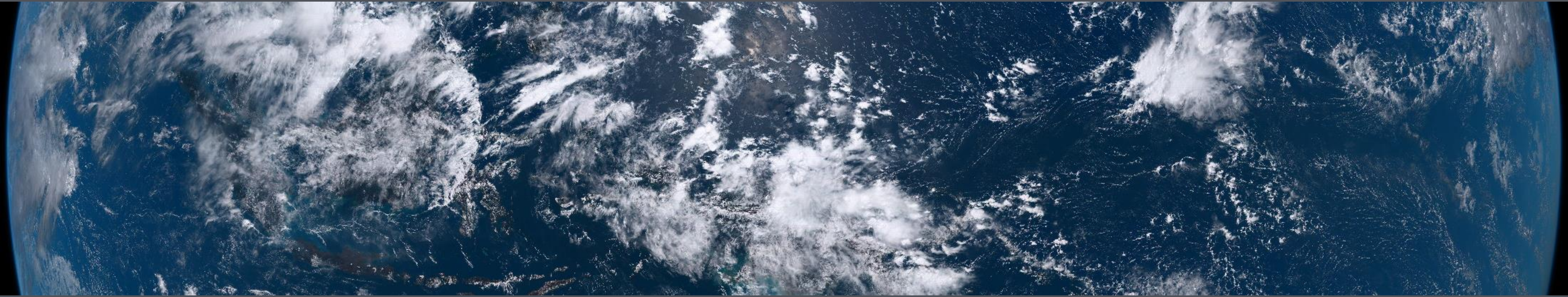
WCSSP South East Asia

WEATHER REGIMES IN SOUTH EAST ASIA



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EGU 2021

MOTIVATION

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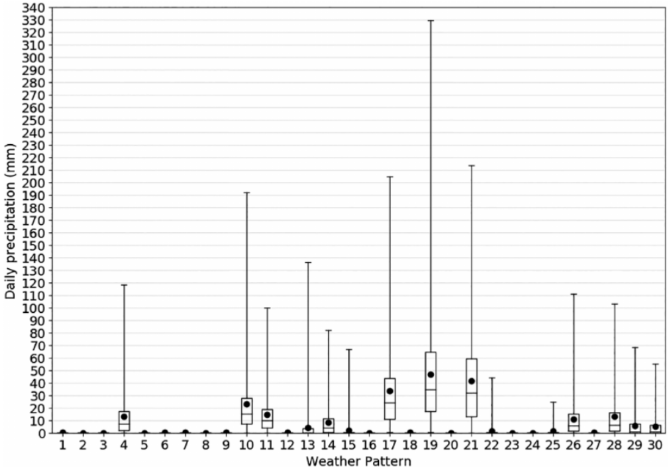
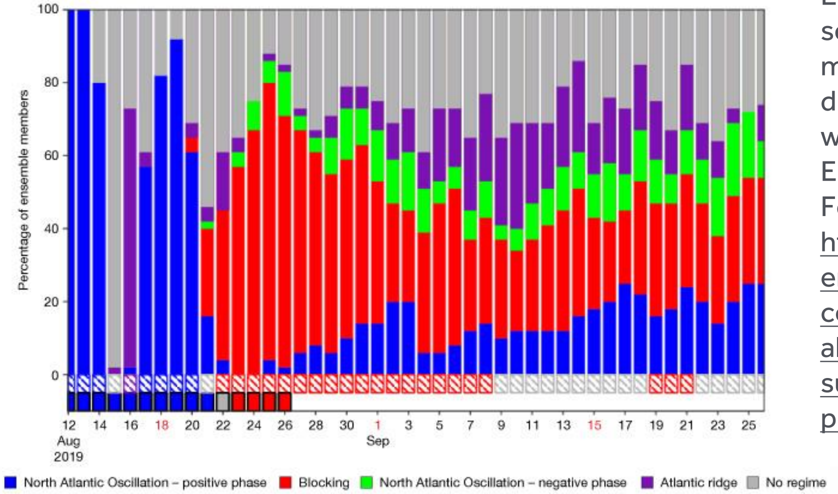
- Weather regimes are quasi-stationary spatial patterns of atmospheric circulation, upon which synoptic-scale behaviour is dependent.
- Thus, the probability of high impact weather is conditional on weather regime.
- Weather regimes may be predictable on larger timescales than individual high impact weather events.
- A good understanding of the relationship between these regimes and HIW will allow forecasters to identify periods of increased risk of HIW at earlier lead times, giving more time to develop plans to mitigate the impact of the HIW.
- The figures to the right demonstrate (top) the conditioning of rainfall on regimes and (bottom) the predictability of regimes in seasonal forecasts, from applications of regime-based analysis to India and Europe.



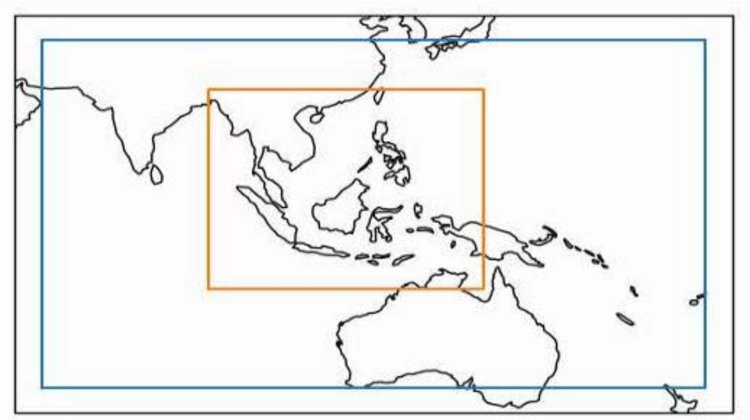


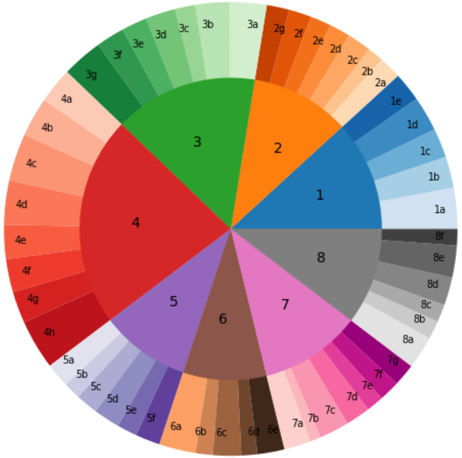
Top: boxplots of Mumbai rainfall distribution across 30 regimes calculated from wind flow over the Indian region. Neal et.al 2019 (IJC) DOI: 10.1002/joc.6215

Bottom: percentage of ECMWF ensemble seasonal forecast members that predict different types of weather regimes for the European domain. (Laura Ferranti, 2019 https://www.ecmwf.int/en/about/media-centre/news/2019/annual-seminar-focuses-sub-seasonal-seasonal-predictions)

METHODOLOGY

- In previous studies of different regions, weather regime clustering has often been applied after sub-setting to a predefined season.
- However, our approach has been designed to allow the optimal seasons to be determined by the clustering algorithm.
- We apply a two-tiered approach:
    - First we perform cluster analysis on a large planetary-scale tropical domain (35S-35N, 60E-180E). This analysis separates patterns of large-scale variability, including the seasonal cycle and ENSO. (Tier 1: 8 clusters)
    - Following this, we perform a secondary clustering analysis for each tier 1 regime on the South-East Asia domain (15S-25N,90E-140E). In this case, we limit the input data to dates identified as belonging to each tier 1 regime. (Tier 2: 5-8 subclusters per tier 1 cluster, 51 subclusters in total)
- In each case, clustering is performed using daily ERA-5 850 hPa wind vectors from 1979-2018. Principal component analysis is used to reduce the dimensionality of the datasets. The optimal number of clusters was determined using the Gap Method.
- We compare to a 'flat' methodology that seeks 51 clusters from the outset, on the small domain only.





Top: map of small and large domains.

Left: pie chart showing relative frequencies of tier 1 (inner circle) and tier 2 (outer circle) regimes.

TIER 1 CLUSTERS

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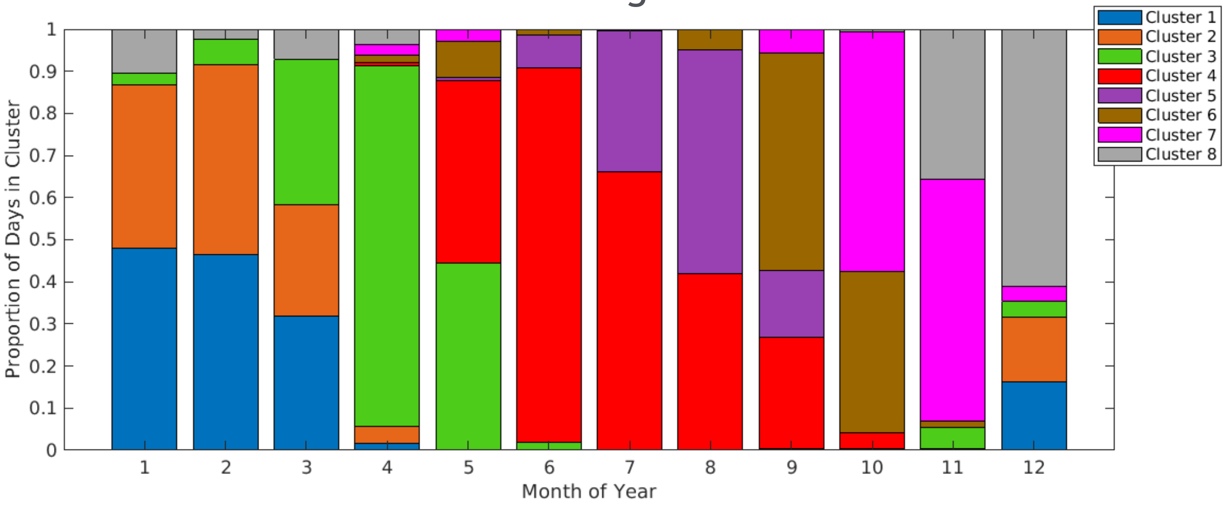
#	Short Description	Month	LS Var
1	Inactive NE Monsoon / Weak Austral Monsoon	DJFM	El Nino MJO 678
2	Active NE Monsoon/ Intense Austral Monsoon	DJFM	La Nina MJO 45
3	Northward Transition /April Transition	MAM	
4	Regular SW/Boreal Monsoon	MJJA	
5	Intense SW Monsoon /Active Boreal Monsoon	JAS	MJO 567
6	SW/Boreal Monsoon Retreat	SO	El Nino
7	Southward Transition 1 /October Transition	ON	Later in El Nino
8	Southward Transition 2 /NE Monsoon Onset	ND	

Seasonal Regime Timing
Colour: tier 1 regime classification



Tier-1 regimes primarily describe the seasonal cycle and its associated monsoons. Some dependence on El Nino and La Nina is also present, particularly during the Austral/NE Monsoon.

TIER 1 CLUSTERS

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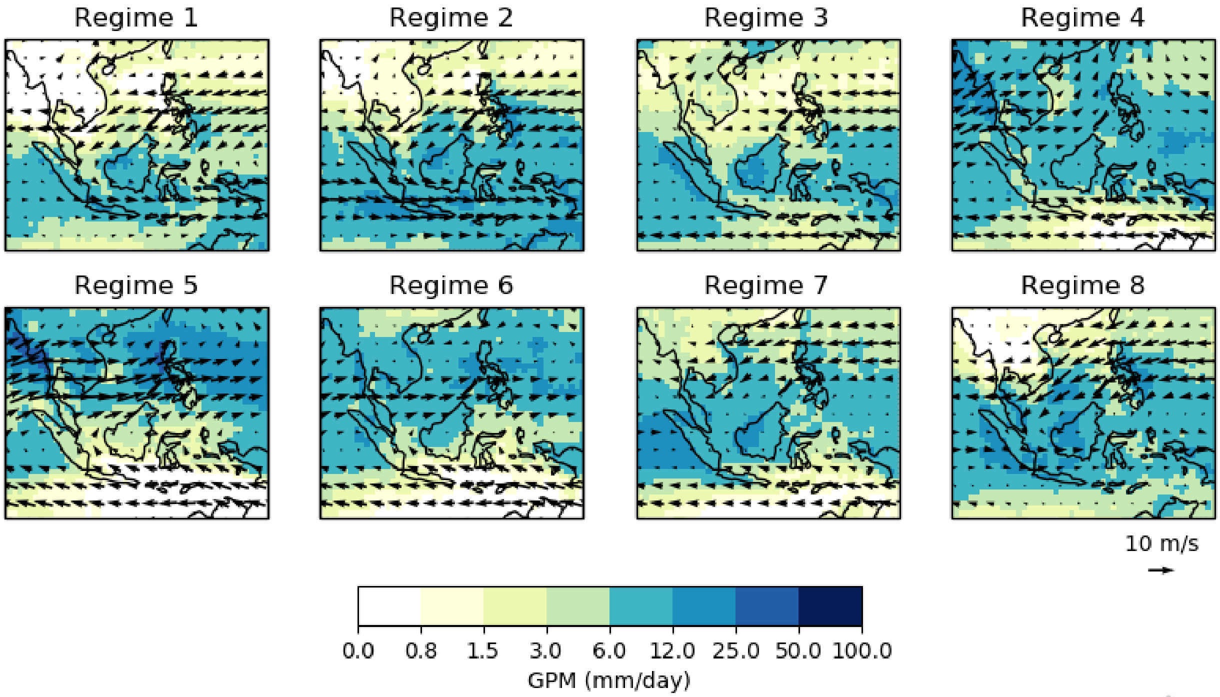
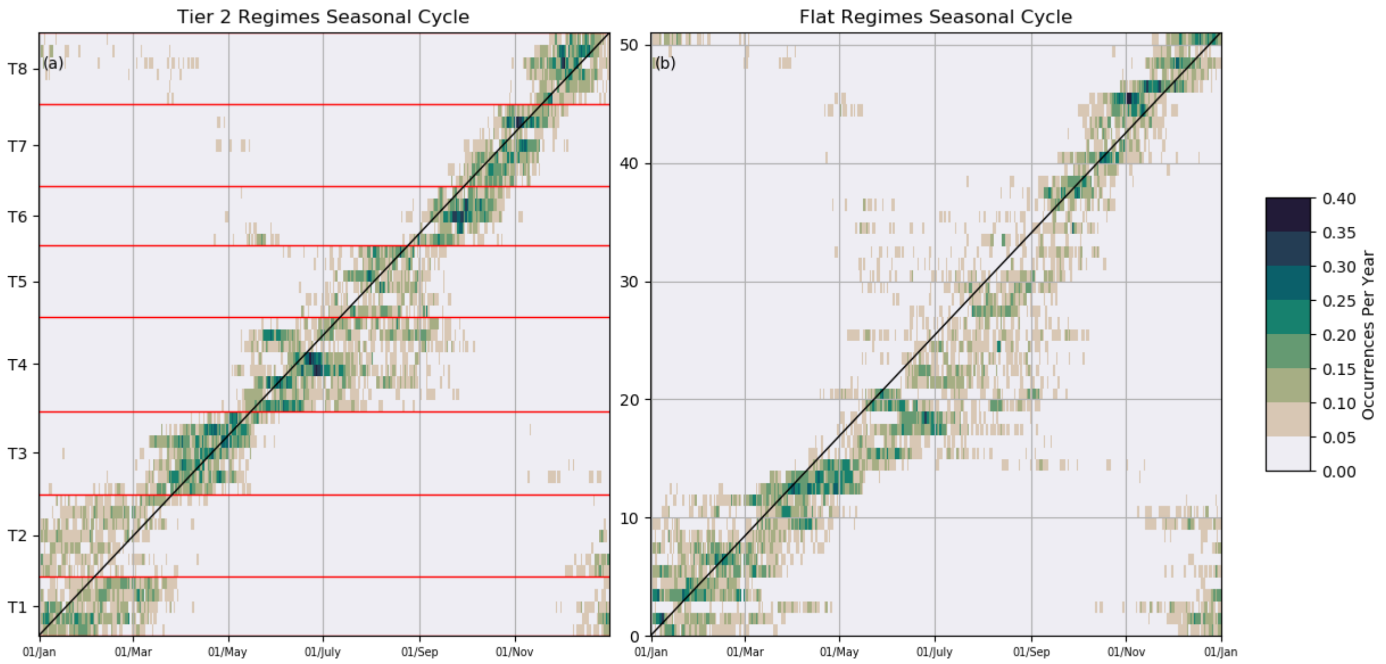
ERA-5 850 hPa winds and GPM rainfall composites of tier 1 clusters

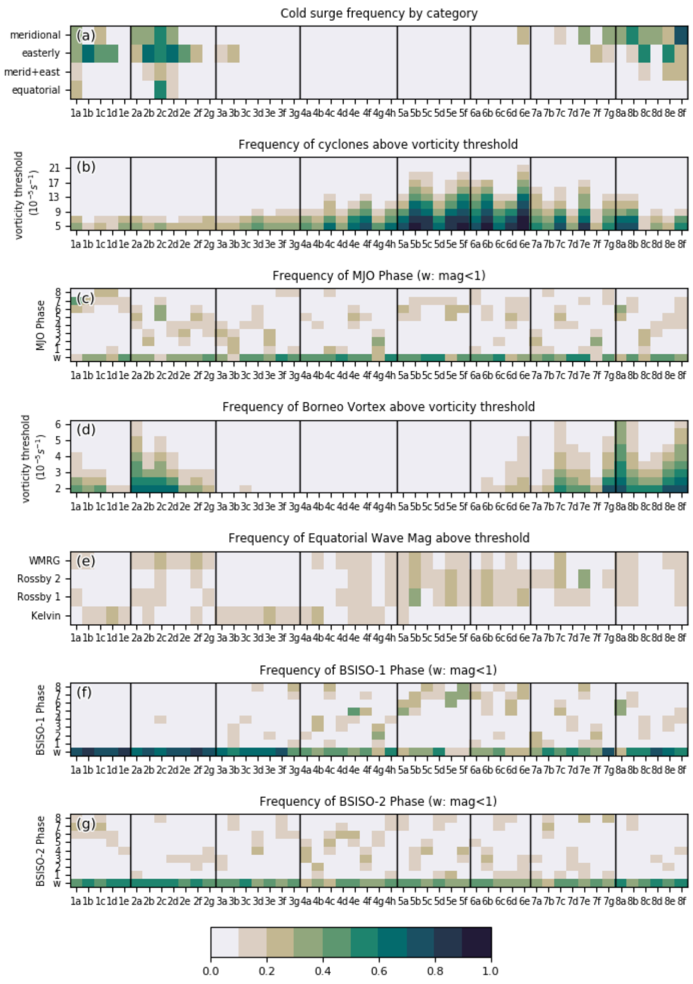


TIER 2 AND FLAT: SEASONAL CYCLES

The tier-2 and flat regimes are also tied to seasonal cycle, particularly during the transition seasons.

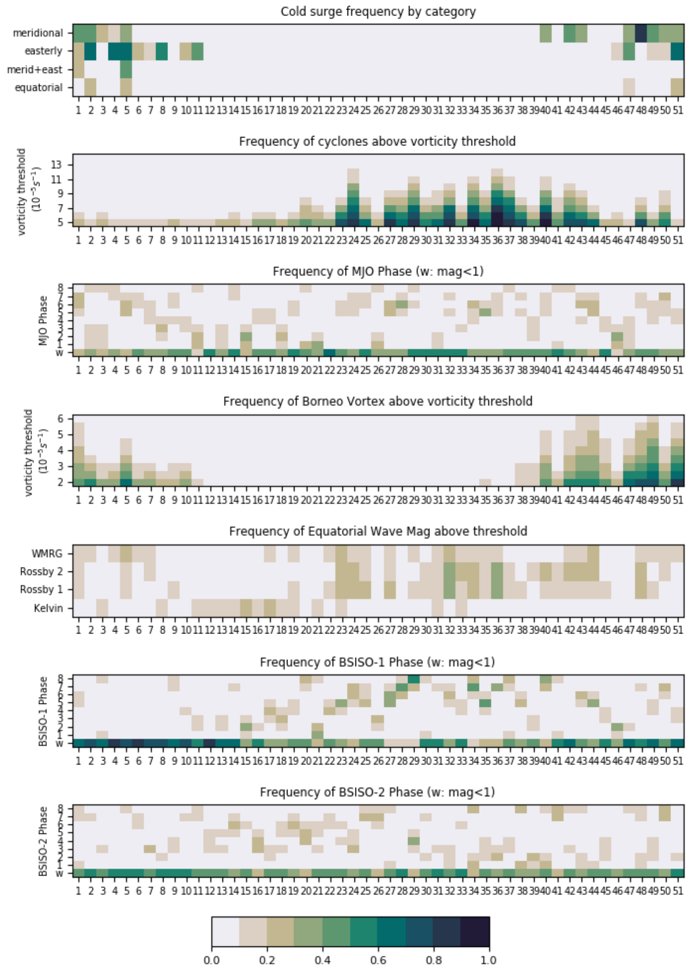


PHENOMENA CO-INCIDENCE RATES



<< TIERED

FLAT >>



Rates of event observation conditioned on regime occurrence

See final slide for event definitions

PHENOMENA CO-INCIDENCE RATES

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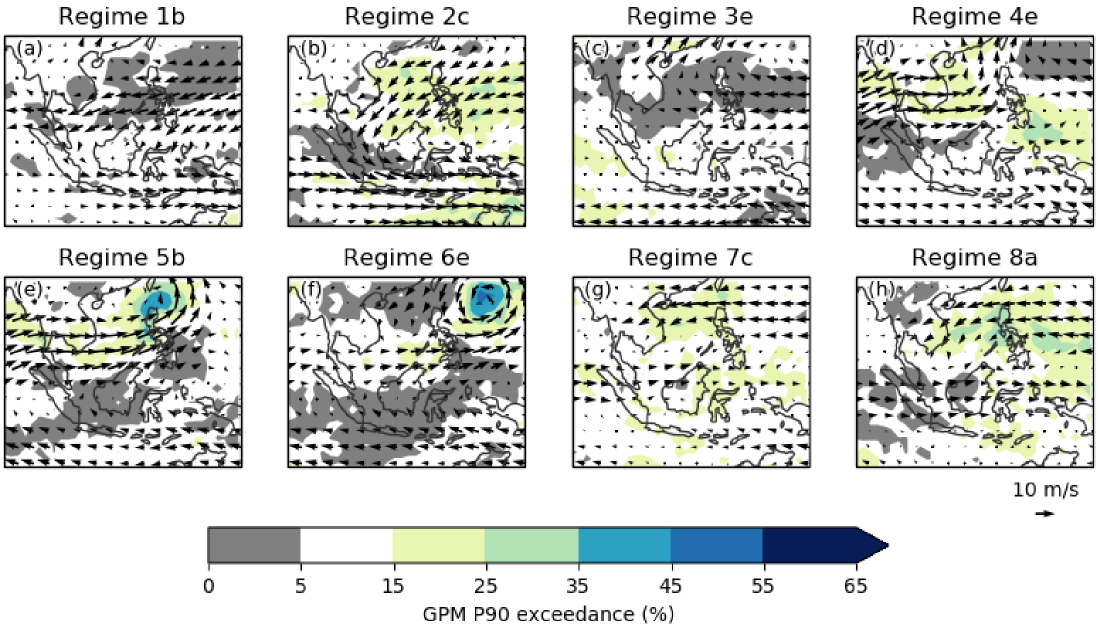
- We compute the fraction of days in each regime and sub-regime for which the following criteria are met:
- Cold Surges (Chang et al 2005)
  - Meridional: 925 hPa V averaged between 110-117.5°E along 15°N is less than -8 m/s
  - Easterly: 925 hPa U averaged between 7.5- 15°N along 120°E is less than -8 m/s
  - Merid+East: both of the above
  - 925 V averaged over 105-115°E, 5-0°S is less than -5m/s (Hattori et al. 2011)
- Northern Hemisphere Tropical Cyclones (Hodges et al. 2017)
  - A cyclonic vortex, determined by tracking vertically averaged (850-600hPa) vorticity in ERA-Interim at T63 resolution at 6 hourly time resolution, with filtered vorticity exceeding a given threshold (between 4e-5 s^{-1} and 2.5e-4 s^{-1}), is present in the SE-Asia domain plus a 5 degree buffer. Tracking was performed in the NH only.
- MJO (Wheeler and Hendon, 2004)
  - RMM based MJO is in each phase with magnitude >1, or RMM based MJO magnitude is < 1
- Borneo Vortex
  - A cyclonic vortex, determined by tracking vertically averaged (850-600hPa) vorticity in ERA-Interim at T63 resolution at 6 hourly time resolution, with filtered vorticity exceeding a given threshold (between 1e-5 s^{-1} and 9e-5 s^{-1}), in the region (100-120°E, 0-12°N)
- BSISO 1&2 (Lee et al. 2012)
  - BSISO1 is in each phase with magnitude >1, or BSISO1 magnitude is < 1
  - BSISO2 is in each phase with magnitude >1, or BSISO2 magnitude is < 1
- Equatorial Waves (Yang et al 2003)
  - The wave amplitude of 850-hPa winds filtered to the respective wave frequencies and then averaged from 90°–140°E, exceeds its own 40 year P90.
  - Waves frequencies considered: Kelvin, WMRG, Rossby 1 and Rossby 2.

- The Borneo Vortex and Tropical Cyclone datasets were produced as part of the Newton Fund project under the auspices of the WCSSP Southeast Asia project by Dr Kevin Hodges of the National Centre for Atmospheric Science and Department of Meteorology, University of Reading.

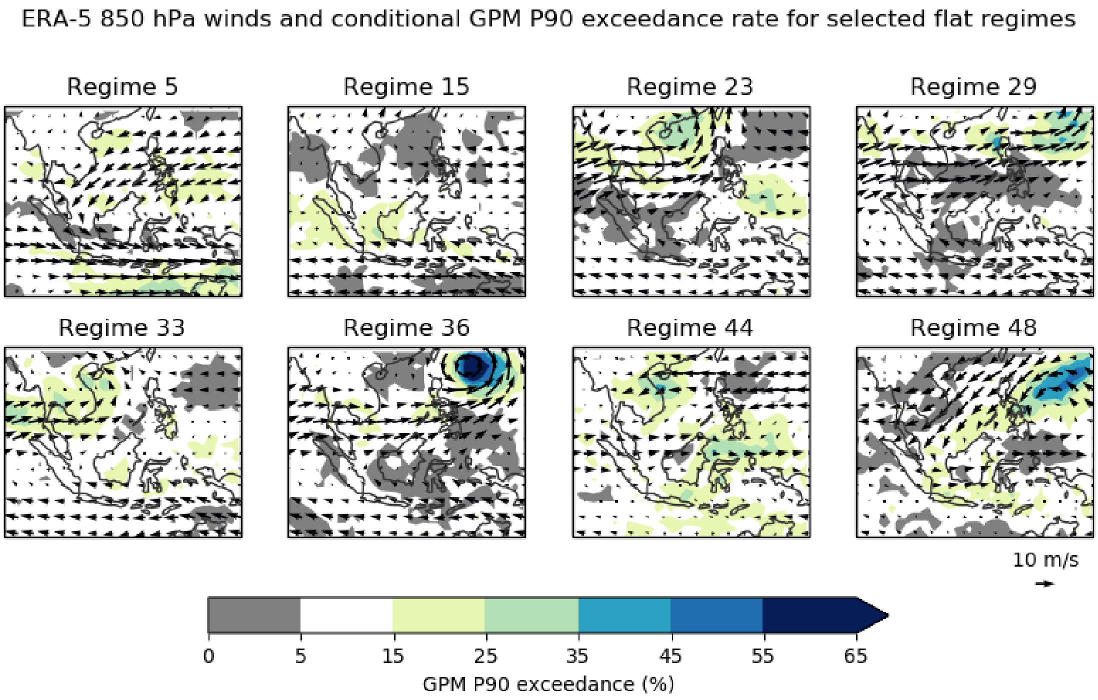
SELECTED TIERED PATTERNS

ERA-5 850 hPa winds and conditional GPM P90 exceedance rate for selected tiered regimes



Pattern	Season	Key Features
1b	Austral Summer (Suppressed phase)	Easterly Surge
2c	Austral Summer (Active phase)	Cross Equatorial Surge
3e	Northward Transition	Kelvin Wave
4e	Boreal Monsoon	BSISO 1 Phase 5
5b	Active Boreal Monsoon	Tropical Cyclone
6e	Boreal Monsoon Retreat	Tropical Cyclone
7c	Southward Transition 1	Borneo Vortex
8a	Southward Transition 2	Borneo Vortex

SELECTED FLAT PATTERNS



Pattern	Season	Key Features
5	December – February	Cross-Equatorial Surge
15	April – May	Kelvin Wave
23	June – August	BSISO1 Phase 5
29	July – September	BSISO-2 Phase 8
33	September – October	Equatorial Rossby-2 Wave
36	September – October	Tropical Cyclone
44	October – November	Borneo Vortex
48	November – December	Meridional Surge

RELATIONSHIP WITH SYNOPTIC VARIABILITY

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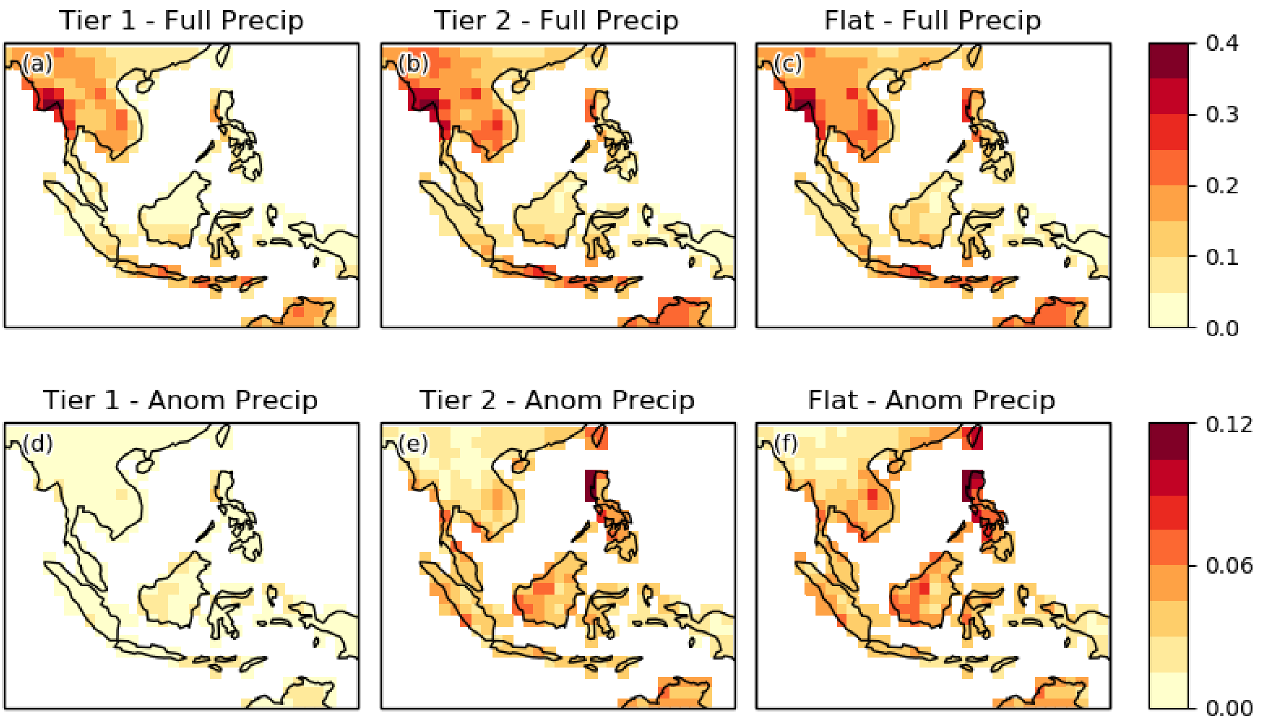
- Though the first tier does distinguish ENSO and the MJO, inclusion of the second tier markedly improves the variance explained.
- Tier 2 captures more large-scale variability (rows 1-4) than the flat regimes.
- Flat regimes capture more synoptic scale variability (rows 5-12)
- Equatorial waves not well captured (propagating vs stationary features)
- See final slide for full event definitions.

Climate/synoptic index: variance explained

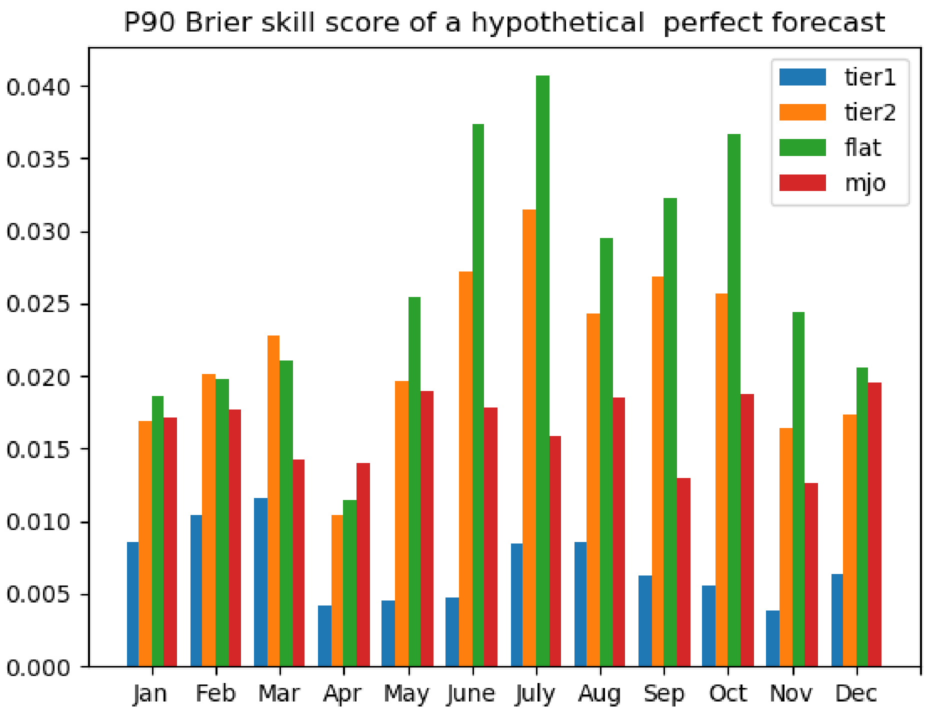
		Tier-1	Tier-2	Flat
1	Day of Year	0.721	**0.748**	0.668
2	Nino 34 SST	0.066	**0.152**	0.128
3	DMI	0.031	**0.1**	0.088
4	RMM MJO	0.077	**0.247**	0.237
5	BSISO1	0.099	0.339	**0.367**
6	BSISO2	0.032	0.167	**0.187**
7	Cross Equatorial Cold Surge	0.065	**0.283**	0.252
8	Easterly Cold Surge	0.256	0.399	**0.427**
9	Meridional Cold Surge	0.182	0.293	**0.323**
10	M+E Cold Surge	0.065	0.141	**0.165**
11	Tropical Cyclone	0.137	0.22	**0.237**
12	Borneo Vortex	0.15	0.208	**0.23**
13	Kelvin Wave	0.027	0.049	0.049
14	Rossby-1 Wave	0.063	0.101	**0.11**
15	Rossby-2 Wave	0.05	0.09	**0.099**
16	WMRG Wave	0.05	0.086	**0.093**

RELATIONSHIP WITH RAINFALL: VARIANCE EXPLAINED

- Tier-2 and flat: total precipitation variance explained: 10-40% over most land-based regions
- This compares favourably to similar studies, including Neal et al (2020) – India
- When the seasonal cycle is removed, 4-12% of variance is still explained by the tier-2 regimes.
- Flat regimes explain more variance than the tiered regimes.



RELATIONSHIP WITH HIW: BRIER SKILL



- *How much can be deduced about the likelihood of extreme precipitation given prior knowledge of regime assignment?*
- To answer this, we calculate the Brier Skill Score of a hypothetical perfect forecast.
  - For each day, calculate the probability of exceeding the seasonal P90 based on P90 exceedance of other days assigned to same regime.
  - Compare this to binary observed exceedance
  - Reference: climatology.
- Flat has best skill: about 1.6 times better than only knowing MJO phase.

HIW IN 2019

This table shows the enhanced/suppressed probability of rainfall exceeding 25mm/day from a regime forecast compared to climatology on a selection of days and locations for which high impact weather was reported on FloodList.com.

This indicates the degree of certainty a regime forecast may be able to provide. The regime methodology features a low degree of forecast 'sharpness' due to its statistical nature.

	Date	Location	Rainfall	Clim. Prob(%)	Tier	Tier Prob	Flat	Flat Prob
1	2019-01-03	Southern Thailand (100.5,7.5)	276.5 mm	6.7 (0.7)	1b	x0.2 (x0.0)	51	x2.9 (x6.4)
2	2018-12-28	Central Philippines (123.0,13.5)	263.5 mm	12.0 (1.5)	2a	x2.4 (x2.2)	1	x1.2 (x2.7)
3	2019-01-22	South Sulawesi, Indonesia (120.0,-4.5)	25.5 mm	6.2	2a	x1.5	1	x2.0
4	2019-03-18	Papua, Indonesia (139.5,-3.0)	66.4 mm	8.5	1e	x1.0	6	x1.1
5	2019-03-15	Java, Indonesia (108.0,-6.0)	38.0 mm	7.7	8e	x1.1	2	x2.4
6	2019-04-26	South Sumatra, Indonesia (103.5,-4.5)	42.4 mm	6.5	3e	x1.7	13	x1.8
7	2019-05-03	Sumatra, Indonesia (99.0,1.5)	25.8 mm	6.4	6a	x1.6	14	x1.2
8	2019-05-17	Maluku and Timor Leste (129.0,-3.0)	33.7 mm	9.5	6a	x0.5	20	x0.9
9	2019-05-28	North Vietnam (105.0,22.5)	52.0 mm	9.1	4g	x0.7	21	x1.4
10	2019-06-02	Sarawak, Malaysia (112.5,0.0)	51.5 mm	9.2	3g	x2.0	15	x2.1
11	2019-06-08	Sulawesi, Indonesia (121.5,-3.0)	77.8 mm	7.7	4g	x1.2	18	x2.0
12	2019-06-12	East Kalimantan, Indonesia (114.0,0.0)	34.0 mm	8.0	4c	x0.7	20	x1.1
13	2019-06-08	Mindanao, Philippines (124.5,7.5)	28.6 mm	3.7	4g	x0.7	18	x2.0
14	2019-06-24	North West Vietnam (102.0,21.0)	30.4 mm	6.6	4h	x0.7	30	x1.1
15	2019-07-03	North Central Vietnam (106.5,18.0)	211.4 mm	4.5 (0.5)	4e	x1.6 (x4.3)	23	x3.2 (x6.5)
16	2019-07-16	Luzon, Philippines (121.5,18.0)	92.6 mm	8.4 (1.0)	5e	x1.9 (x2.9)	32	x6.3 (x19.7)
17	2019-08-03	Laos and Vietnam (103.5,19.5)	152.8 mm	10.9 (0.3)	5e	x1.3 (x0.0)	28	x1.4 (x2.9)
18	2019-08-23	Luzon, Philippines (121.5,18.0)	162.6 mm	10.2 (1.7)	5b	x3.7 (x6.2)	32	x5.1 (x11.2)
19	2019-08-29	Widespread Vietnam (108.0,16.5)	206.5 mm	9.0 (1.5)	4f	x0.7 (x0.8)	31	x0.5 (x0.0)
20	2019-10-15	Central Vietnam (106.5,18.0)	56.5 mm	12.2	7f	x0.3	46	x0.3
21	2019-10-22	Malaysia and Sumatra (103.5,1.5)	40.6 mm	4.7	6c	x0.9	15	x1.3
22	2019-10-30	Southern Central Vietnam (109.5,13.5)	177.7 mm	13.9 (1.2)	7b	x0.7 (x0.6)	41	x0.3 (x0.0)
23	2019-11-09	Luzon, Philippines (121.5,16.5)	48.5 mm	10.4	6d	x1.0	38	x0.7
24	2019-11-10	Daklak, Vietnam (108.0,12.0)	176.8 mm	4.5 (0.2)	6d	x1.5 (x3.9)	38	x2.1 (x4.7)
25	2019-11-20	Southern Luzon, Philippines (121.5,18.0)	48.0 mm	9.5	8c	x0.5	46	x1.0
26	2019-12-01	South Thailand/Malaysia (102.0,6.0)	88.8 mm	18.4	7e	x0.2	48	x0.8
27	2019-12-02	Central Philippines (123.0,13.5)	163.1 mm	14.8 (1.9)	7e	x1.2 (x1.1)	48	x1.5 (x2.1)
28	2019-12-05	Luzon, Philippines (121.5,18.0)	65.8 mm	7.0	7g	x1.3	42	x6.6
29	2019-12-09	Sabah, Malaysia (118.5,6.0)	67.1 mm	10.2	7f	x0.2	46	x0.3
30	2019-12-13	Johor, Malaysia (103.5,1.5)	86.2 mm	8.1	8c	x1.5	11	x0.9
31	2019-12-18	Malaysia and Thailand (103.5,4.5)	62.0 mm	18.1	8c	x1.7	47	x1.8
32	2019-12-18	Riau, Indonesia (103.5,0.0)	31.0 mm	8.0	8c	x1.8	47	x1.7
33	2019-12-30	North Sumatra (97.5,3.0)	26.5 mm	8.8	1c	x1.0	2	x1.3
34	2019-12-31	Jakarta, Indonesia (106.5,-6.0)	81.4 mm	10.1	1c	x1.5	2	x1.6

Table 3: Case study rainfall and rainfall likelihood during selected extreme weather events. Units of rainfall are mm/day and are based on GPM precipitation at nearest grid-cell. Climatological probabilities denote the likelihood of exceeding 25 mm/day at the event location in a 60-day climatological window surrounding the date of the event. Regime probabilities indicate the enhanced or suppressed probability of exceedance given the occurrence of the assigned regime as a ratio over the climatological probability. When the observed rainfall exceeds 90 mm/day, numbers in brackets denote the probability or enhanced/suppressed probability of exceeding 100 mm/day.

SUMMARY

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- The application of two k-means clustering algorithms to South East Asian regions has extracted two sets of weather patterns that are able to distinguish both large-scale variability (ENSO, monsoons) and synoptic weather phenomena (cold surges, MJO/BSISO, tropical cyclones, Borneo vortices, equatorial waves).
- The tiered methodology aims to firstly identify large-scale variability and secondly identify synoptic scale variability within each large-scale regime, while the flat methodology aims to identify both modes of variability at once.
- The flat methodology can explain more vector wind and rainfall variance than the two-tiered methodology, however the two-tiered methodology better captures large scale variability.
- Regime-based forecasts will feature a low degree of forecast sharpness due to limitations in their formulation.
- Both sets of weather patterns have the potential to be useful for forecasting the increased likelihood of high impact weather.
- **The predictability of these regimes will be discussed in a separate presentation, titled "Weather regimes in South East Asia: Sub-seasonal predictability of the regimes and the associated high impact weather" and presented by Paula LM Gonzalez (EGU21-7411)**