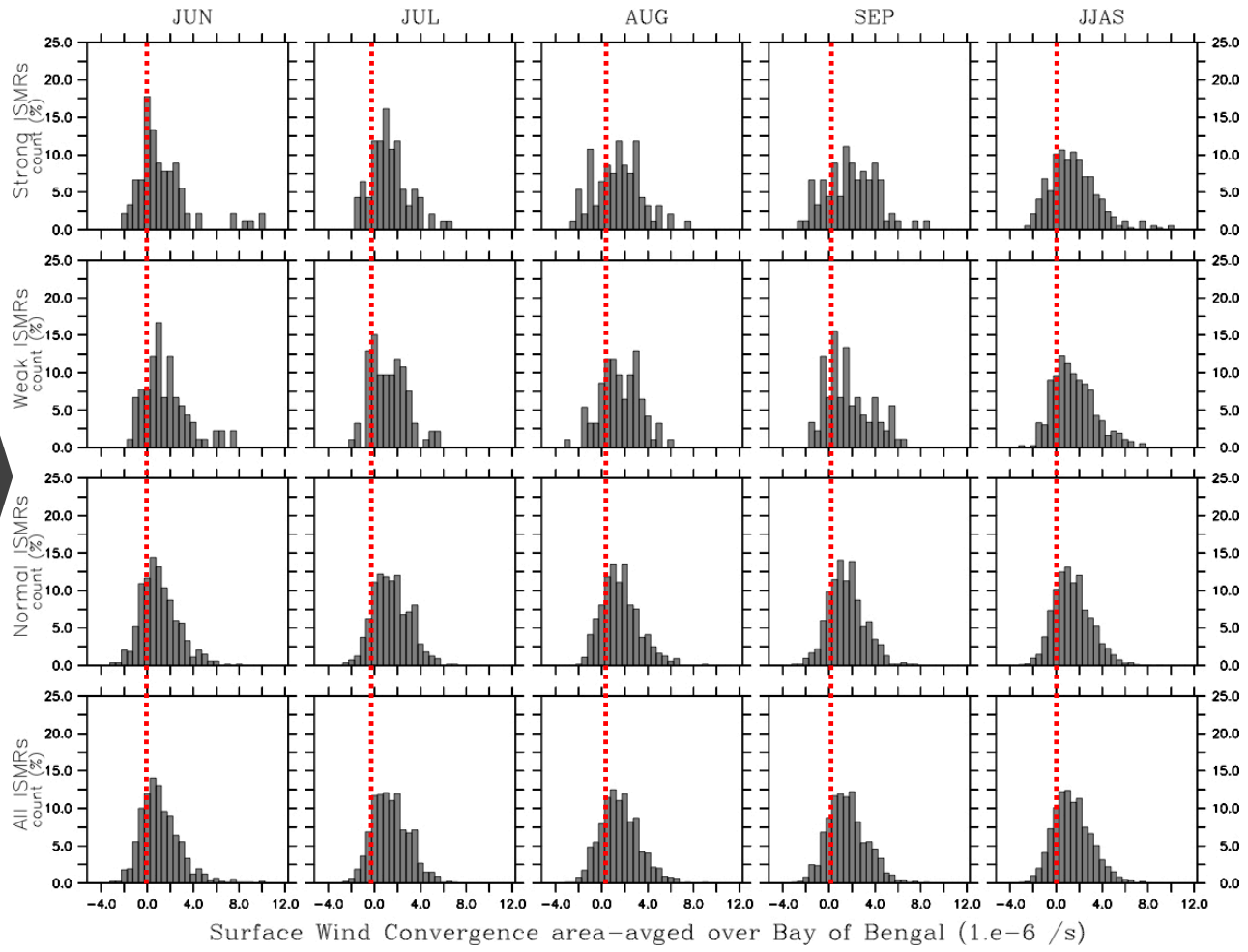
Result #3: Wind convergence shows different in space and time Jun through September between strong and weak ISMRs.



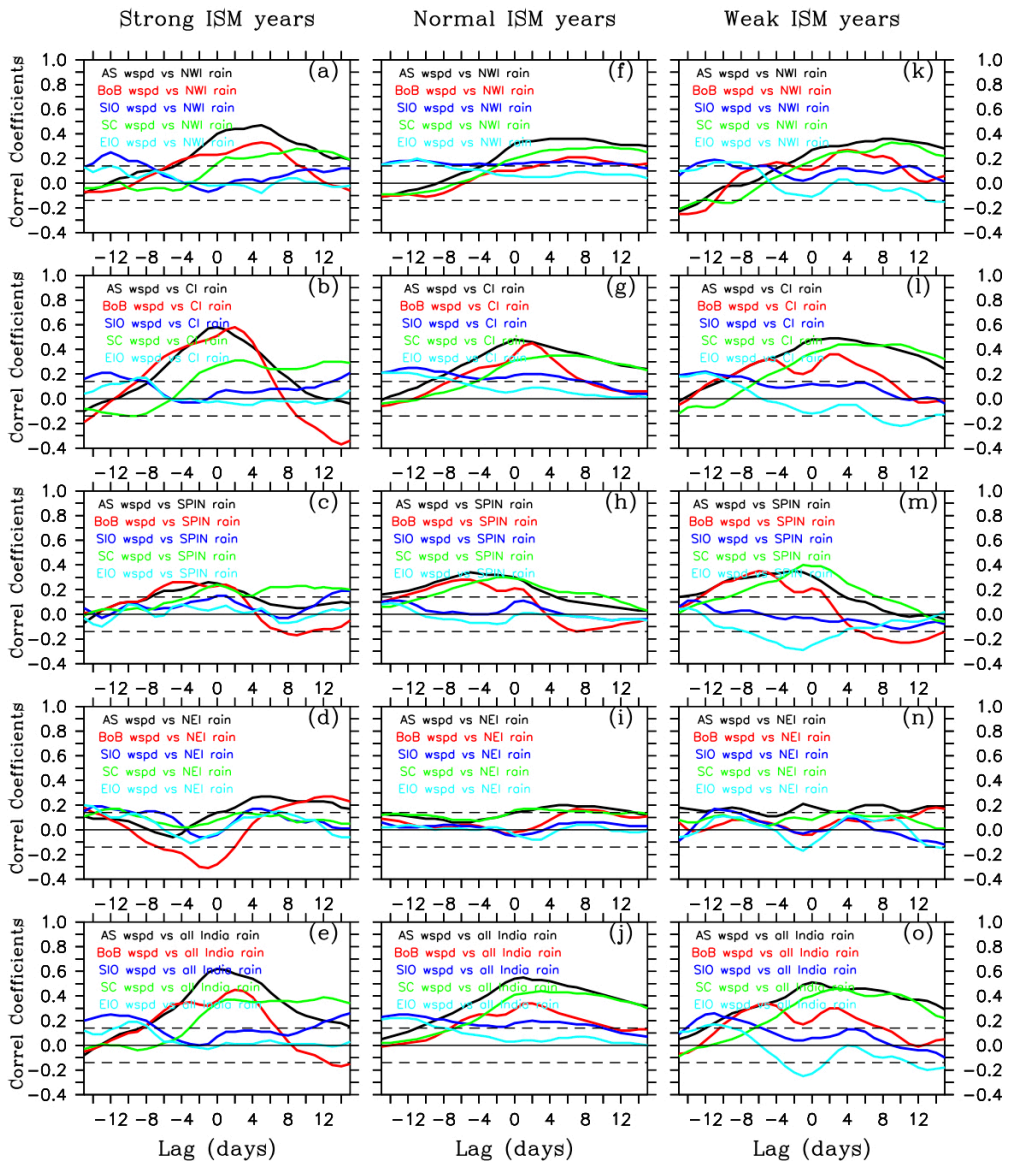
Result #4: The PDF in daily AS wind speed shows more frequent strong winds during strong ISMRs than weak ISMRs.



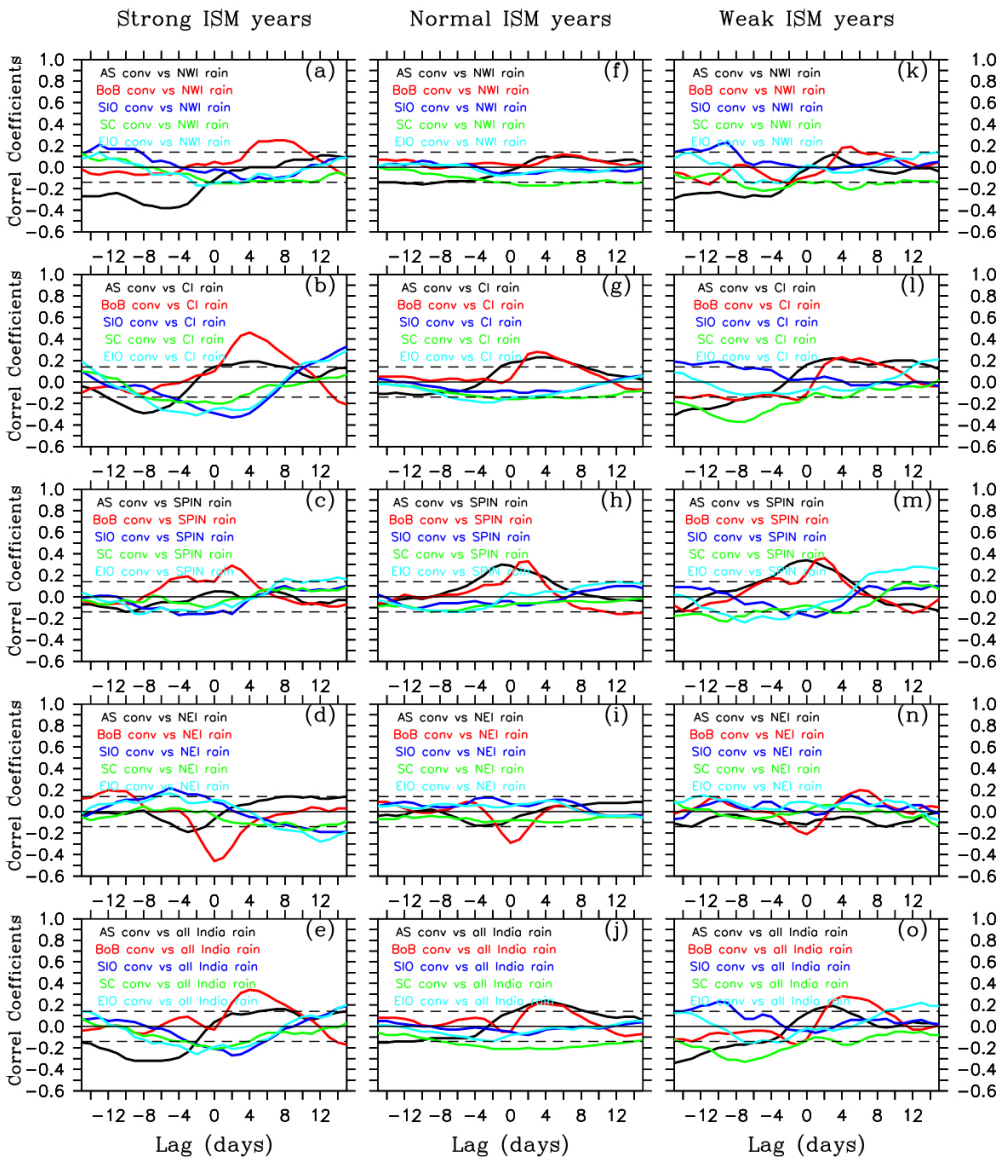
Result #5: The PDF in daily BoB wind convergence shows more frequent surface wind convergence during strong ISMRs than weak ISMRs.



Result #6 Lag correlations between wind speed and rainfall show different roles of short-time fluctuations of wind speed in Indian rainfall between strong and weak ISMsR.



Result #7: Lag correlations between wind convergence and rainfall show different roles of short-time fluctuations of wind convergence in Indian rainfall between strong and weak ISMRs.



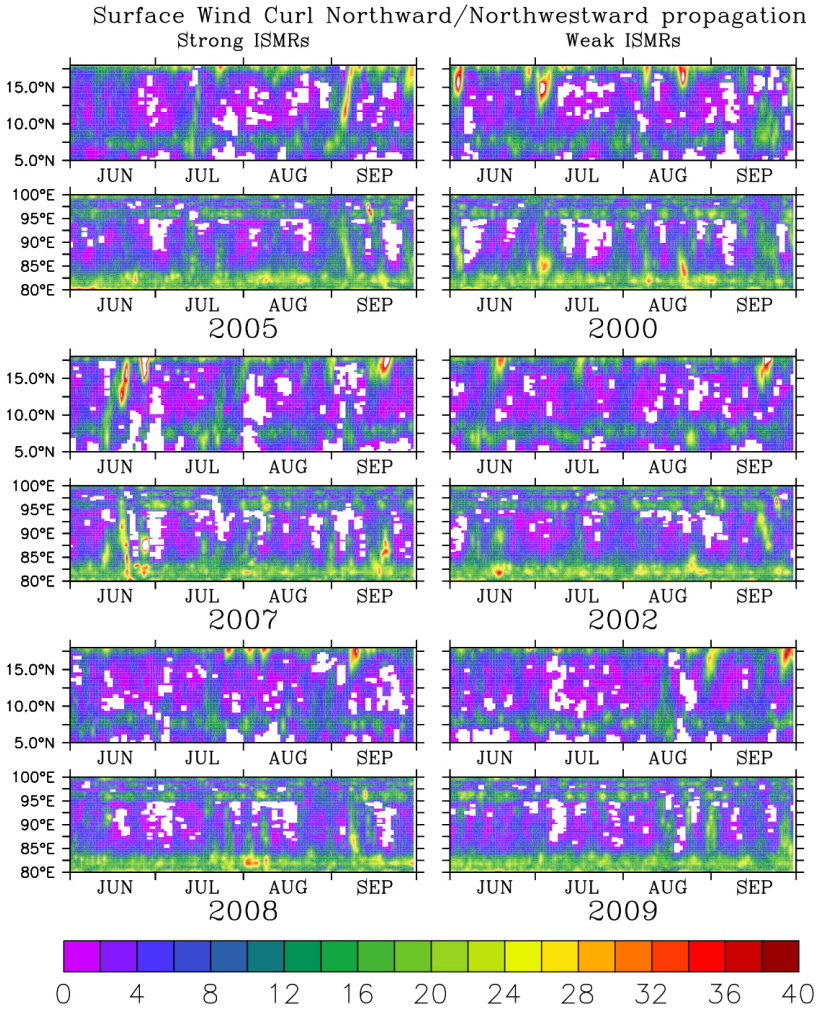
Continued.....

Result #8: Lag correlations between wind convergence and rainfall show different roles of short-time fluctuations of wind fields in Indian rainfall between strong and weak ISMRs.

	AS			BoB			SIO		
	wspd	conv	curl	wspd	conv	curl	wspd	conv	curl
Strong ISMRs									
NWI	Yes	No	No	Yes	Yes	Yes	No	No	No
CI	Yes	Yes	No	Yes	Yes	Yes	No	No	No
SPIN	Yes	No	No	Yes	Yes	Yes	No	No	No
NEI	Yes	No	Yes	No	No	No	No	No	No
All-India	Yes	No	No	Yes	Yes	Yes	No	No	No
Weak ISMRs									
NWI	Yes	No	No	Yes	Yes	No	No	No	No
CI	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
SPIN	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
NEI	Yes	No	No	No	Yes	Yes	No	No	Yes
All-India	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes

Whether the correlation of wind fields leading rainfall up to 1 week is significant at a 99% confidence level is denoted by “Yes” or “No”

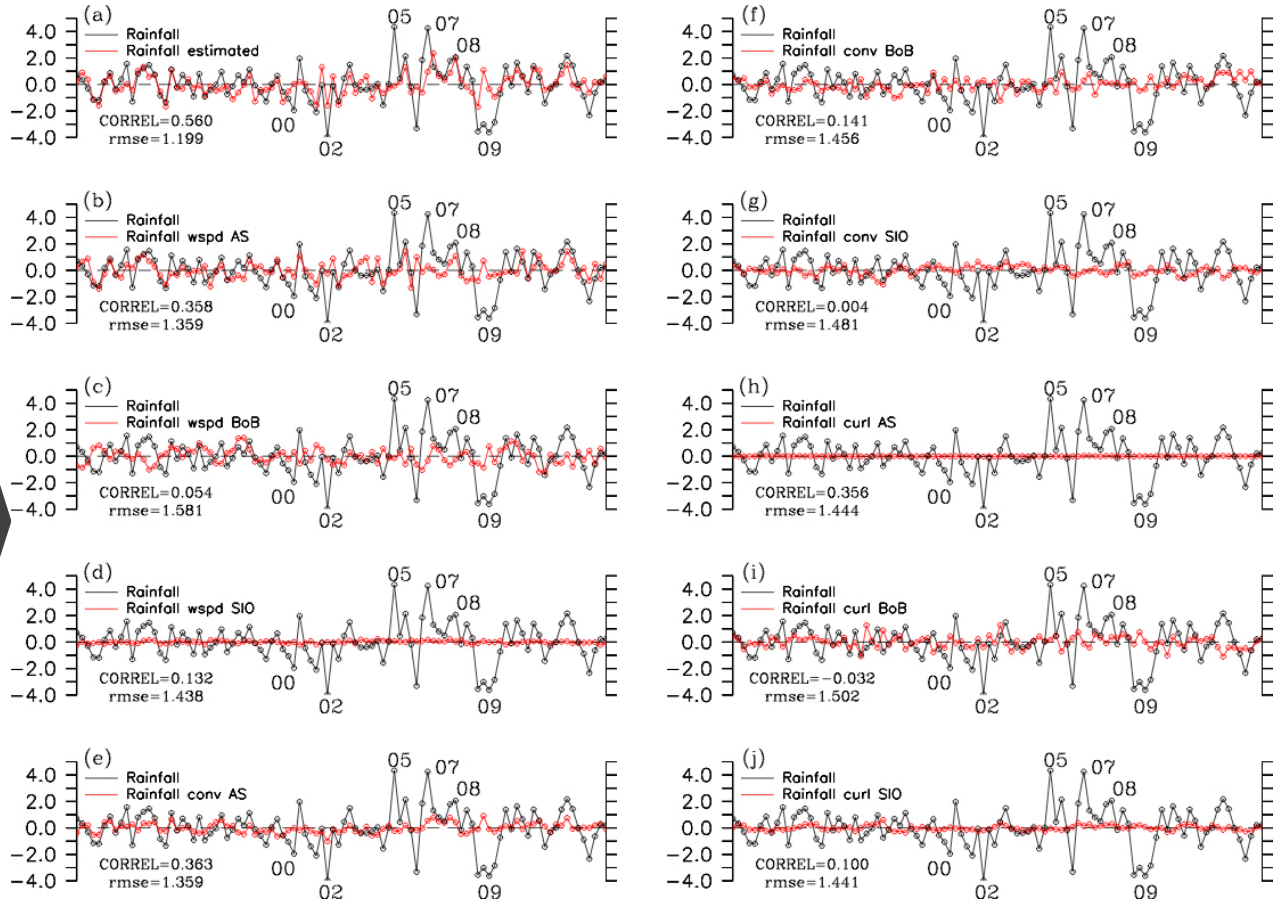
Result #9: Surface wind curl northward/northwest ward propagation over the Bay of Bengal between strong and weak ISMRs.



Averaged between **83°E–95°E**

Averaged between **5°N–10°N**

Result #10: MLR analysis shows contribution of monthly wind fields to monthly rainfall in the entire India.



Anomalous monthly rainfall (in red) in June through September estimated from wind speed, wind convergence, and wind curl in the AS, BoB, and SIO using multiple linear regression model was compared to the actual rainfall (in black). **a** rainfall estimated from the total nine components; **b**, **c**, **d**rainfall estimated from wind speed in the AS, BoB, and SIO, respectively; **e**, **f**, **g** rainfall estimated from wind convergence in the AS, BoB, and SIO, respectively; and **h**–**j** rainfall estimated from wind curl in the AS, BoB, and SIO, respectively. Correlation coefficient and root-mean-square error (rmse) for each component are denoted at the left bottom of each panel

Continued.... Summary of MLR for all-India

Result #10: MLR analysis shows contribution of monthly wind fields to monthly rainfall in the entire India (R^2=0.31)

Components	Coefficients	Significance at 95% level	Significance at 99% level
Wind speed in AS (X^1)	1.28	Yes	Yes
Wind speed in BoB (X^2)	−0.85	Yes	Yes
Wind speed in SIO (X^3)	0.29	No	No
Wind conv in AS (X^4)	0.60	No	No
Wind conv in BoB (X^5)	1.03	Yes	No
Wind conv in SIO (X^6)	0.90	No	No
Wind curl in AS (X^7)	0.01	No	No
Wind curl in BoB (X^8)	−0.33	No	No
Wind curl in SIO (X^9)	0.23	No	No

Continued.... Summary of MLR for NWI

Result #10: MLR analysis shows contribution of monthly wind fields to monthly rainfall in NWI (R^2=0.21)

Components	Coefficients	Significance at 95% level	Significance at 99% level
Wind speed in AS (X^1)	1.36	Yes	Yes
Wind speed in BoB (X^2)	−1.17	Yes	Yes
Wind speed in SIO (X^3)	0.35	No	No
Wind conv in AS (X^4)	0.17	No	No
Wind conv in BoB (X^5)	0.71	No	No
Wind conv in SIO (X^6)	0.34	No	No
Wind curl in AS (X^7)	0.13	No	No
Wind curl in BoB (X^8)	−0.27	No	No
Wind curl in SIO (X^9)	0.11	No	No

Continued.... Summary of MRL for CI

Result #10: MLR analysis shows contribution of monthly wind fields to monthly rainfall in CI (R^2=0.38)

Components	Coefficients	Significance at 95% level	Significance at 99% level
Wind speed in AS (X^1)	2.04	Yes	Yes
Wind speed in BoB (X^2)	−0.61	No	No
Wind speed in SIO (X^3)	0.65	No	No
Wind conv in AS (X^4)	1.55	No	No
Wind conv in BoB (X^5)	1.21	No	No
Wind conv in SIO (X^6)	1.62	No	No
Wind curl in AS (X^7)	-0.11	No	No
Wind curl in BoB (X^8)	−0.30	No	No
Wind curl in SIO (X^9)	0.46	No	No

Continued.... Summary of MLR for SPIN

Result #10: MLR analysis shows contribution of monthly wind fields to monthly rainfall in SPIN (R^2=0.18)

Components	Coefficients	Significance at 95% level	Significance at 99% level
Wind speed in AS (X^1)	0.998	No	No
Wind speed in BoB (X^2)	−1.20	Yes	No
Wind speed in SIO (X^3)	0.12	No	No
Wind conv in AS (X^4)	1.65	Yes	No
Wind conv in BoB (X^5)	2.06	Yes	No
Wind conv in SIO (X^6)	0.54	No	No
Wind curl in AS (X^7)	-0.62	No	No
Wind curl in BoB (X^8)	−0.44	No	No
Wind curl in SIO (X^9)	-0.08	No	No

Continued.... Summary of MLR for NEI

Result #10: MLR analysis shows contribution of monthly wind fields to monthly rainfall in NEI (R^2=0.10)

Components	Coefficients	Significance at 95% level	Significance at 99% level
Wind speed in AS (X^1)	0.20	No	No
Wind speed in BoB (X^2)	−0.31	No	No
Wind speed in SIO (X^3)	-0.13	No	No
Wind conv in AS (X^4)	-1.42	No	No
Wind conv in BoB (X^5)	0.06	No	No
Wind conv in SIO (X^6)	1.03	No	No
Wind curl in AS (X^7)	0.74	No	No
Wind curl in BoB (X^8)	−0.34	No	No
Wind curl in SIO (X^9)	0.41	No	No

Summary

- Statistical evidence showing that *short-time* (i.e., sub-monthly) fluctuations of Indian Ocean winds (wind speed, convergence and curl) are more related to the strength of ISMR than its *long-time* (i.e., monthly) fluctuations;

- Two hypothetical baseline mechanisms on how short-time fluctuations of Indian Ocean surface winds may affect ISMR during strong and weak ISMRs:

  (1) winds in the AS region affect ISMR through *moisture transport by more frequent strong winds (wind speed) on short timescales during strong ISMRs than weak ISMRs*, and

  (2) winds in the BoB affect ISMR through *the northward movement of more frequent convective systems represented by more frequent surface wind curl (vorticity) and convergence in the BoB during strong ISMRs than weak ISMRs*.

Extra Slides

Call for papers on Special Issue entitled "Asian Monsoons: Observations and Prediction" in an open access MDPI Journal *Atmosphere*.

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Special Issue "**Asian Monsoons: Observation and Prediction**"

Introduction: We are organizing a Special Issue entitled "Asian Monsoons: Observation and Prediction" for the open-access journal Atmosphere (ISSN 2073-4433; CODEN: ATMOCZ; https://www.mdpi.com/journal/atmosphere; Impact Factor: 2.046). Based on your high-quality work and experience in this area, we warmly invite you to submit a manuscript for publication in this Special Issue.

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- East Asian monsoon
- South Asian monsoon
- Indian monsoon
- Monsoon forecasting
- Monsoon decadal changes
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