Air-Sea Interactions Affecting Cold Surge Propagation and Its Impact on Extreme Rainfall in Indonesia

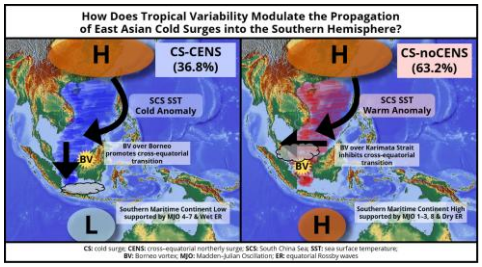
RISET PPMI FITB 2026

Narizka Nanda Purwadani[1,2], Muhammad Rais Abdillah[3], Nining Sari Ningsih[4], and Erma Yulihastin[2]

[1]Doctoral Program in Earth Sciences, FITB [2]Research Center for Climate and Atmosphere, BRIN

[3]Atmospheric Science Research Group, FITB [4]Applied and Environmental Oceanography Research Group, FITB

Abstract



Graphical abstract of the main findings.

Keyword: Cold surge, cross-equatorial northerly surge, winter monsoon, tropical variabilities.

Introduction

- Cold surge (CS) event:
  - A cold air outbreak from Siberia during the boreal winter.
  - A major synoptic driver of heavy rainfall across the western Maritime Continent.
- CS can trigger a cross-equatorial northerly surge (CENS) and cause extreme rainfall in northern Java.
- A strong CS does not guarantee a CENS transition—the correlation between CS and CENS indices is weak.
- Tropical climate variability possibly modulates the CS–CENS relationship.

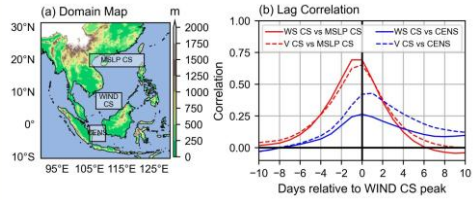


Figure 1. Domain map and correlation between CS and CENS.

Research Method

Data (Daily from Dec — Feb 81/82 to 20/21)
ERA-5 Reanalysis (Wind, MSLP, Moisture Flux), OISST (SST), MSWEP (Precipitation), NOAA Interpolated OLR, BOM (RMM data)

Method

1. **Definition of CS events and their classification**
   - CS event : WIND CS index > 11.38 m/s and MSLP CS index > 1017.98 hPa
   - Distinguish CS events that are and are not associated with CENS

2. **Identification of tropical phenomena that modulate the CS and CENS relationship**
   - MJO: RMM data from BOM
   - Equatorial wave: wave-filtering method of Wheeler and Kiladis (1999) on tropical OLR
   - Borneo vortex: detects local minima based on the horizontal slope of streamfunction

Discussion & Result

Statistics and seasonality. Of 201 CS events, 74 (36.8%) became CS-CENS (Table 1). CS-CENS events usually last longer and have stronger northerly wind components, while CS-noCENS events are shorter and dominated by easterly wind components. The CENS probability rises from 17.3% in December to 56.8% in February as the low-pressure trough south of the Maritime Continent expands westward and SCS SST cools.

Parameter		CS	CS-CENS	CS-noCENS
Number of events (events)	Dec	75	13 (17.3%)	62 (82.7%)
	Jan	82	36 (44%)	46 (56%)
	Feb	44	25 (56.8%)	19 (43.2%)
	Total	**201**	**74 (36.8%)**	**127 (63.2%)**
Mean duration (d)		5.17	6.01	4.68
Mean magnitude (m/s)		13.72	13.93	13.61
Mean u (m/s)		−9.3	−8.55	−9.73
Mean v (m/s)		−9.8	−10.76	−9.24

Table 1. CS events per month (% of the month's CS events) and mean characteristics.

Circulation, SST, and rainfall. A low-pressure anomaly center south of the Maritime Continent drives the cross-equatorial flow, while a high-pressure anomaly center inhibits it (Fig. 2). Cooler pre-existing SST in the South China Sea (SCS) favoring the CS-to-CENS transition and warmer SST hindering it (Fig. 3). CS-CENS events primarily cause wet conditions over northern Borneo and northern Java. CS-noCENS events generate widespread rainfall extending from western Borneo to the Malay Peninsula and Sumatra (Fig. 4).

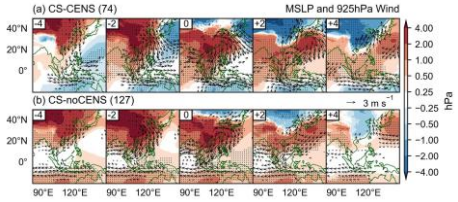


Figure 2. MSLP and 925-hPa wind anomalies.

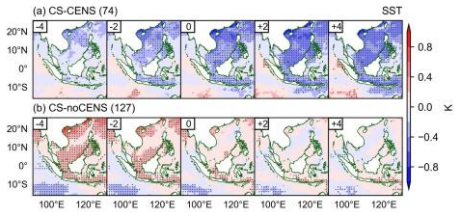


Figure 3. SST anomalies.

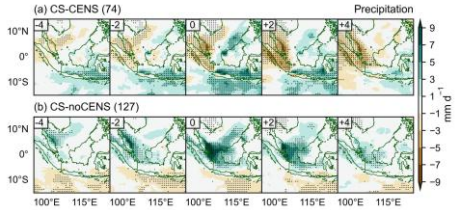


Figure 4. Precipitation anomalies.

Tropical modulation. MJO: CS-CENS is favored in phases 6 (83%) and absent in phase 2 (0%). ER waves: the CENS probability is highest in phase 1 (50%) and lowest in phase 3 (13%). Borneo vortex: A Borneo vortex over Borneo Island promotes cross-equatorial flow, whereas one over the Karimata Strait inhibits it.

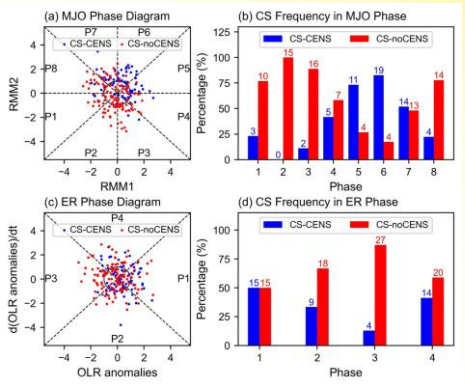


Figure 5. CENS probability by MJO and ER phase.

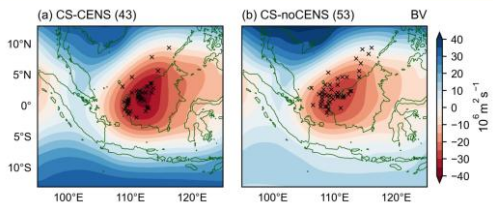


Figure 6. Borneo vortex location.

Roles of MSLP and SST. High pressure south of the Maritime Continent is the primary inhibitor (CENS probability 18% with warm, 38% with cold SCS SST). Under low pressure, cold SCS SST gives 67% versus 34% for warm SST (Fig. 7).

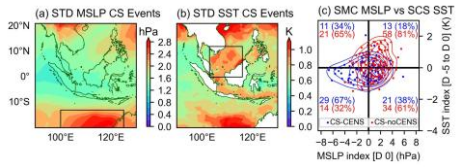


Figure 7. Event variability and SCS SST vs southern MSLP.

Conclusion

- Only 36.8% of cold surges evolve into CENS, characterized by stronger northerly winds, while non-CENS events feature stronger easterlies.
- This southward propagation is primarily driven by southern Maritime Continent low pressure anomalies and potentially supported by cold SCS SST.
- CS-CENS cause wet conditions over northern Borneo and northern Java, while CS-noCENS events generate widespread rainfall extending from western Borneo to the Malay Peninsula and Sumatra.
- The CS and CENS relationship is strongly modulated by seasonality, the MJO, equatorial Rossby waves, and the location of the Borneo vortex.