Meridional SST Gradients and Intraseasonal Rainfall Variability in the Bay of Bengal

Alex Kinsella, Woods Hole Oceanographic Institution

IITM Seminar, March 9, 2023

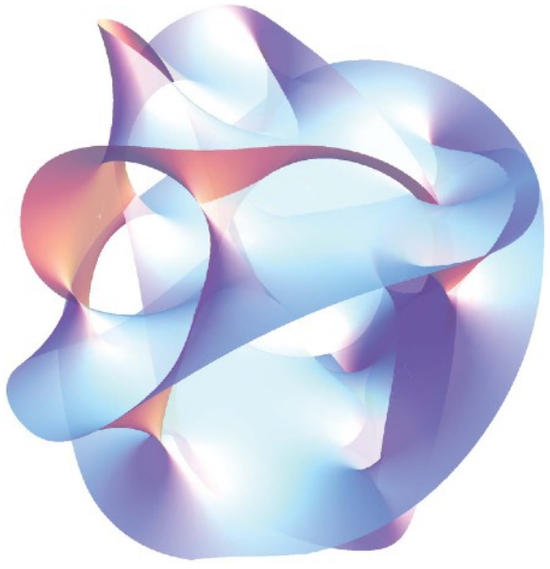
Work in collaboration with Amala Mahadevan and Gualtiero Spiro Jaeger

About Me

- From San Francisco, California, USA

- Postdoctoral investigator at Woods Hole Oceanographic Institution (near Boston, Massachusetts, USA)

- Advised by Amala Mahadevan



- Ph.D. in high energy theoretical physics (dissertation on string theory and geometry) from University of California, Santa Barbara (2021)

- B.S. in physics and mathematics from Stanford University (2015)

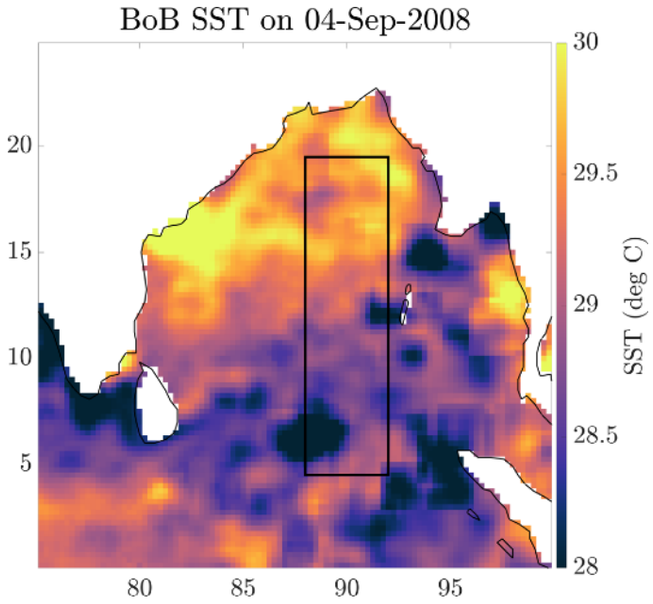
- Research interests: Air-sea interaction in the northern Indian Ocean, cloud dynamics and microphysics

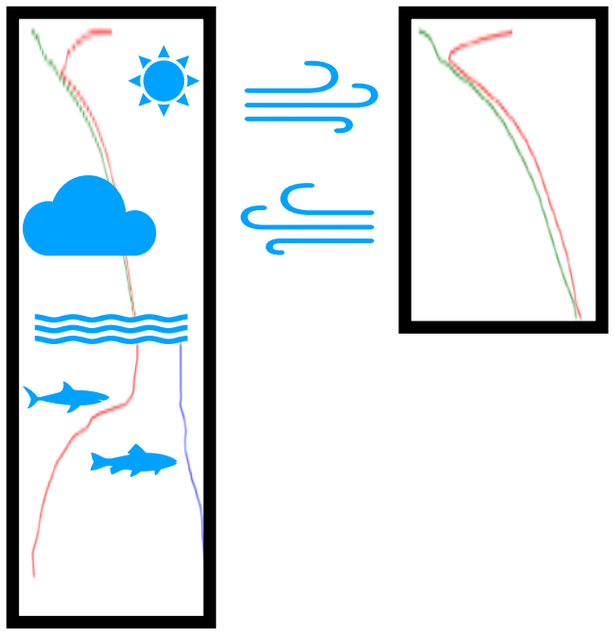
- Personal interests: Birding, botany, weather

Current Work

1. The role of Bay of Bengal meridional SST gradients in monsoon intraseasonal rainfall variability

   - With Gualtiero Spiro Jaeger and Amala Mahadevan





2. Investigation of ISM freshwater feedback in the Bay of Bengal with a coupled column model

   - With William R. Boos and Amala Mahadevan

3. The role of cloud turbulence in the cloud droplet spectrum and autoconversion parameterization

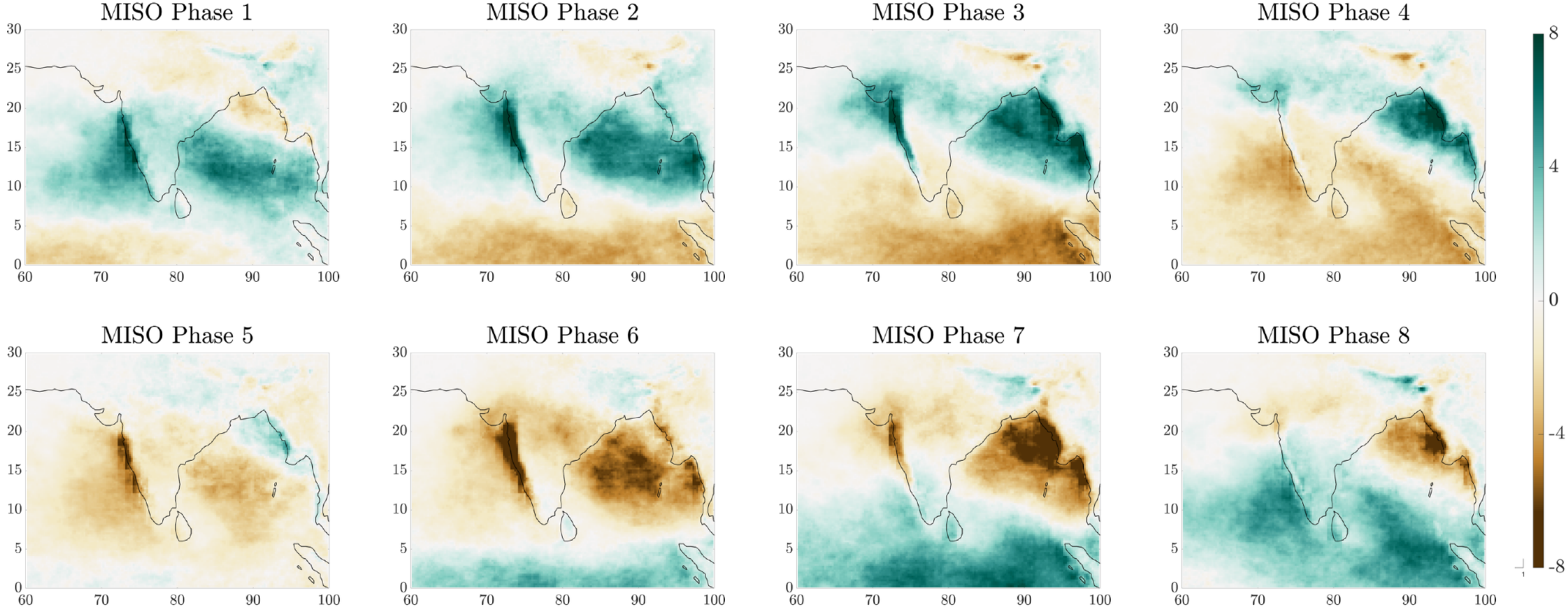
   - With Rama Govindarajan and Amala Mahadevan

Outline

- 1: MISO and SST gradients
- 2: Rainfall and SST gradient climatologies and correlations
- 3: The mixed layer heat budget gradient

Motivation: MISO

- 30-90 day oscillations in monsoon rainfall
- Likely the boreal summer incarnation of the MJO & controlled largely by moisture gradients
- MISO index of Suhas et al. (2013):

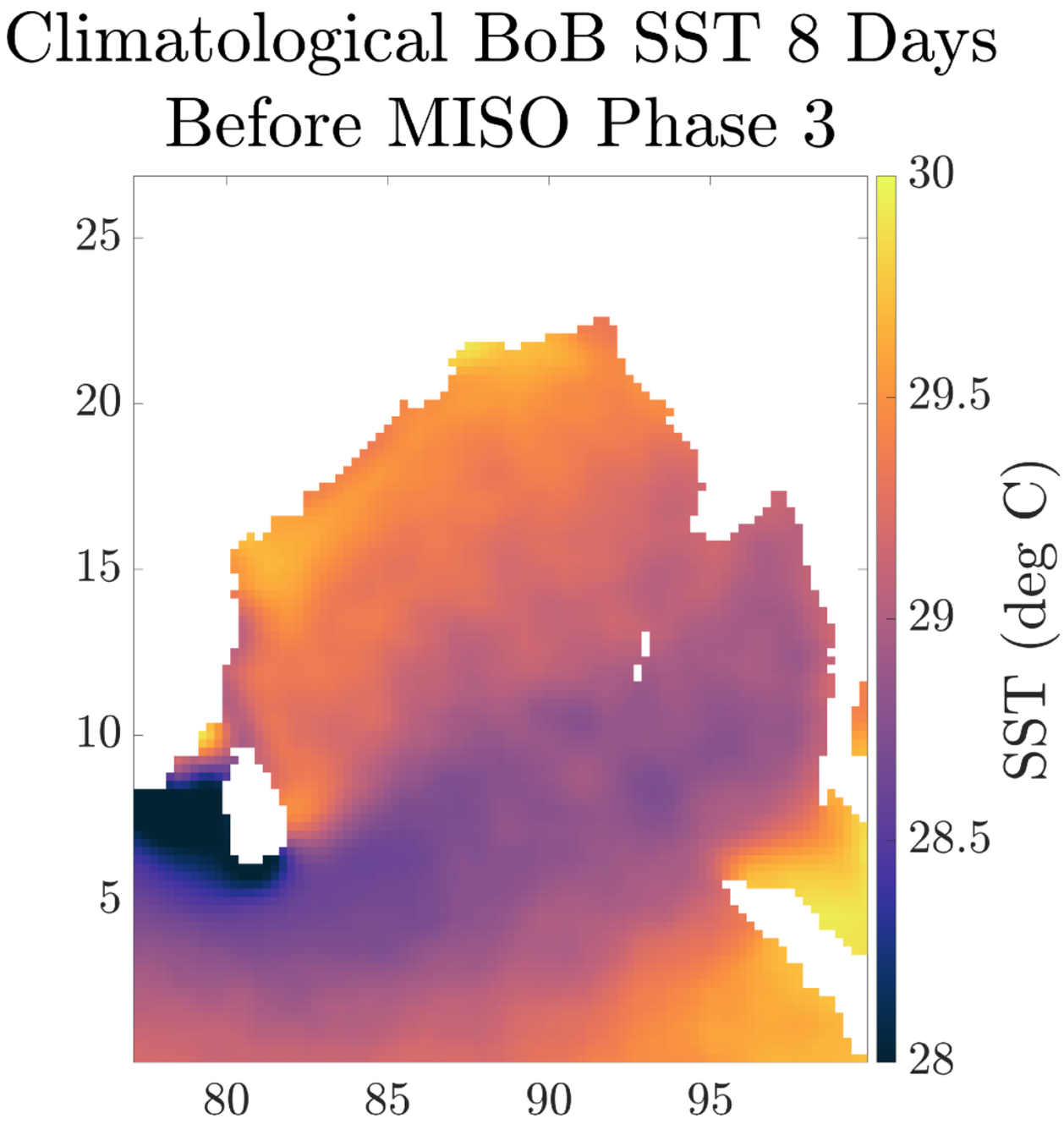


Data: TRMM 1998-2019

SST Gradients and Rainfall: Coupling Mechanisms

- Shankar et al. (2008): Active phase of MISO tends to be preceded by a strongly positive meridional SST gradient in BoB

- See also e.g. Vecchi and Harrison (2002), Joseph and Sabin (2008), Zhang et al. (2018), Li et al. (2022)

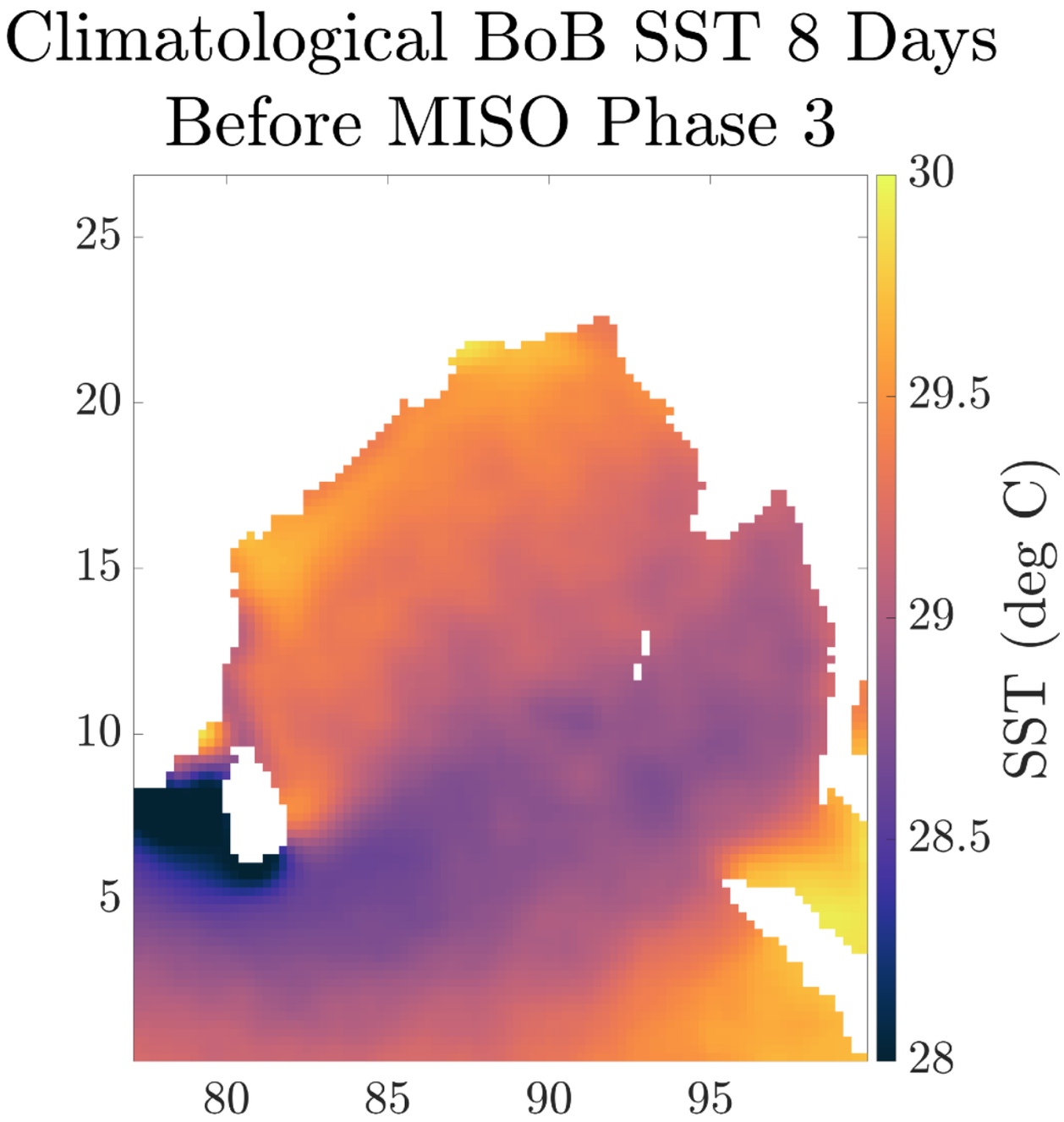


Data: 1998-2021 OISST

SST Gradients and Rainfall: Coupling Mechanisms

<u>Mechanisms</u>

- Sea level pressure adjustment (Lindzen and Nigam 1987)
- Vertical momentum mixing (Wallace et al. 1989; Hayes et al. 1989)
- Radiative feedbacks: atmospheric convection decreases incident shortwave at sea surface



Data: 1998-2021 OISST

Motivating Research Questions

- Does the meridional SST gradient preceding a MISO event determine the strength of the event?

- More generally, is there a distinct difference between MISO events preceded by large or small SST gradients?

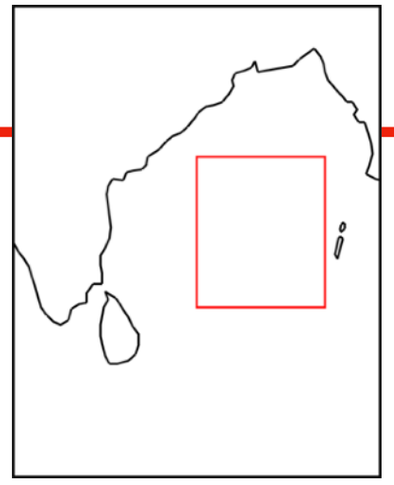
- Which surface flux and mixed layer processes control the SST gradient?

Methods: Datasets/Reanalysis Used

Data	Name	Spatial Resolution	Temporal Resolution	Years Available
Rainfall	TRMM 3B42	1/4 deg	3-Hourly	1998-2019
SST	OISSTv2.1	1/4 deg	Daily	1982-2021
Upper ocean TS	GLORYS12v1	1/12 deg	Daily	1993-2020
Surface heat fluxes	OAFlux	1 deg	Daily	1985-2020
Winds	ERA5	1/4 deg	Hourly	1959-2023

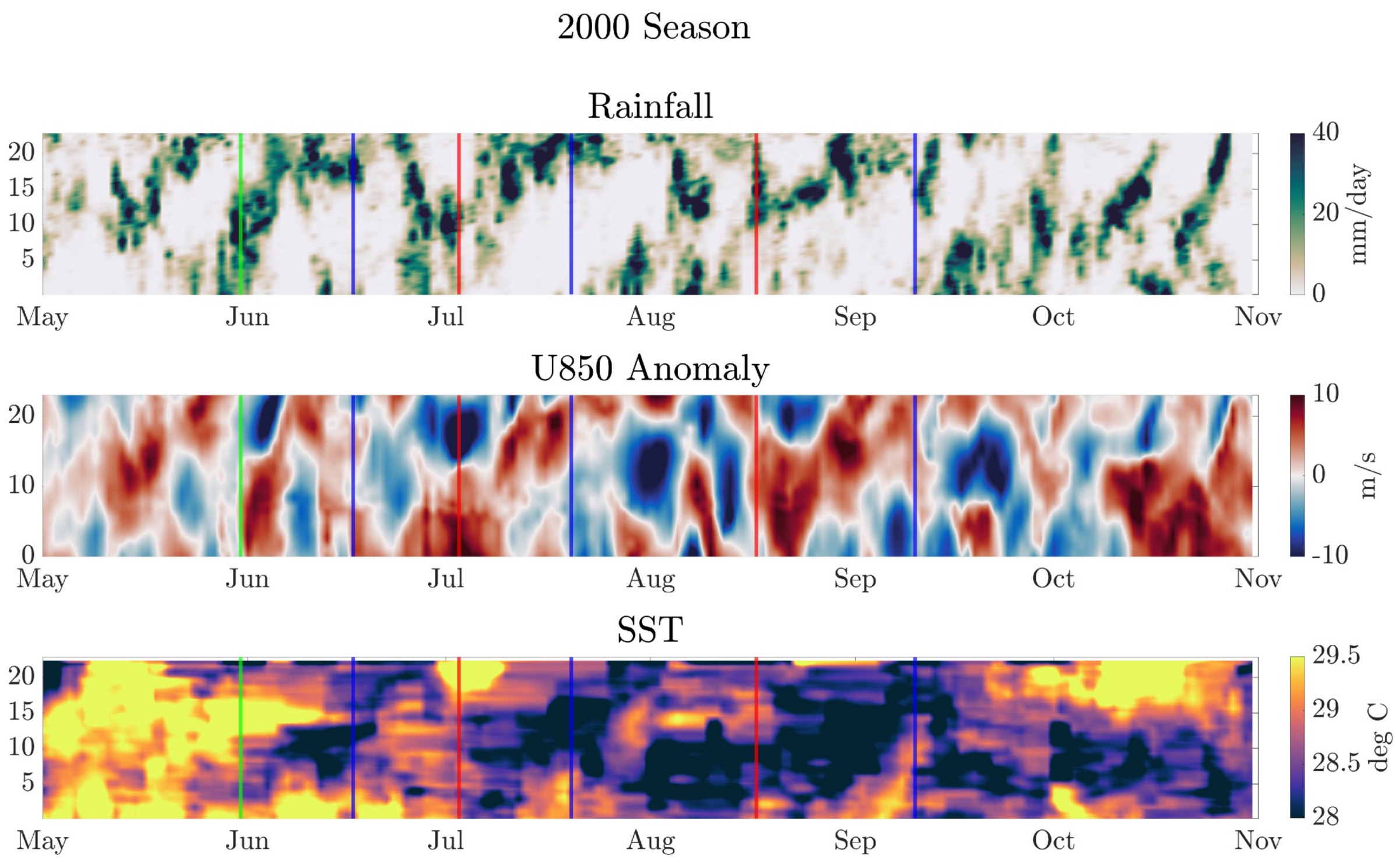
Methods: MISO Event ID

- Method 1: intraseasonal (30-90 day) peaks and troughs of at least one standard deviation in central BoB rainfall (10-15N, 85-92E)



- Method 2: Use an index — so many options!
  - S13, KK12, RMM, OMI, MII, BSISO, and more
  - Indices do not agree with each other well on MISO events

Methods: MISO Event ID



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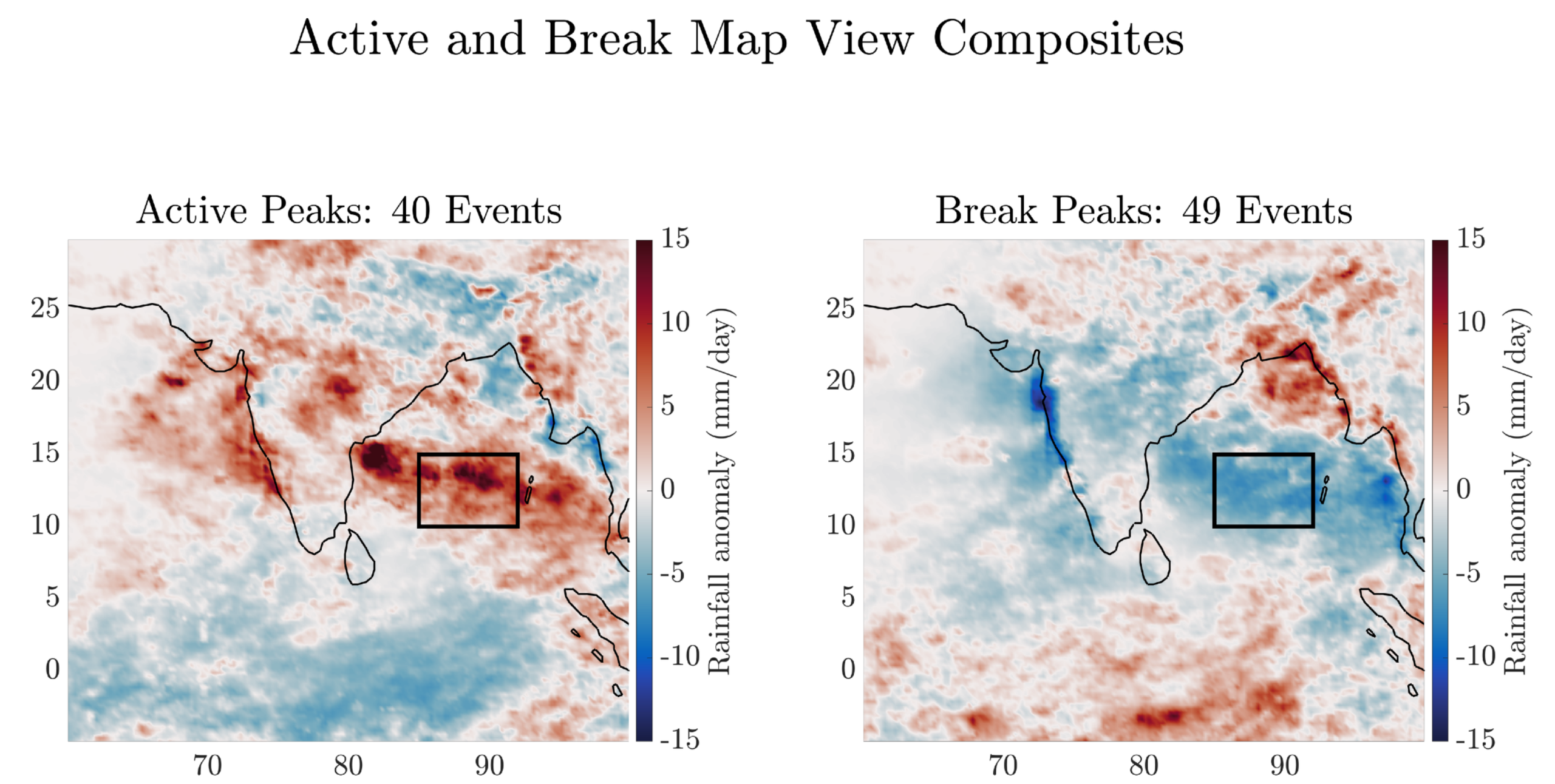
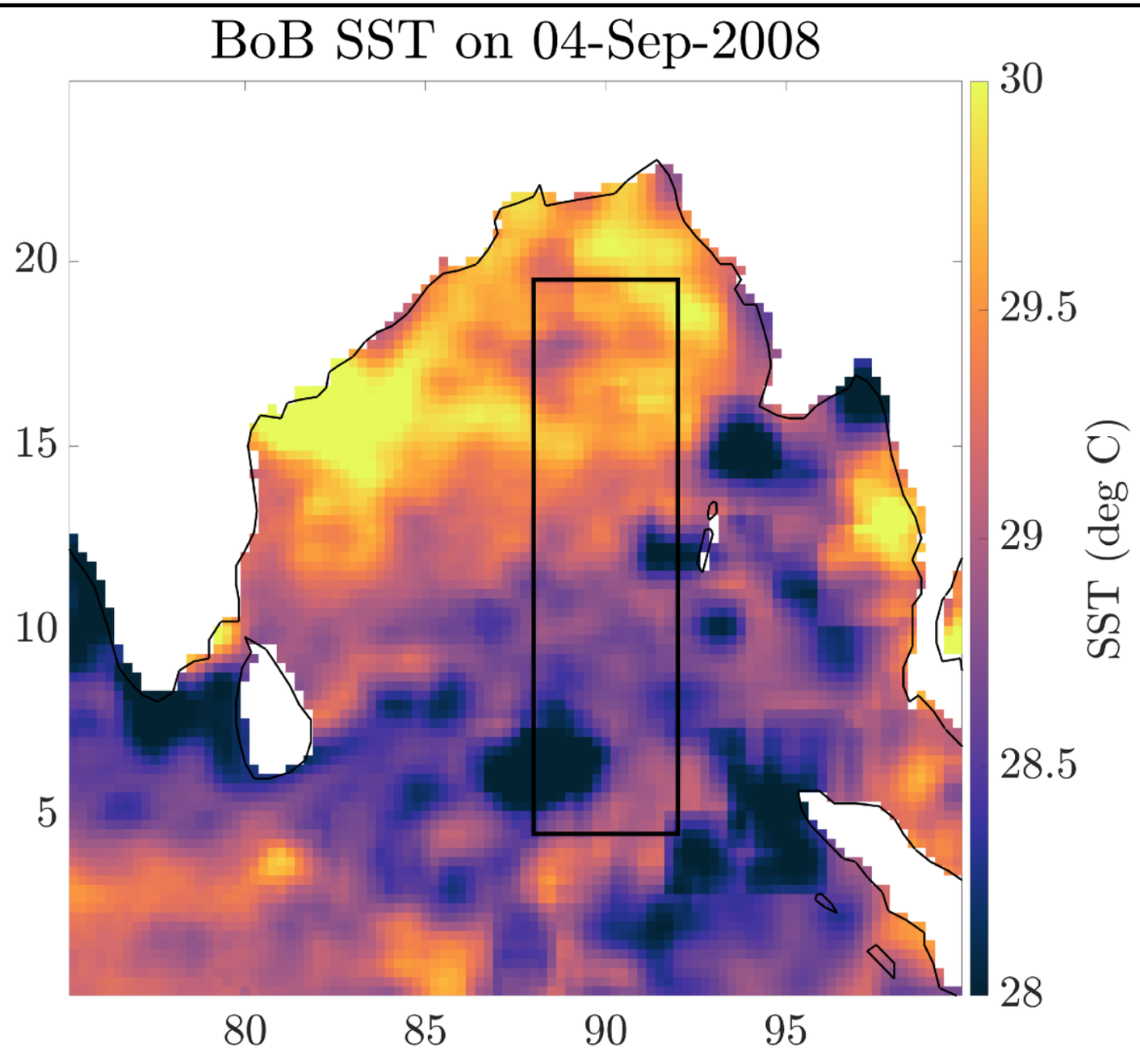
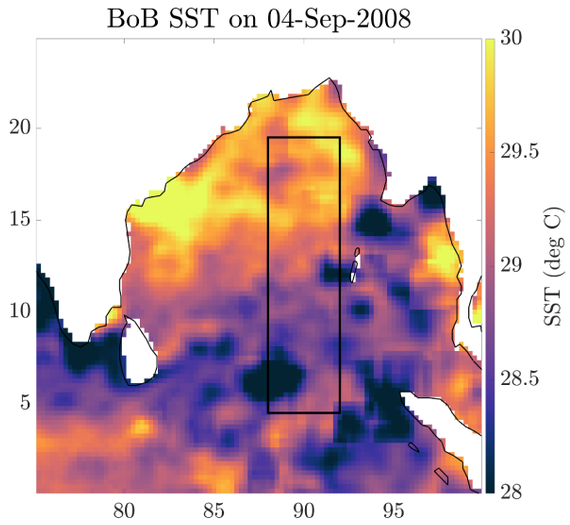


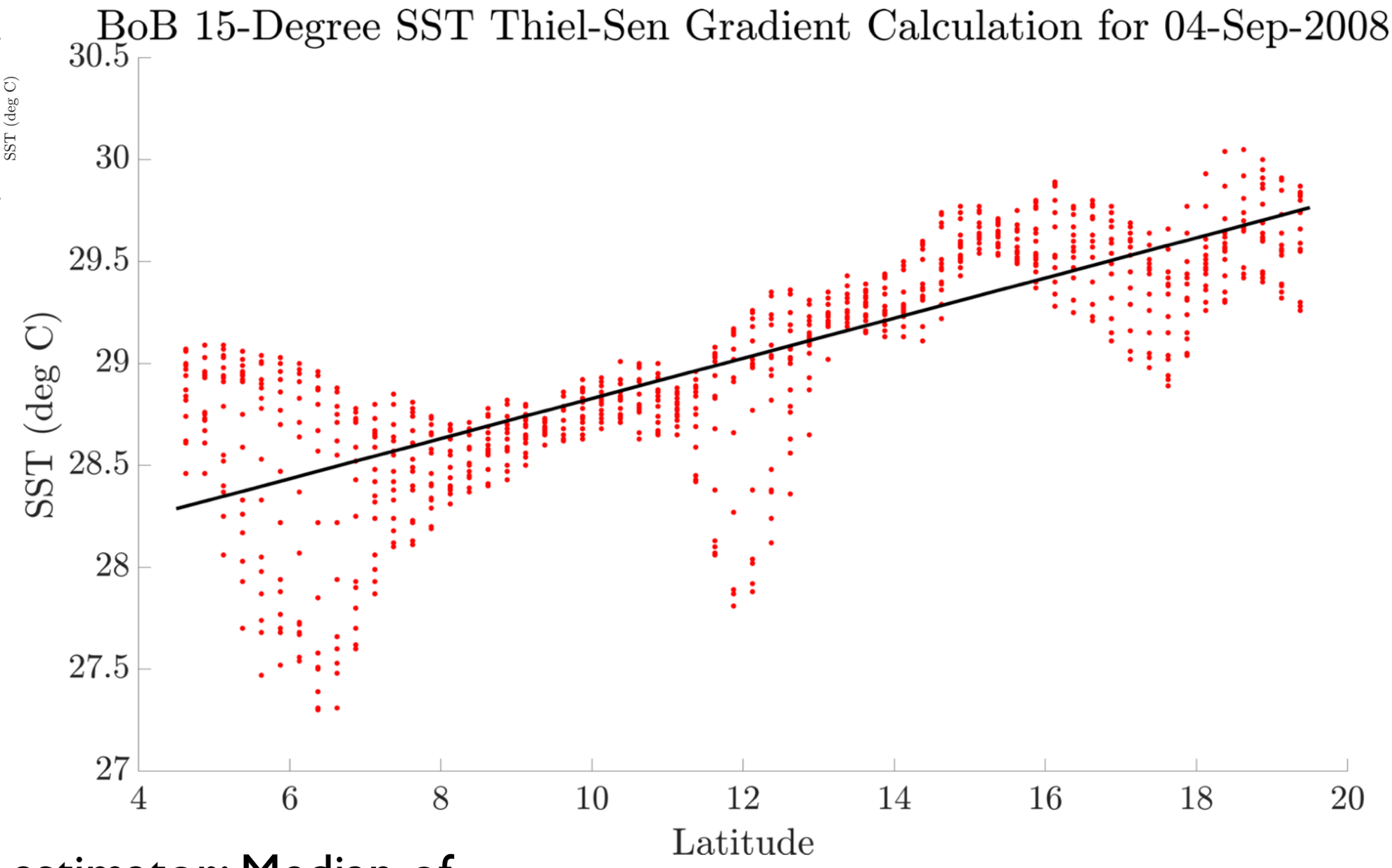
Methods: SST Gradient Calculation



Theil-Sen linear estimator: Median of slopes between all points, excluding those for the same latitude

Methods: SST Gradient Calculation





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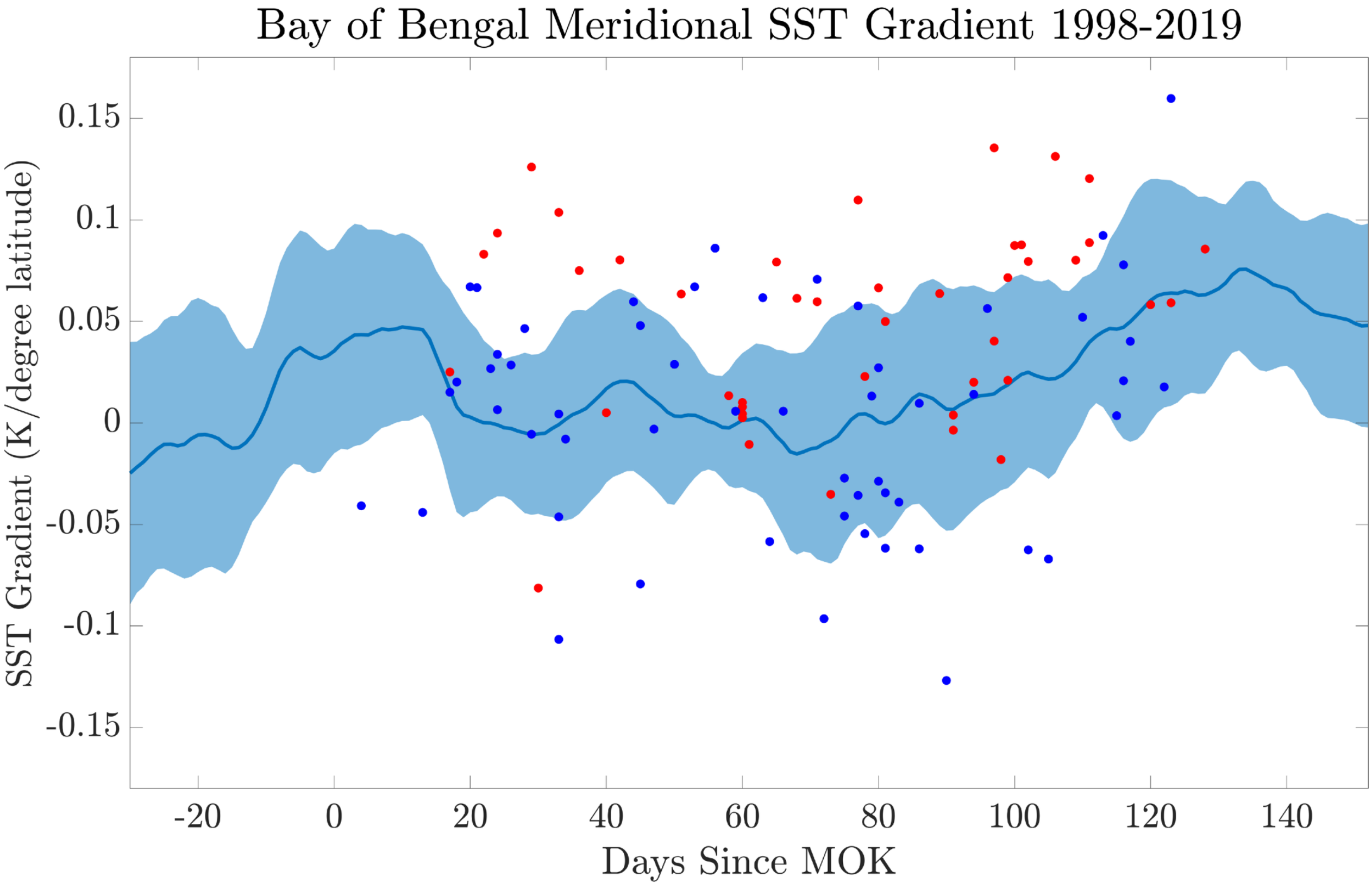
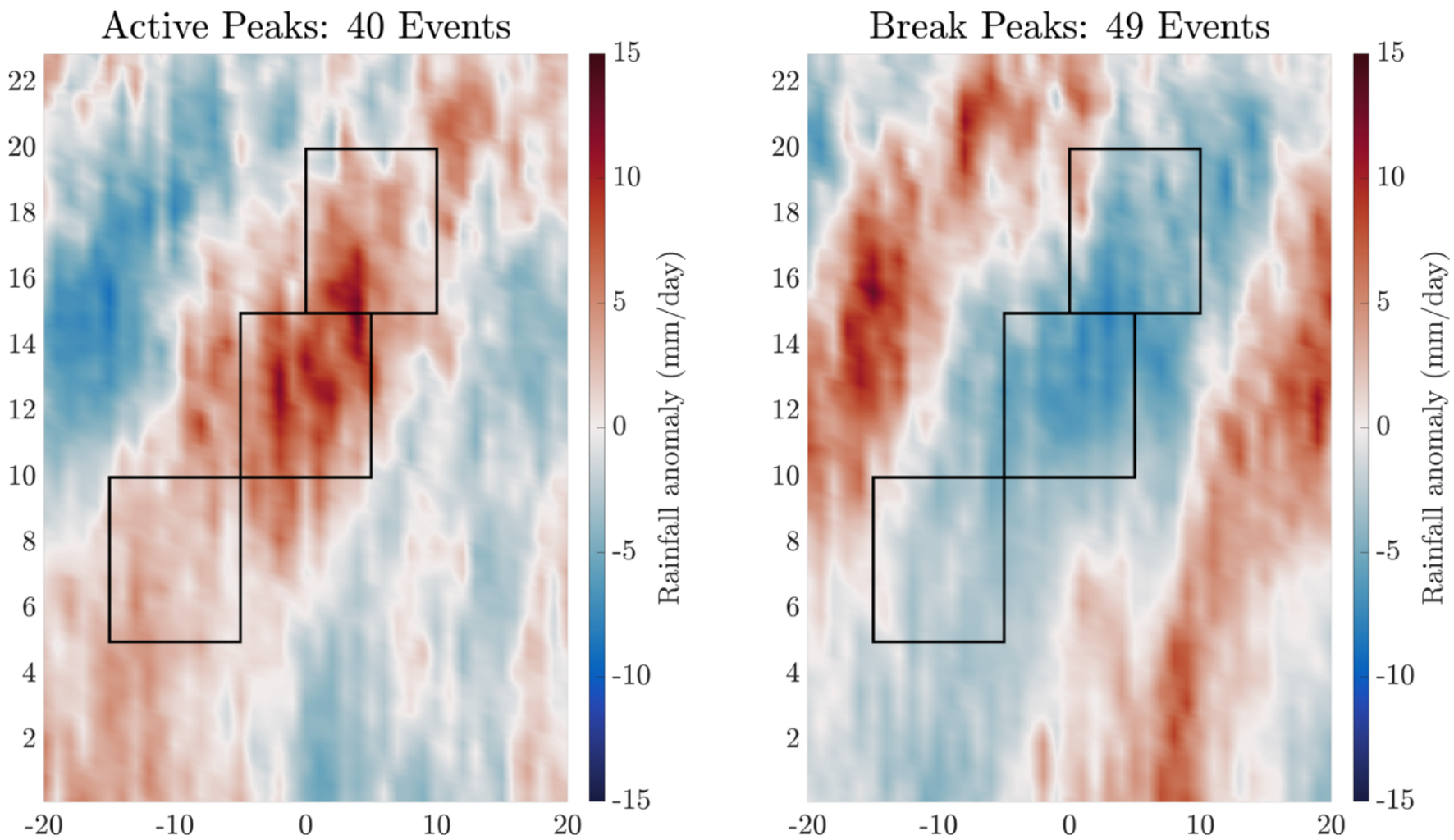
SST Gradients in MISO



SST Gradient vs. Rainfall During MISO



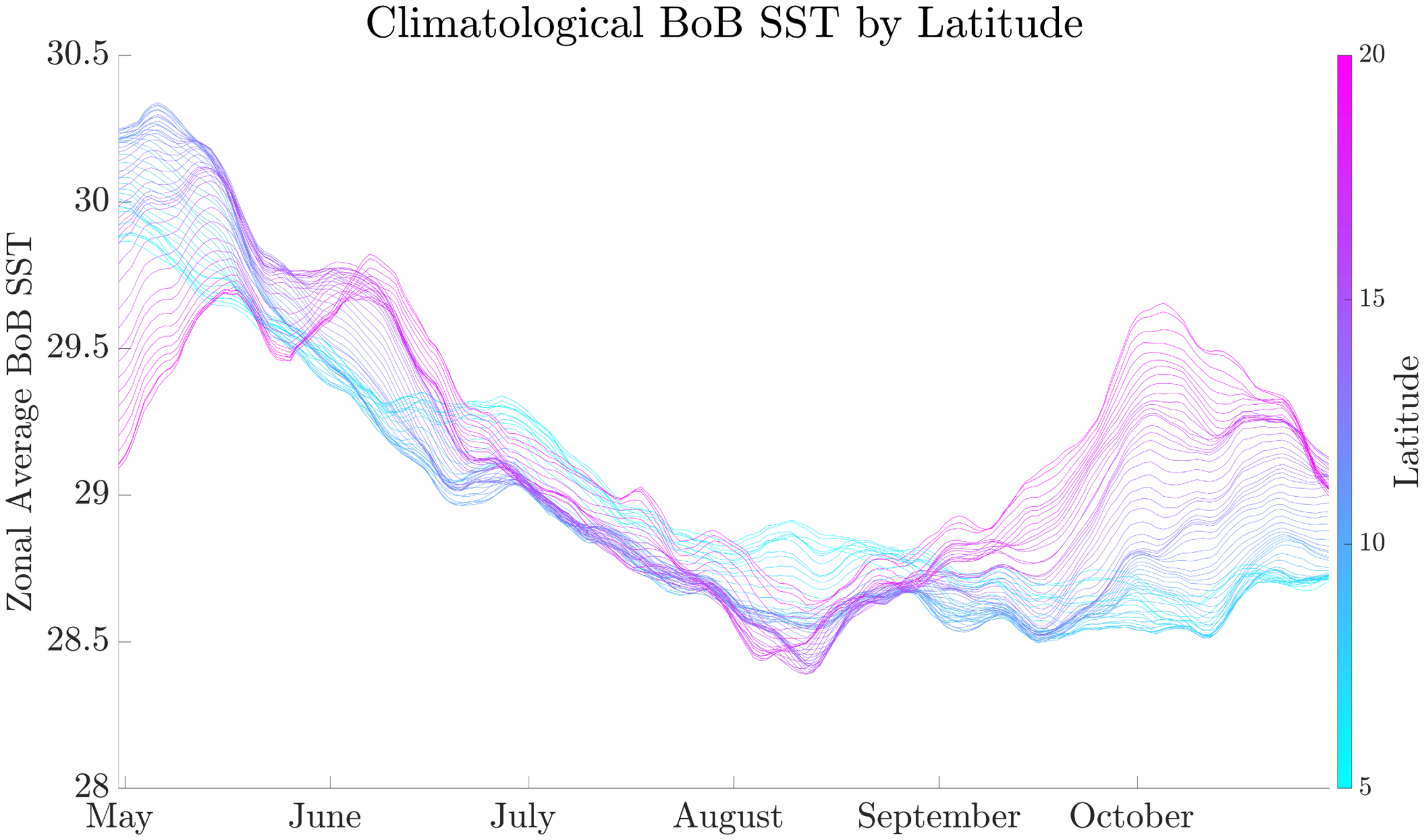
Linear Relations Between SST Gradient and Event Strength			
MISO Type	Pre-Peak	During-Peak	Post-Peak
Active	$m = 39.759 \pm 10.056$ $r^2 = 0.273$ $p = 0.000324$	$m = 66.647 \pm 16.938$ $r^2 = 0.271$ $p = 0.000343$	$m = 34.57 \pm 18.421$ $r^2 = 0.0607$ $p = 0.0683$
Break	$m = 11.31 \pm 5.0921$ $r^2 = 0.0757$ $p = 0.0312$	$m = 21.717 \pm 6.8401$ $r^2 = 0.159$ $p = 0.00264$	$m = 8.8674 \pm 13.12$ $r^2 = 0.0114$ $p = 0.502$

SST Gradient vs. Rainfall During MISO

- Takeaway: When you combine all events, SST gradient does not determine MISO rainfall strength

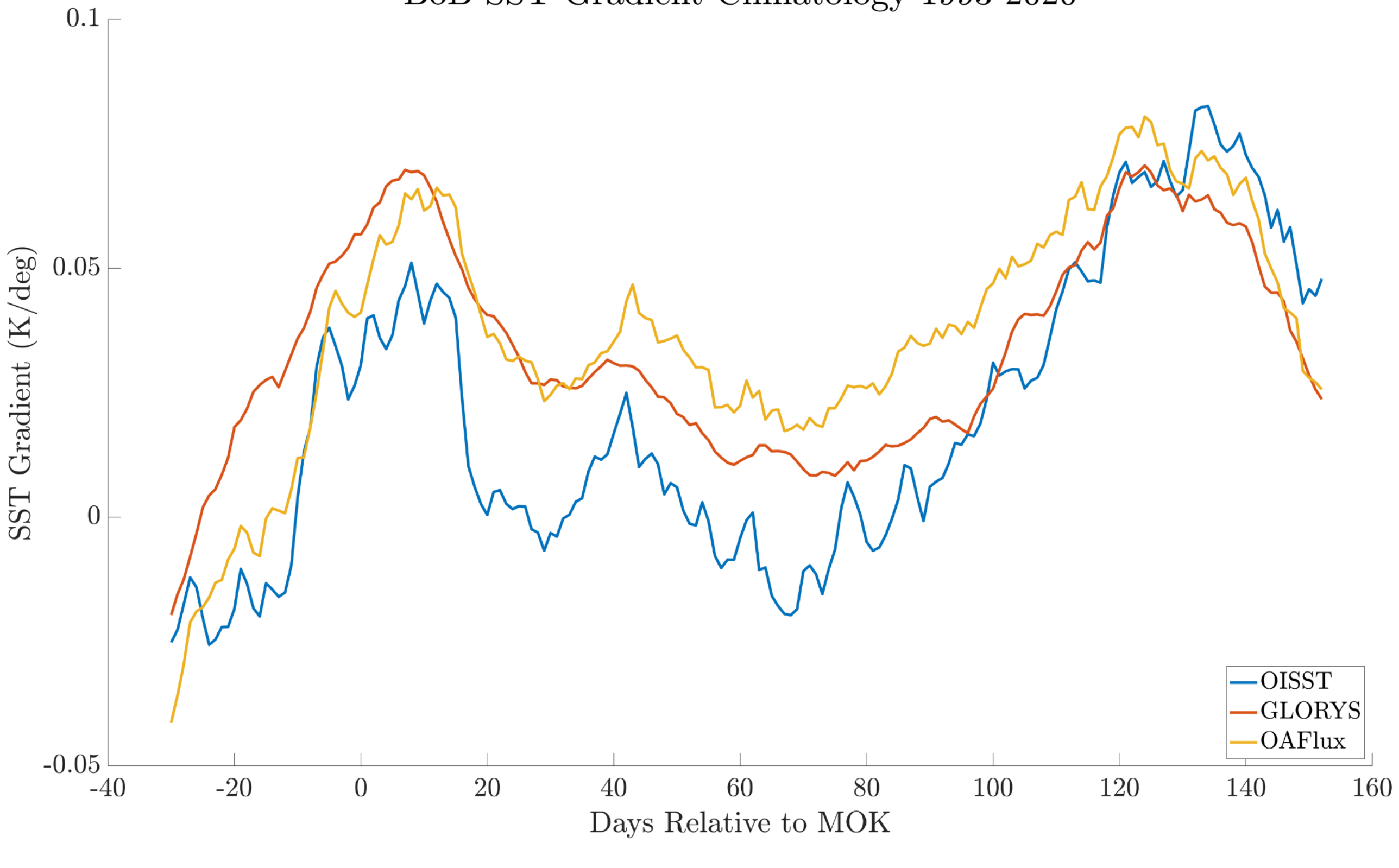
- What's missing?
  - 1: Rapid SST (gradient) change in the BoB
  - 2: Subseasonal context for SST gradient and rainfall

Climatological SST by Latitude

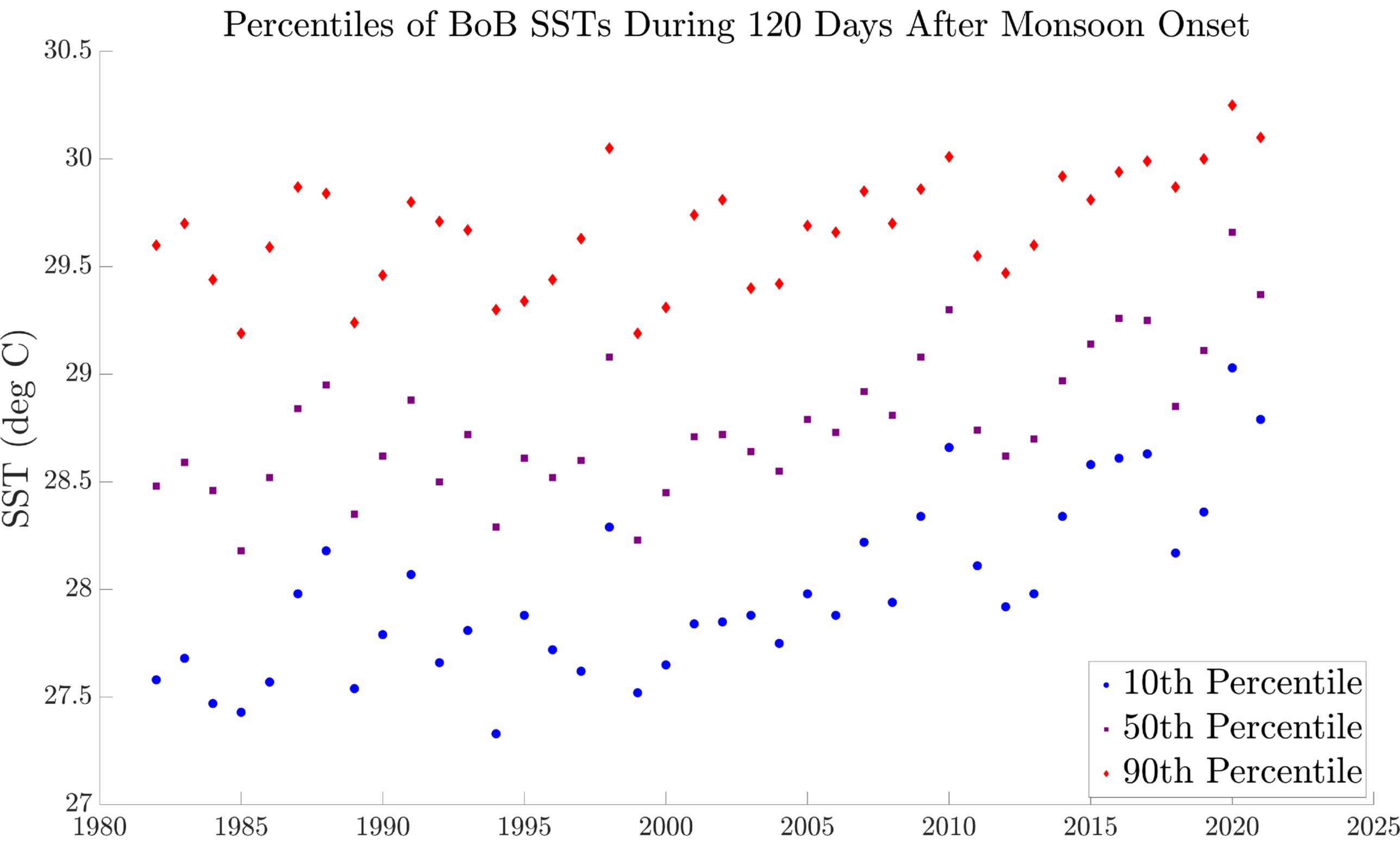


Data: OISST 1998-2019

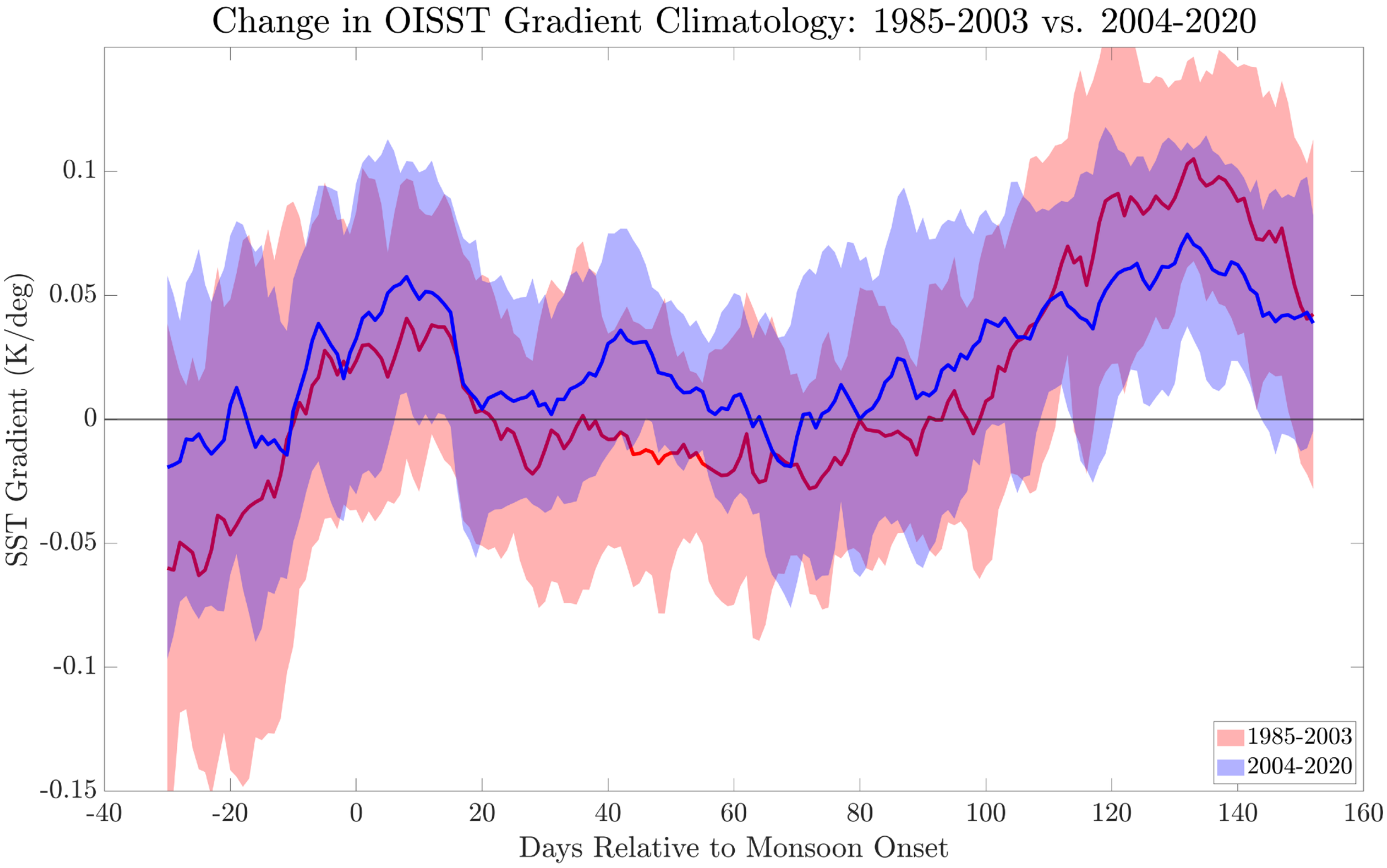
Climatological SST Gradient



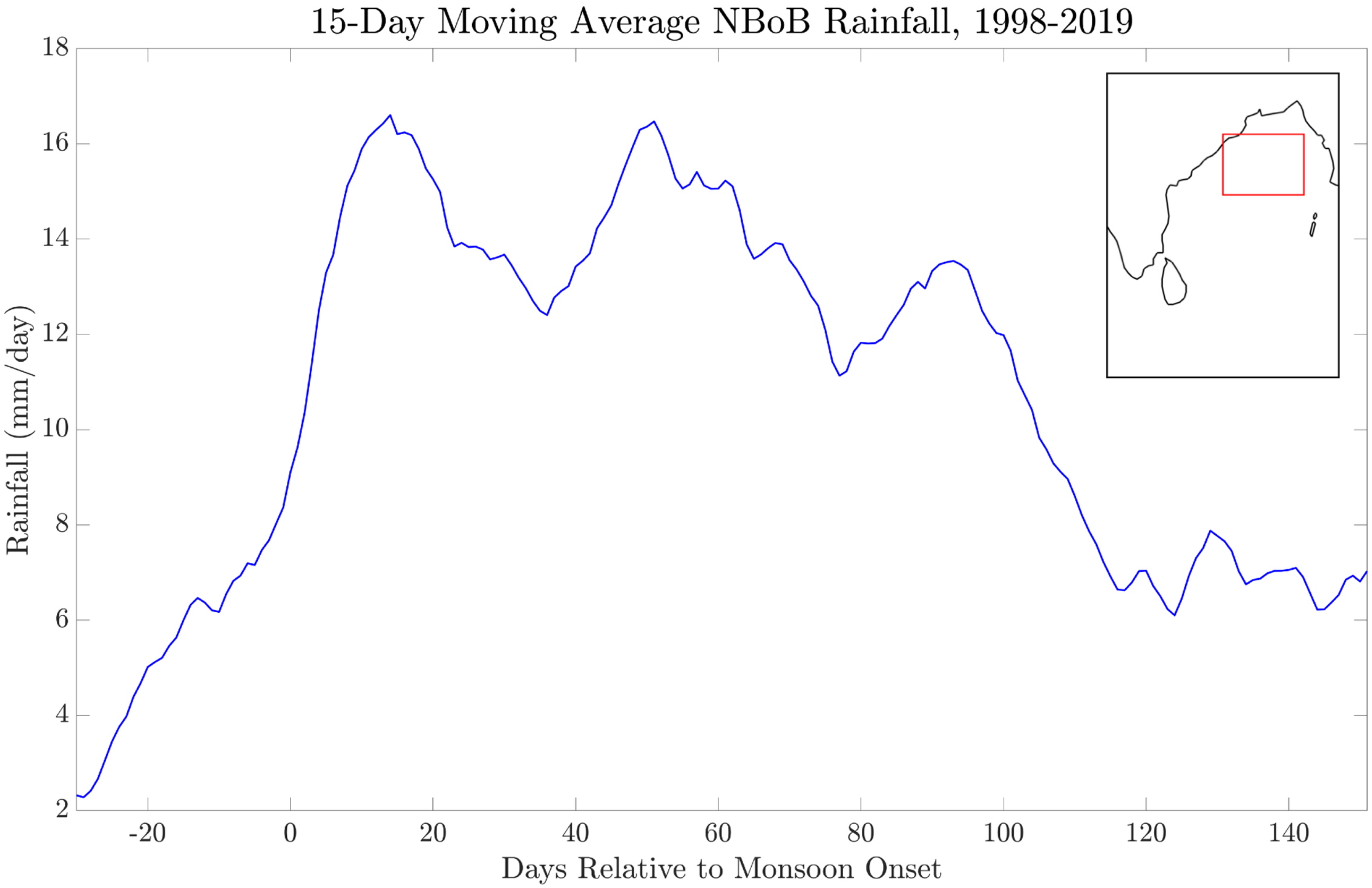
BoB SST Change



BoB SST Gradient Change



SST Gradients and Rainfall



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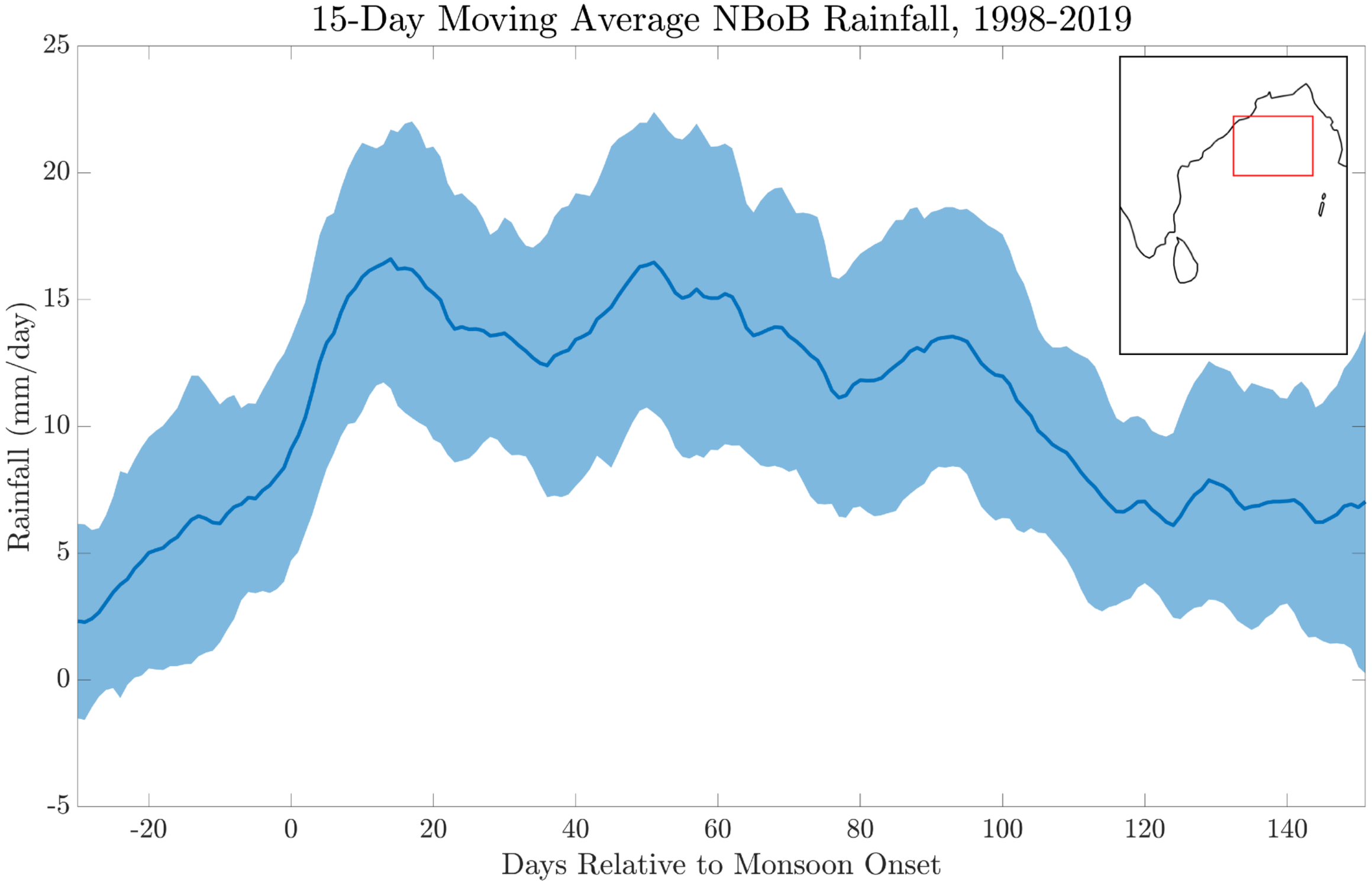

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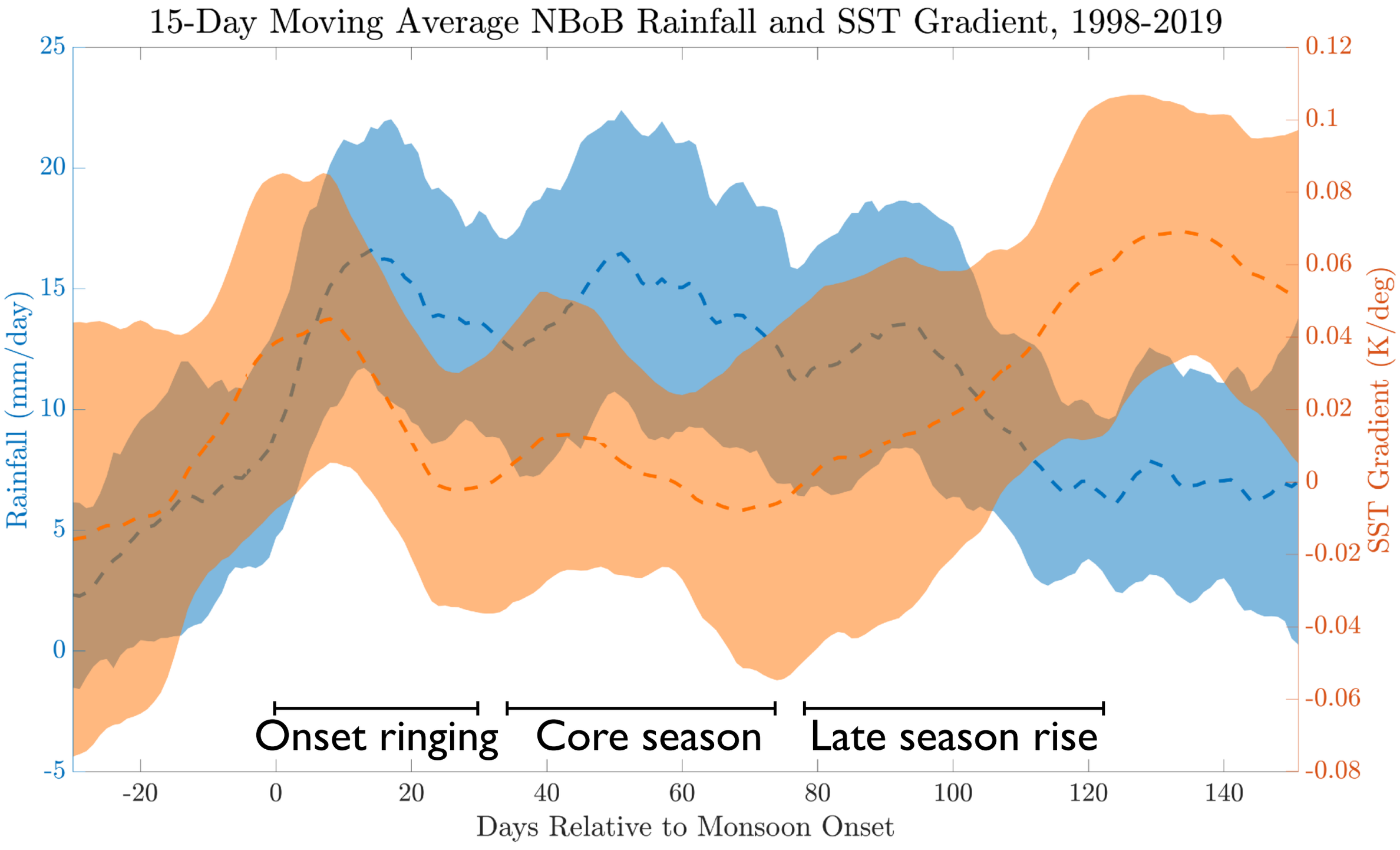
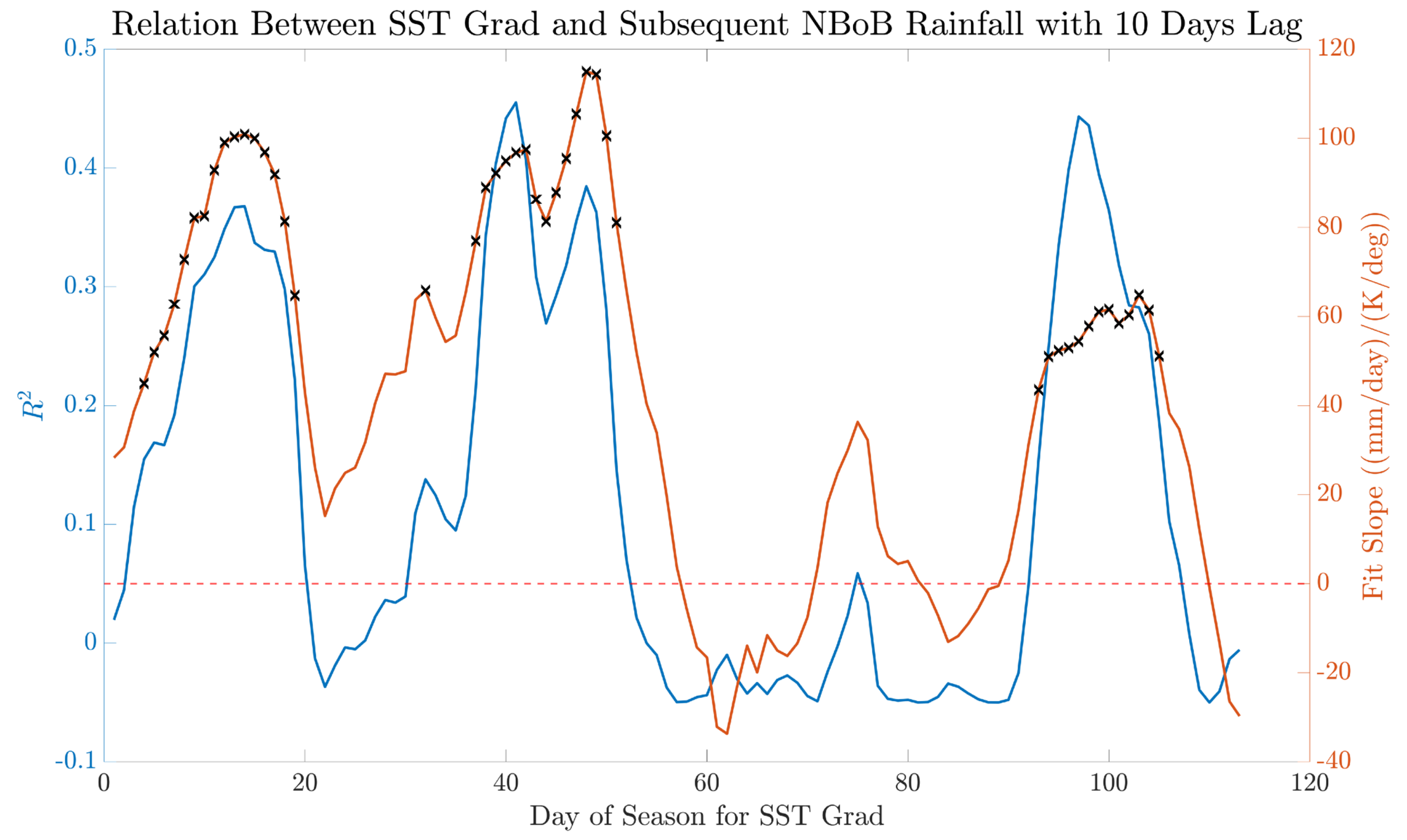
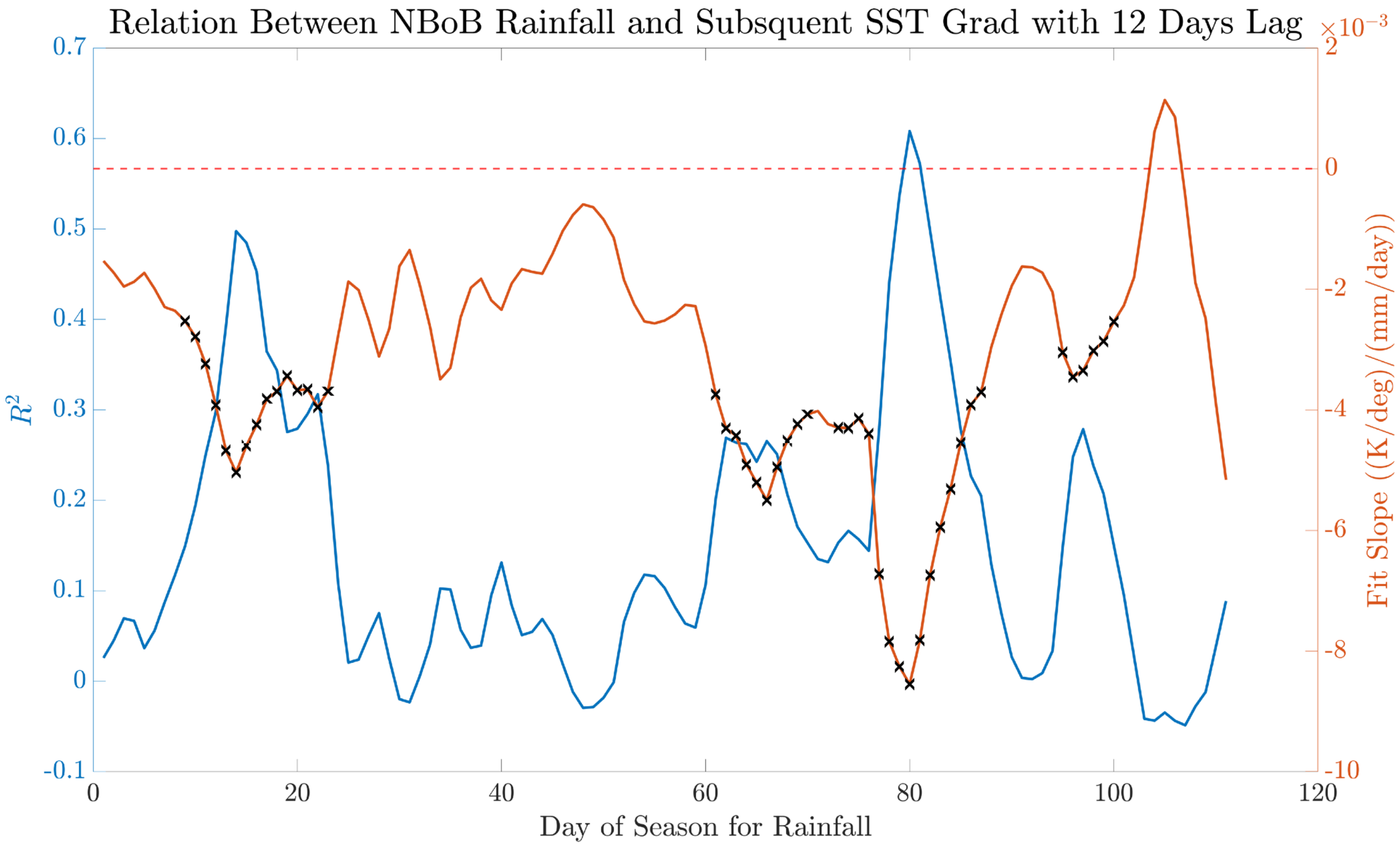


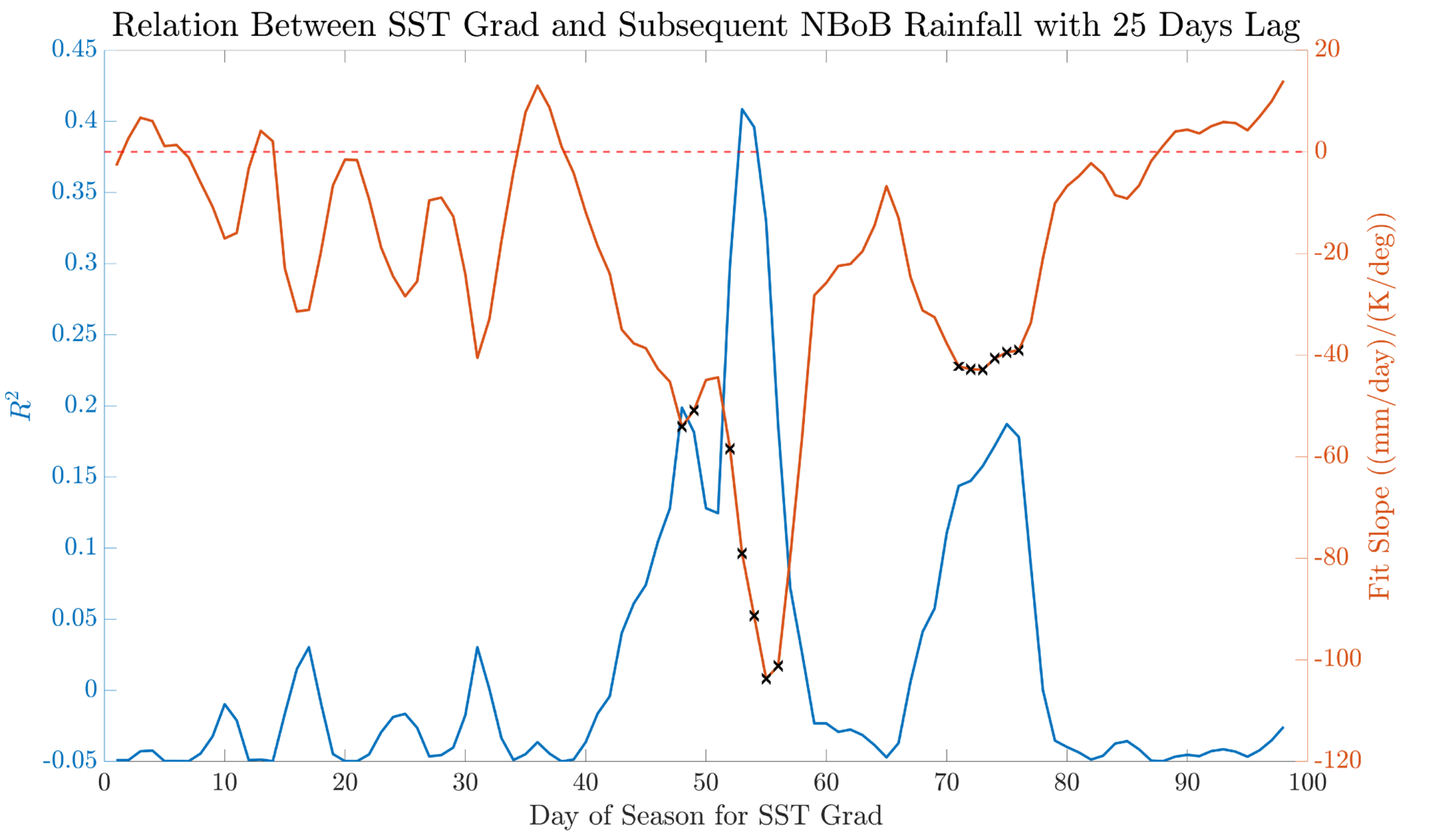
Correlations I



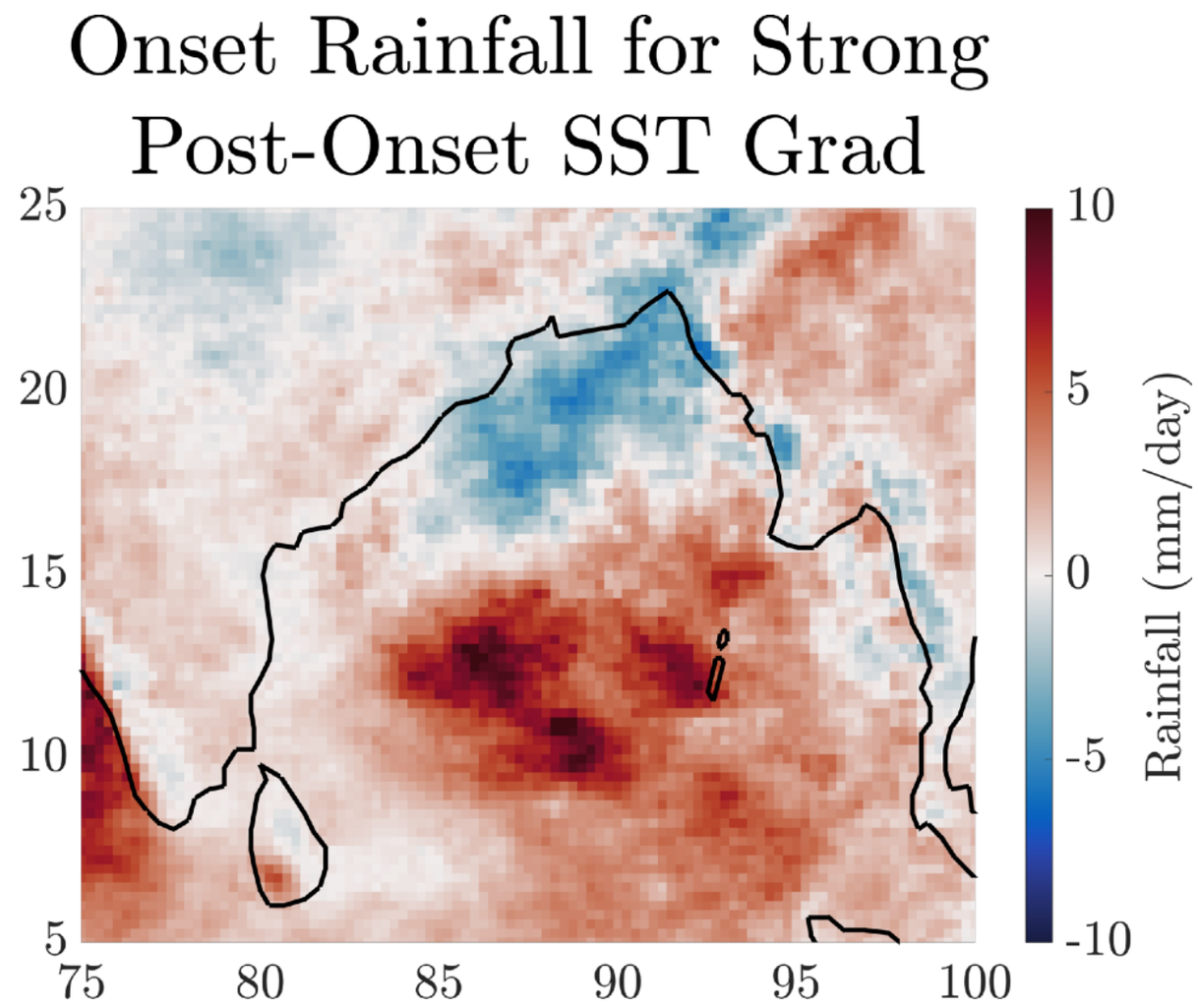
Correlations 2

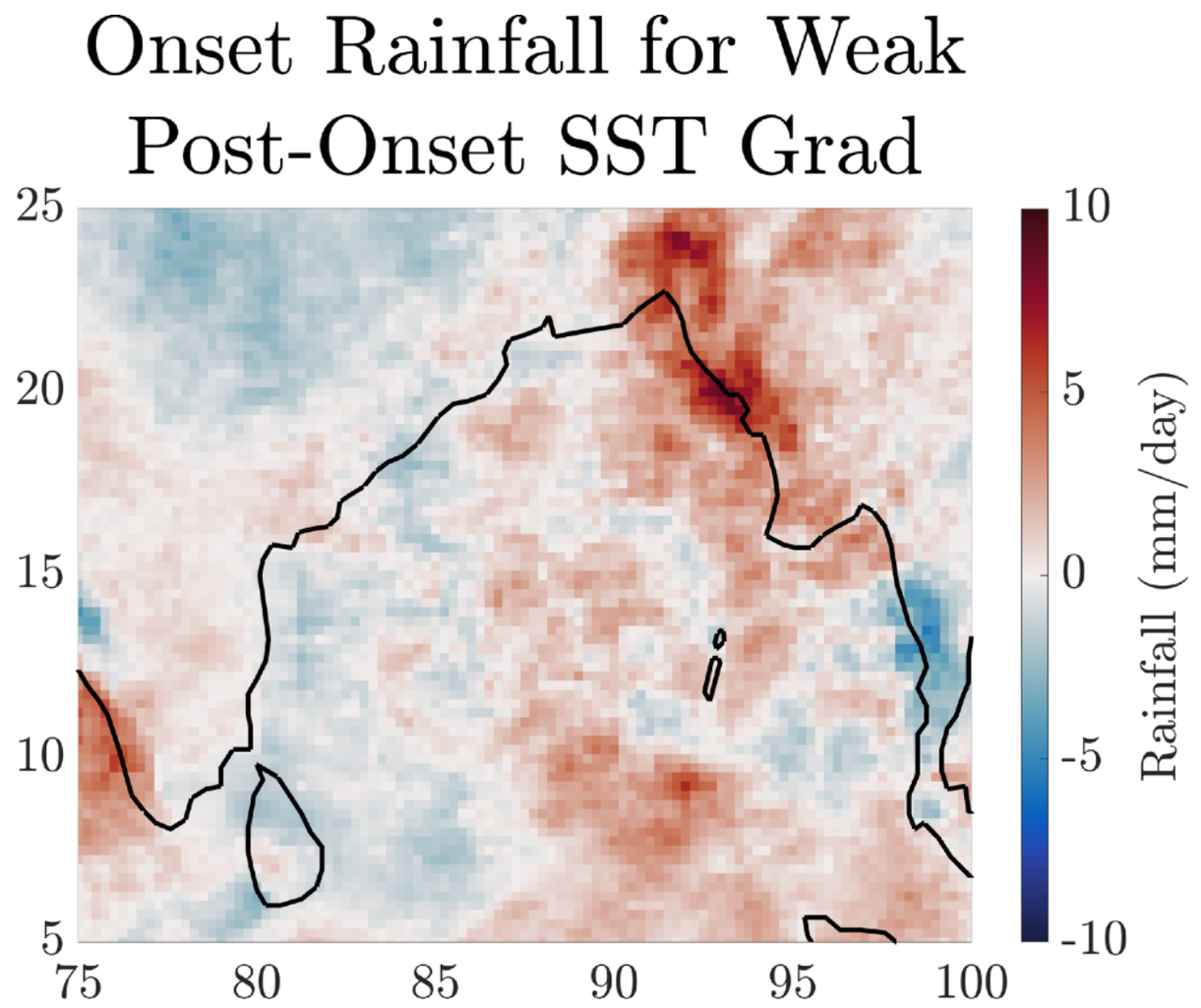


Correlations 3

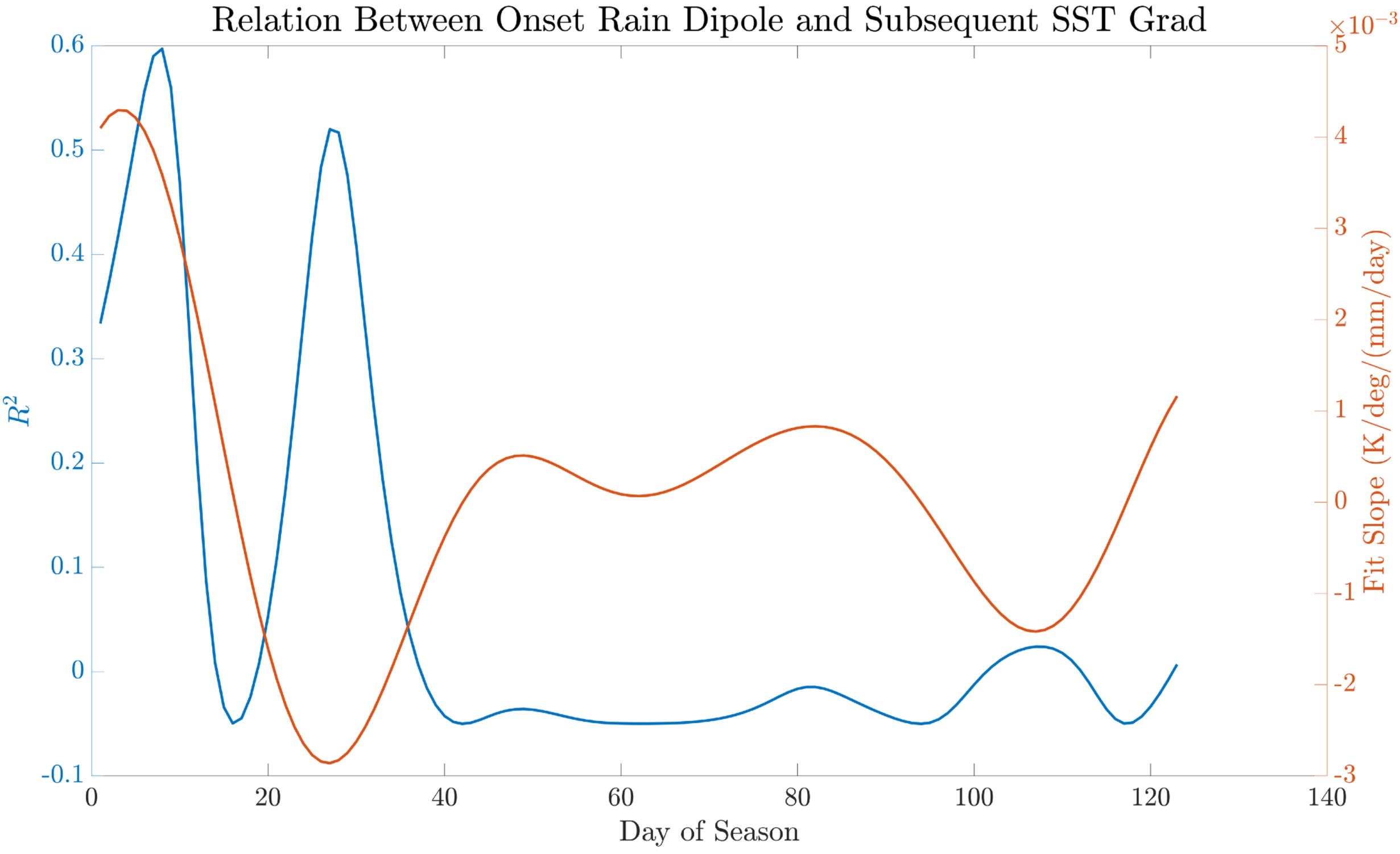


Onset Phase: Rainfall Dipole





Onset Phase: Ringing



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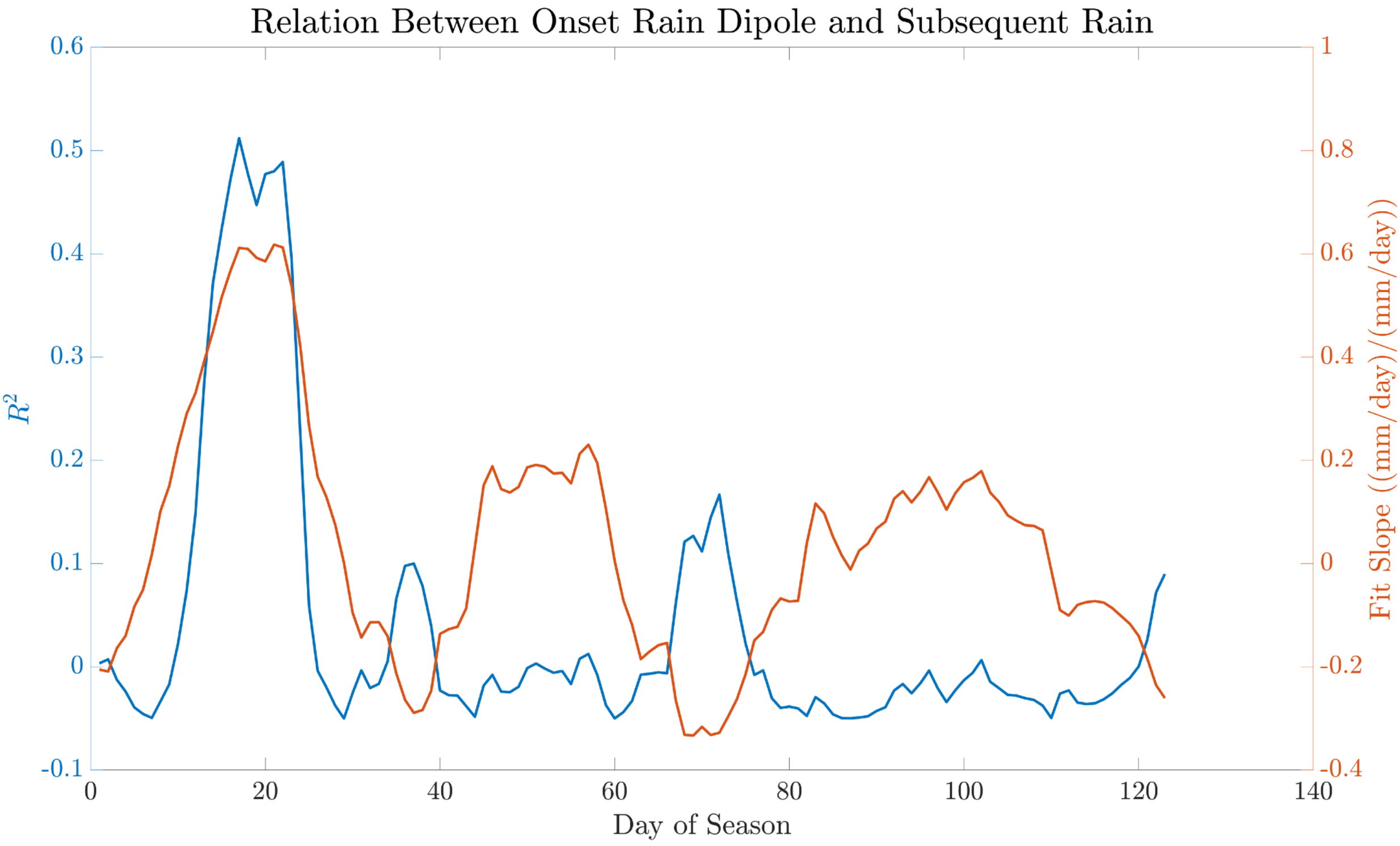
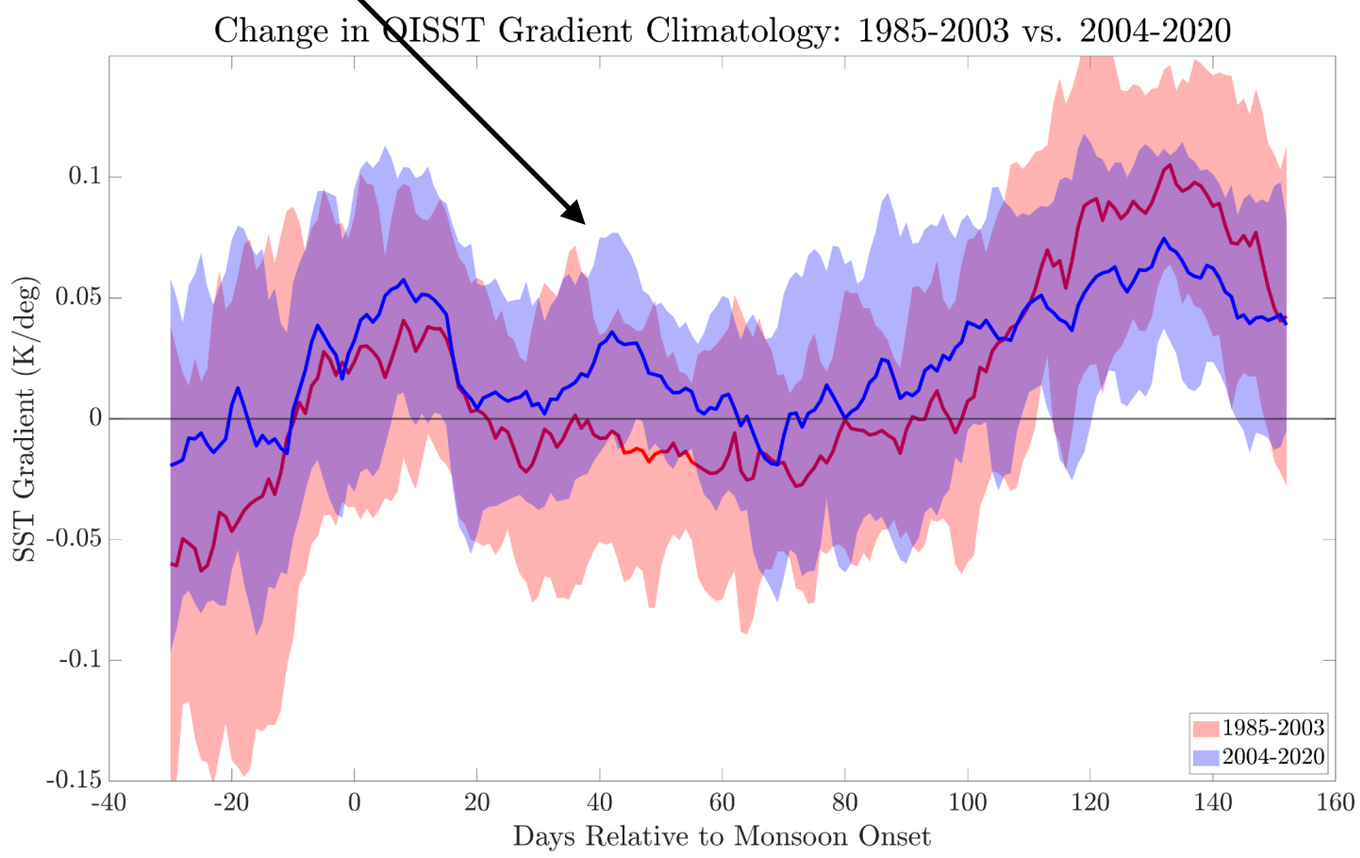


Core Season

- Hypothesis: The climatologically positive SST gradient around day 40 contributes to the rainfall peak around day 50.

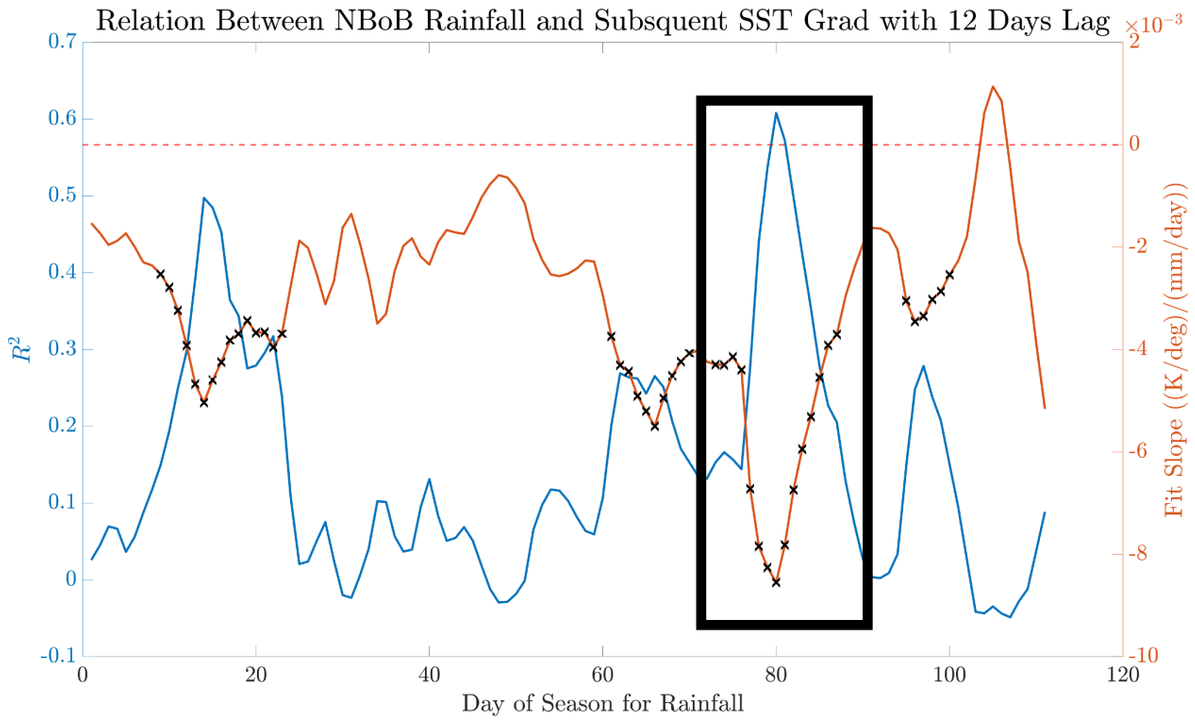
- Question: Why did this peak get stronger in recent decades? Internal variability or forcing?



Late Season: SST Grad Rise

- Hypothesis 1: SST grad rise increases odds of a MISO event during the late season

- Hypothesis 2: Climatological break around day 80 typically initiates the SST gradient rise



Mixed Layer Heat Budget

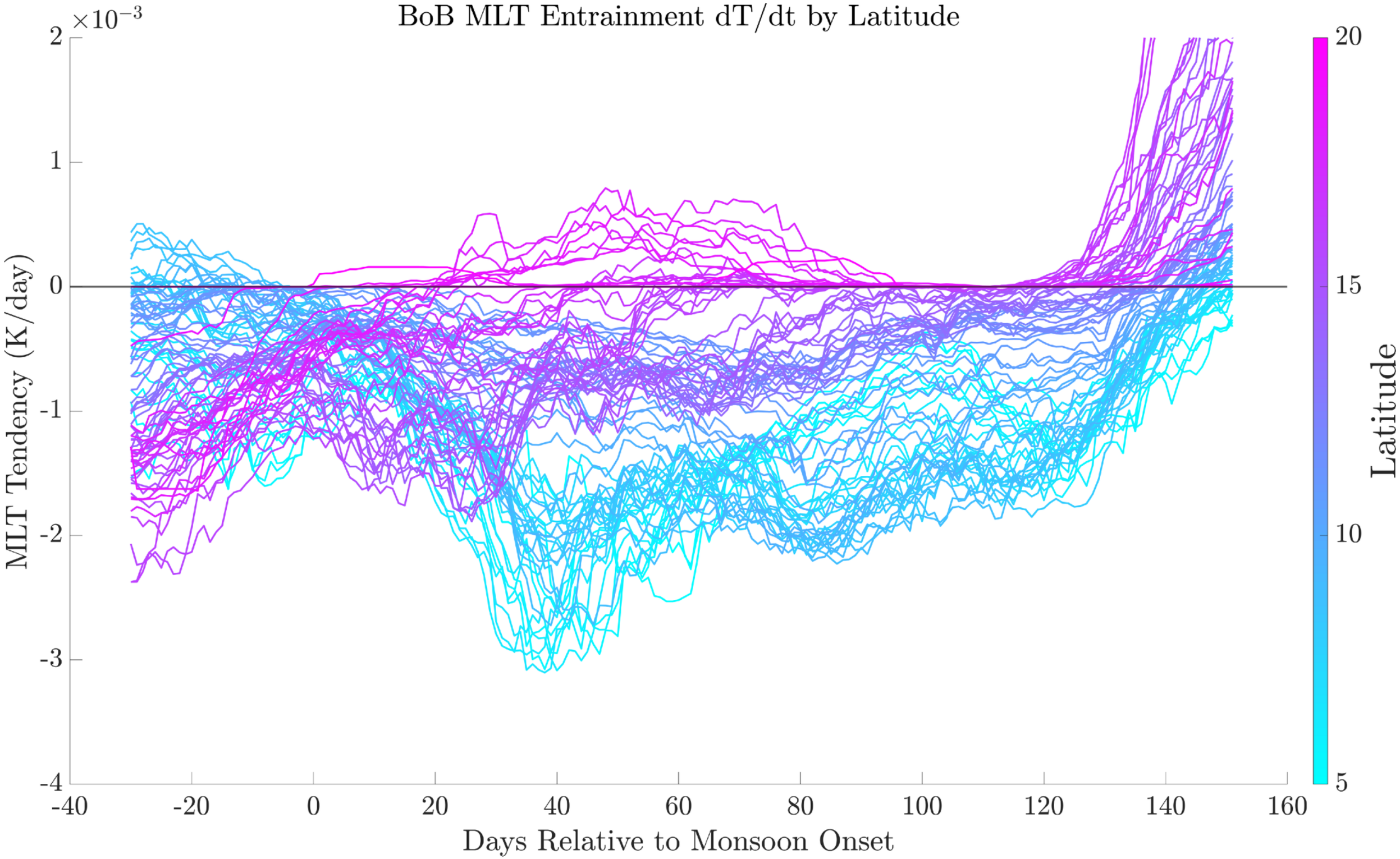
Temperature tendency Surface fluxes Advection Entrainment

$$\frac{\mathrm{d}T_{\mathrm{ML}}}{\mathrm{d}t} \approx \frac{Q_{\mathrm{SW}} + Q_{\mathrm{LW}} + Q_{\mathrm{LHF}} + Q_{\mathrm{SHF}}}{\rho c_p L} + F_{\mathrm{adv}} + F_{\mathrm{ent}}$$

where

$$\left[\begin{array}{l} Q_{\mathrm{SW}} = I\left(c_1\left(1-\exp\left(-L/H_1\right)\right) + c_2\left(1-\exp\left(-L/H_2\right)\right)\right) \\ \\ F_{\mathrm{adv}} = -\vec{v}\cdot\nabla T \\ \\ F_{\mathrm{ent}} = \left(T_{\mathrm{sub}} - T_{\mathrm{ML}}\right)\frac{1}{L}\frac{\mathrm{d}L}{\mathrm{d}t} \end{array}\right.$$

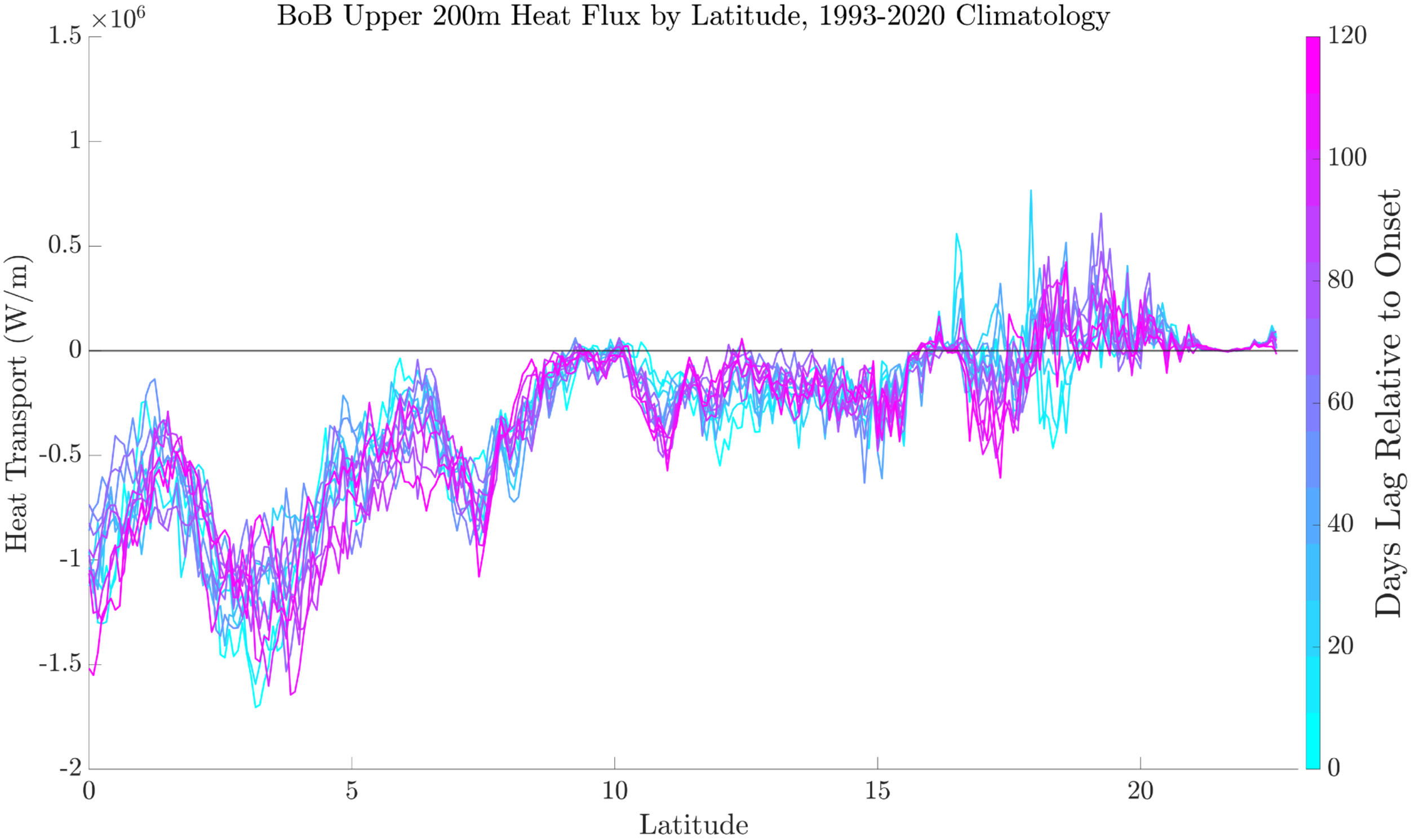
Mixed Layer Heat Budget



Takeaway: Entrainment cooling is not significant in BoB

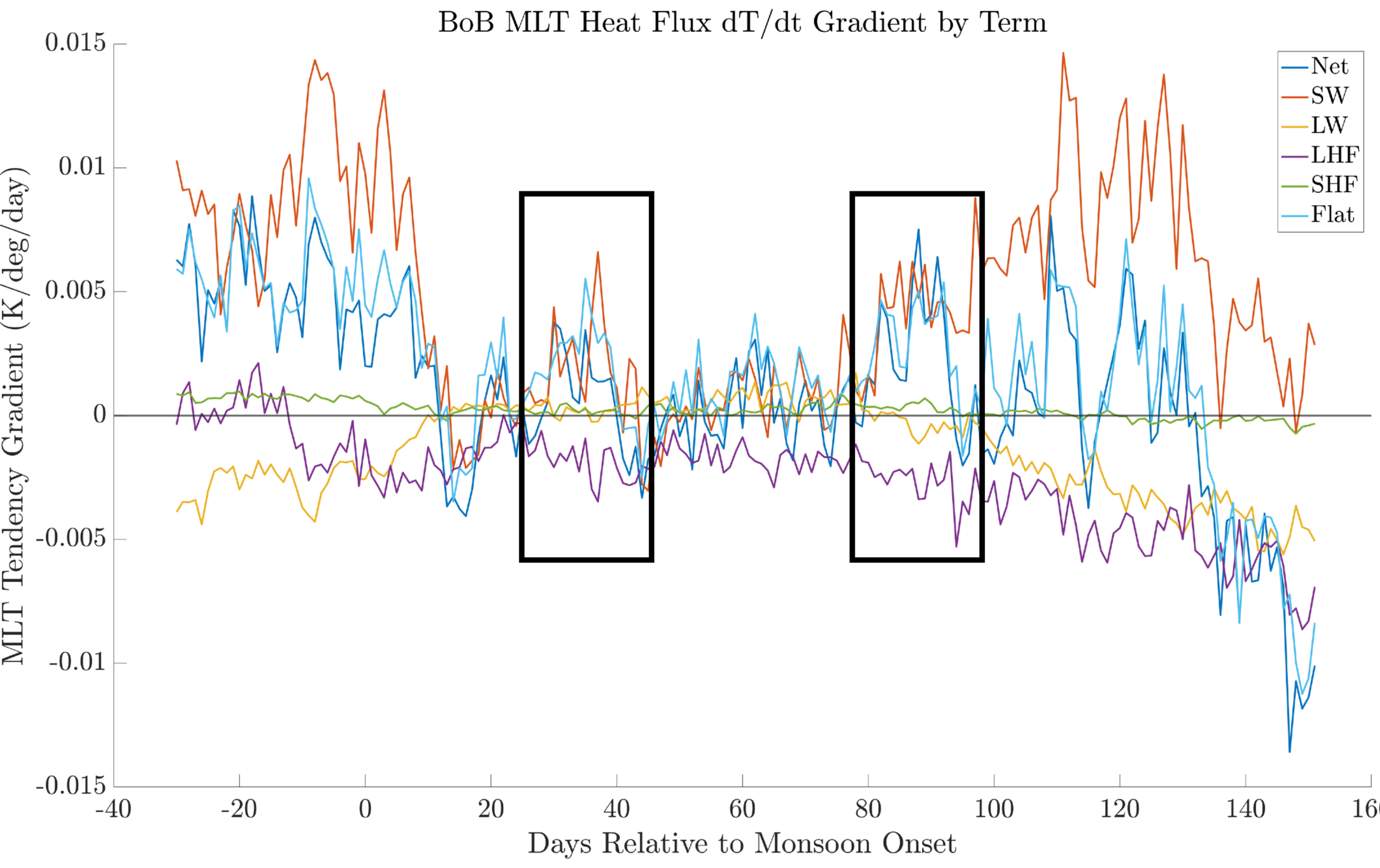
Mixed Layer Heat Budget

Meridional Advection



Takeaway: Meridional advection does not cause the gradient rise

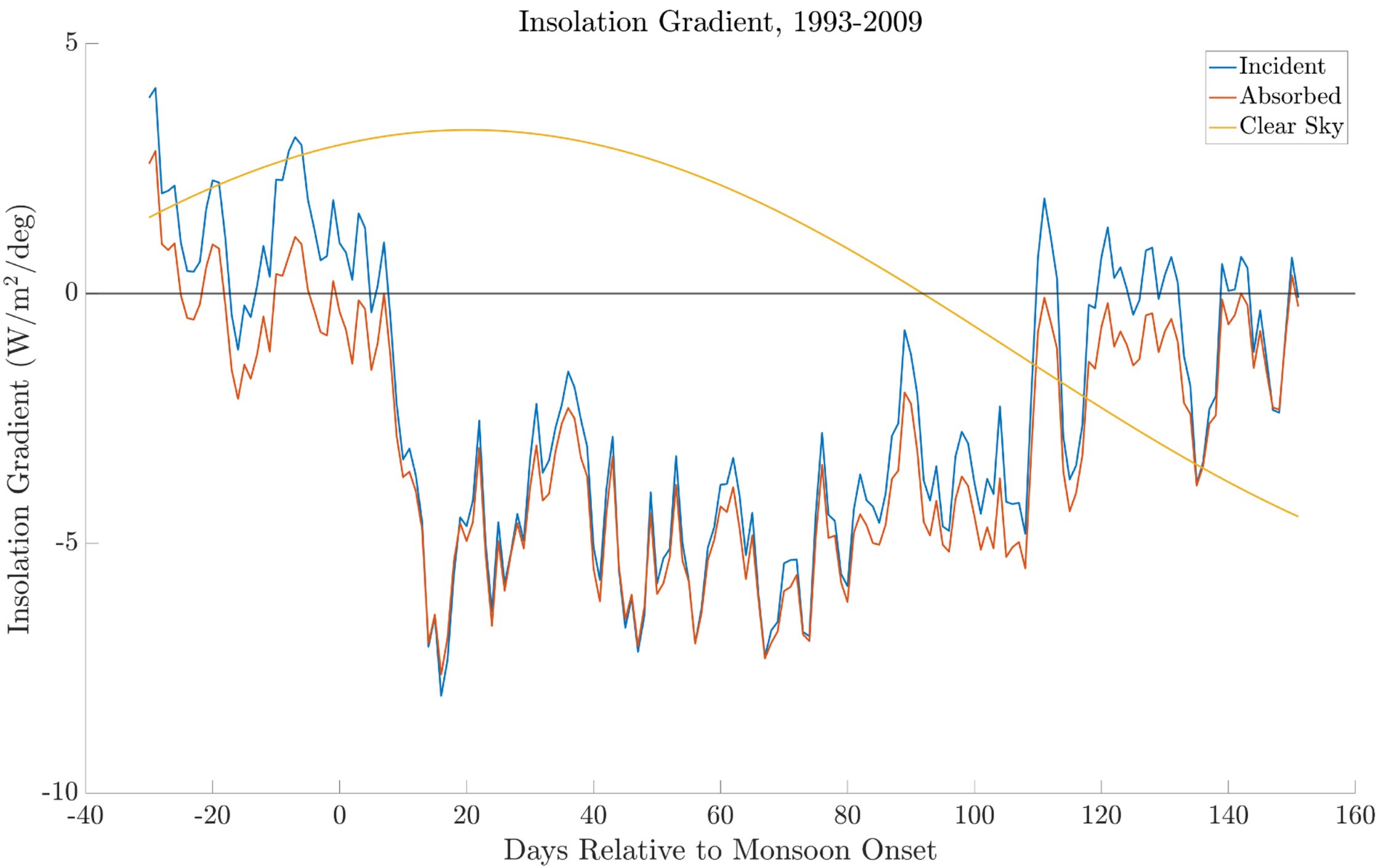
Mixed Layer Heat Budget



Takeaway: Shortwave is the dominant flux term

Mixed Layer Heat Budget

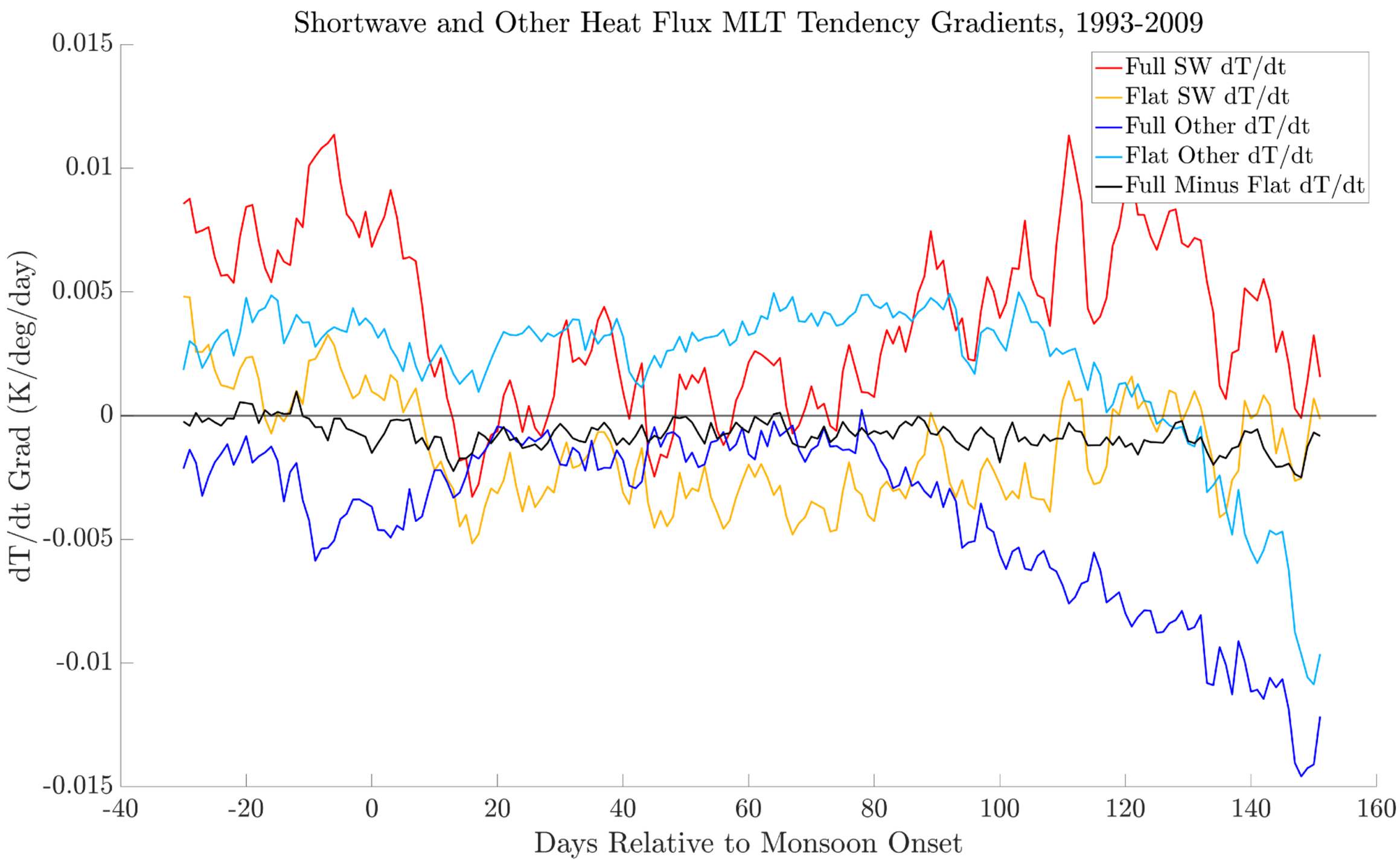
Shortwave: Clouds and Mixed Layer Penetration



Takeaway: Clouds control the shortwave gradient

Mixed Layer Heat Budget

MLD Gradient Effect



Takeaway: The MLD gradient amplifies both positive and negative fluxes

Summary

- The BoB meridional SST gradient is coupled to intraseasonal rainfall during the summer monsoon

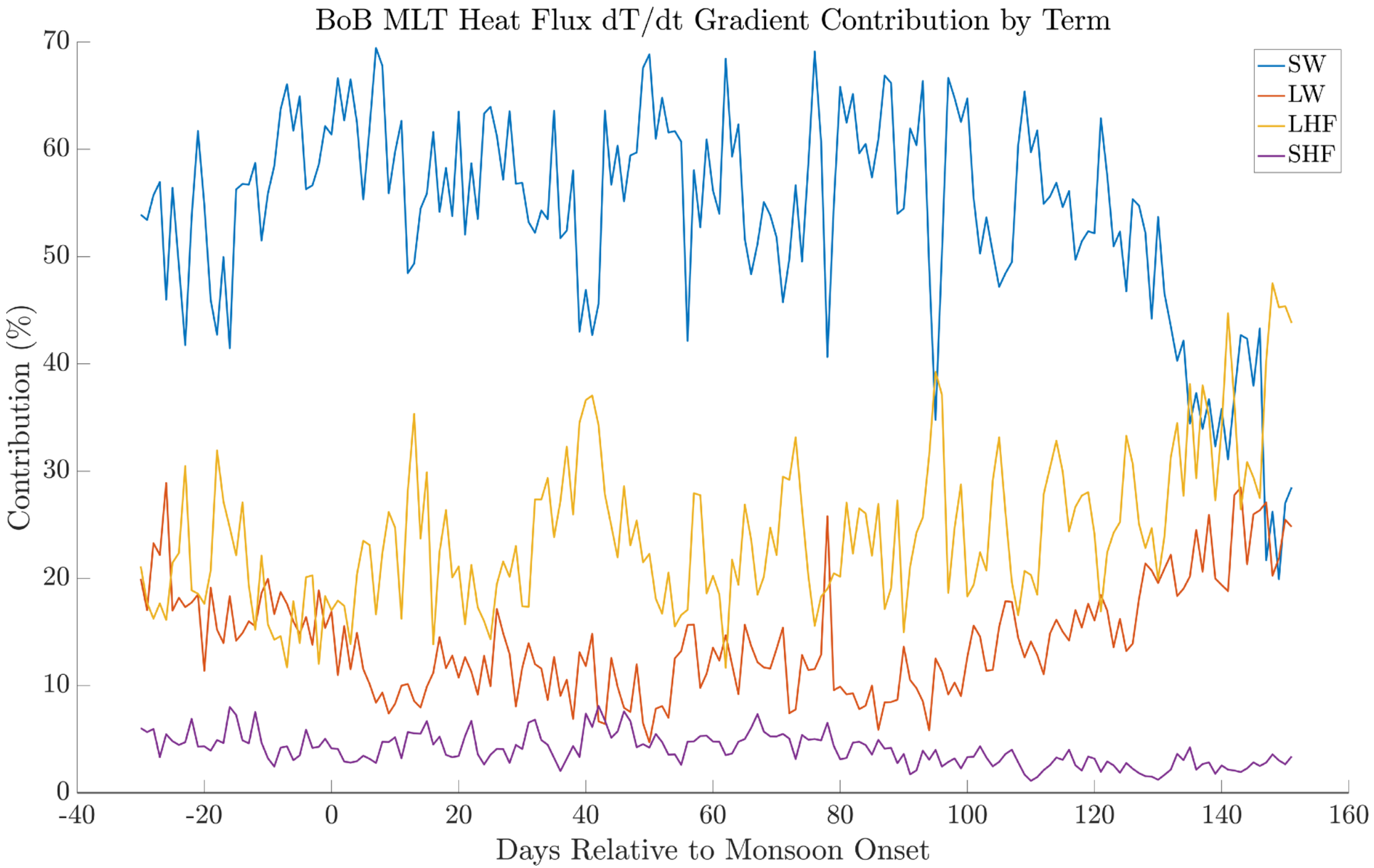
- There does not appear to be a strong linear relation between SST gradient and strength of subsequent rainfall anomalies when comparing all MISO events

- However, there are parts of the season where the SST gradient is particularly correlated with subsequent rainfall and vice-versa

- The SST gradient climatology shows three conceptually distinct phases to the season, with shortwave flux gradients driven by cloud cover controlling the heat budget

Contact: alex.kinsella@whoi.edu

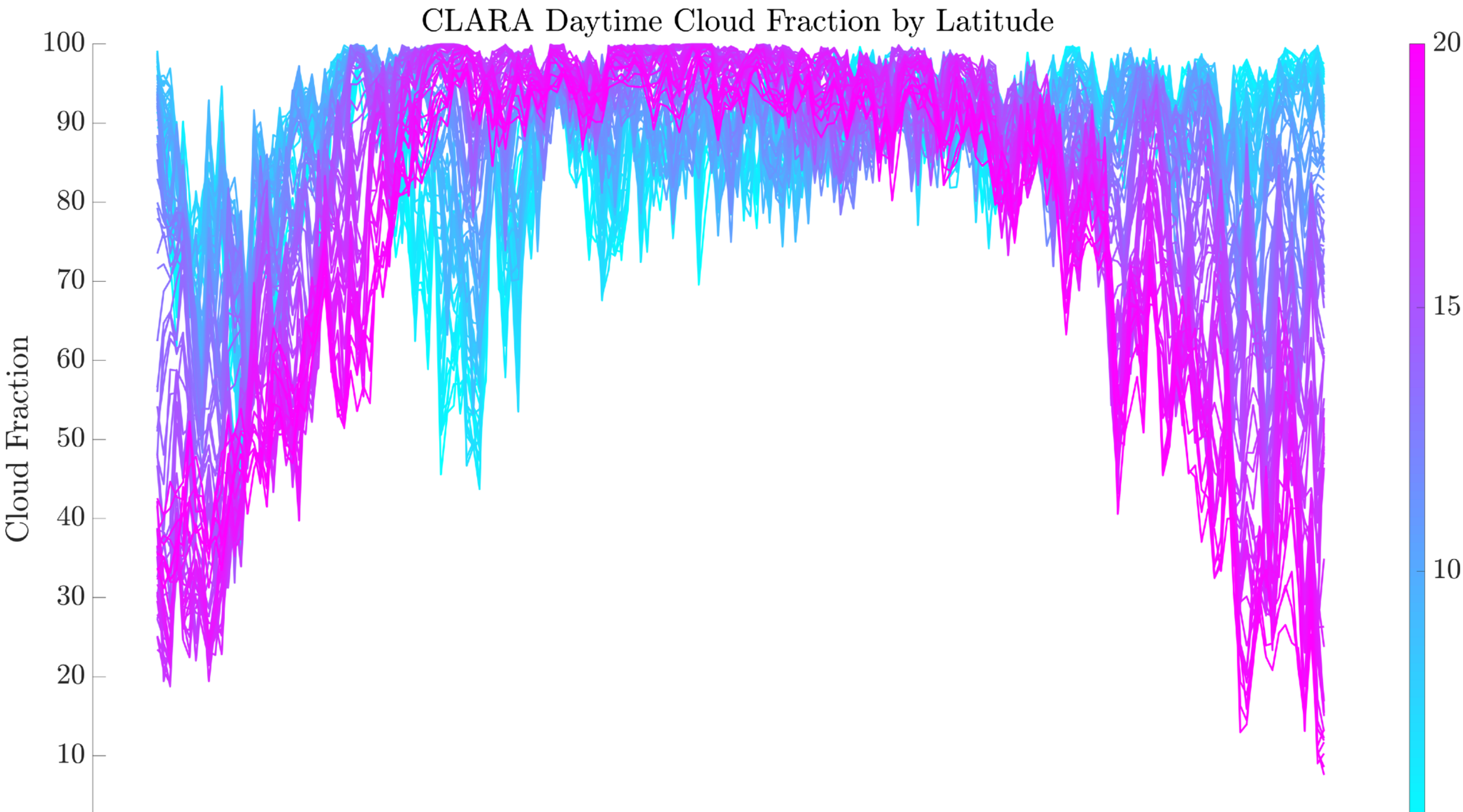
Mixed Layer Heat Budget



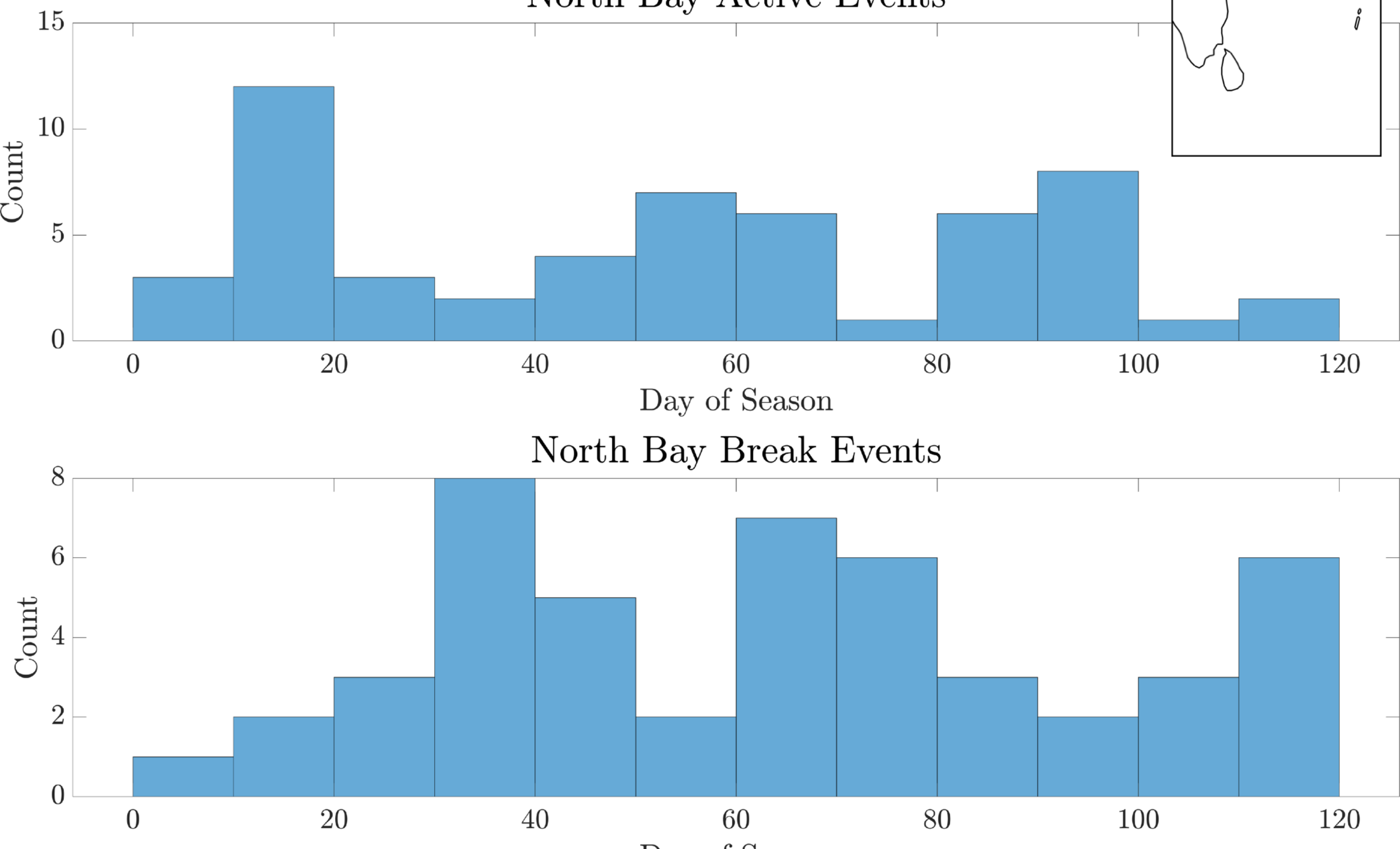
Takeaway: SW flux controls the SST gradient

Mixed Layer Heat Budget

Shortwave



Event Date Histograms



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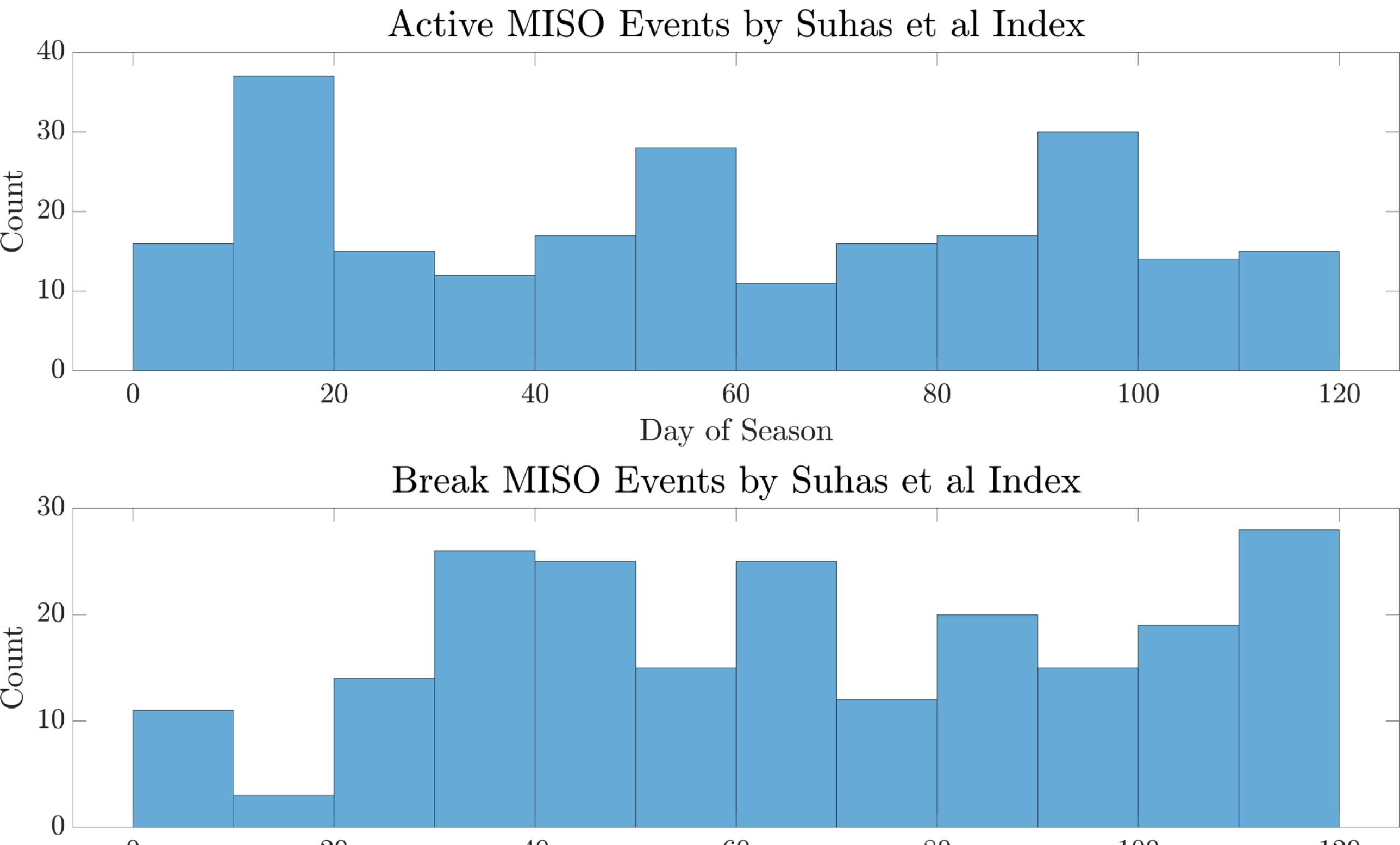

Event Date Histograms