

Atmospheric Blockings over North Atlantic Teleconnect to the Heatwaves over Northwest India: A Study of the Present, +1.5°C and +2.0°C Warming Worlds

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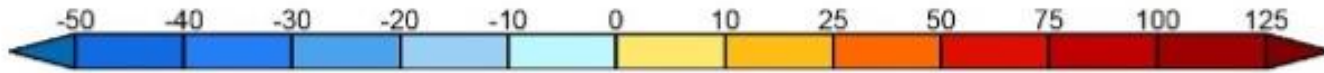
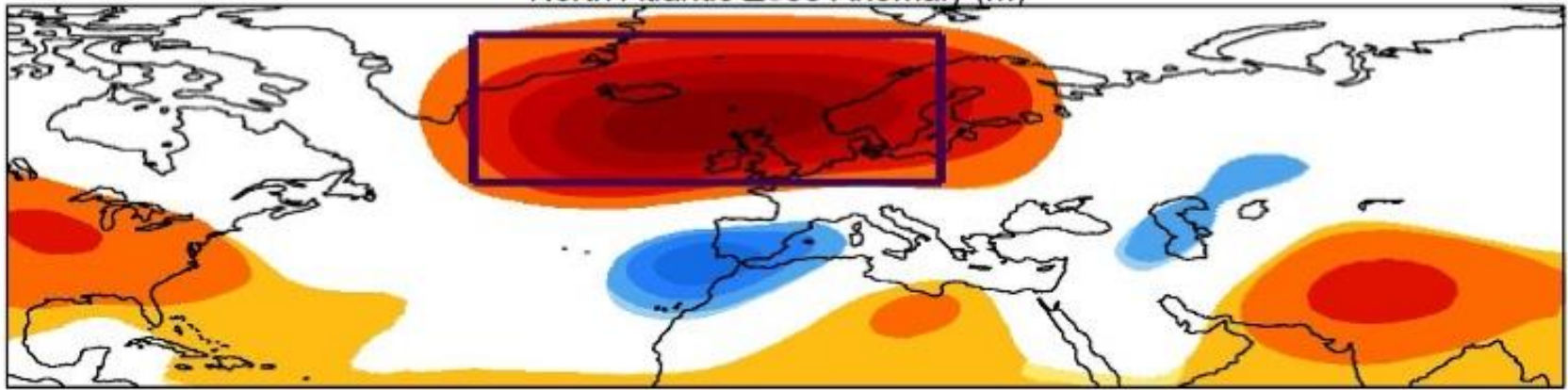
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Composites of Northwest India TMAX preceded by North Atlantic Geopotential Height 500hPa
MAMJ 1979-2018, 35 Events, 335 days Anomalies Mean (Significance at 95% level students 1 tailed t-test)

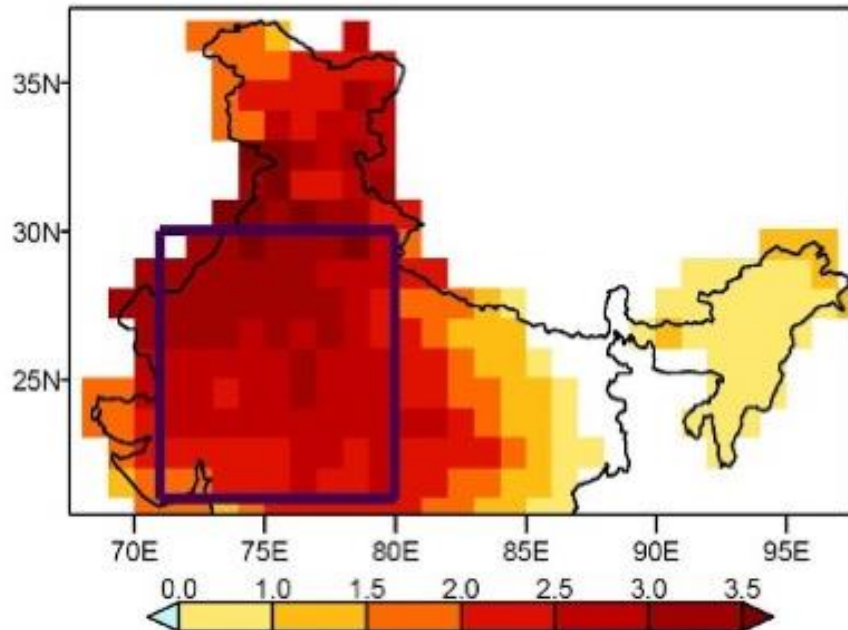
(a)

North Atlantic Z500 Anomaly (m)

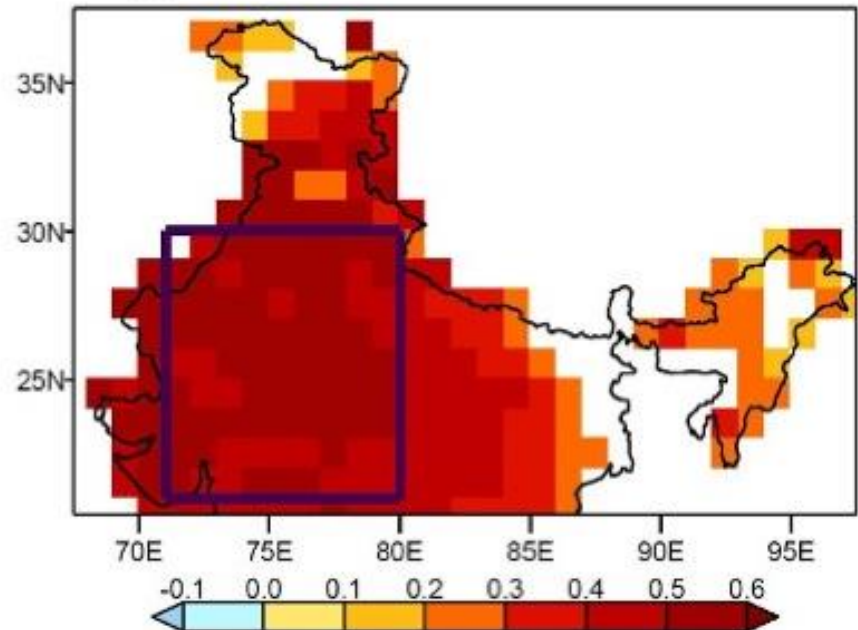


(After Ratnam et al., 2016)

(b) Northwest India TMAX Anomaly (°C)



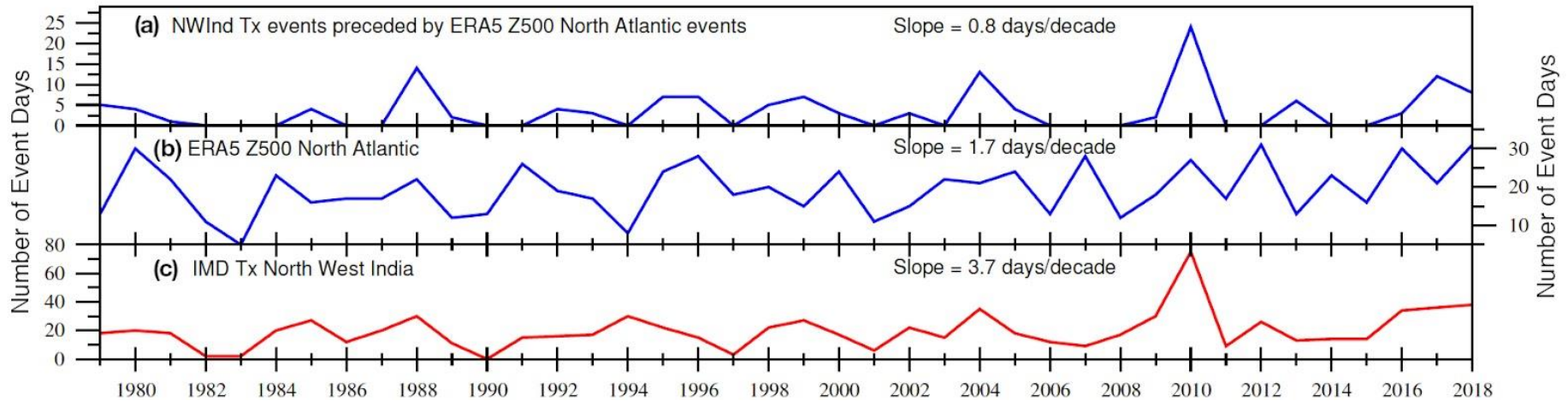
(c) Correlation Z500 Vs TMAX Anomalies



Teleconnection NorthAtlantic Blocking Vs Tmax NWIndia 1979-2018 (MAMJ)

(After Ratnam et al., 2016)

Number of Days : IMD Tmax Vs ERA5 Geopotential Height 500hPa (MAMJ)
 Anomalies are Normalized by its standard deviation. Event Days when Anomaly Norm > 1std



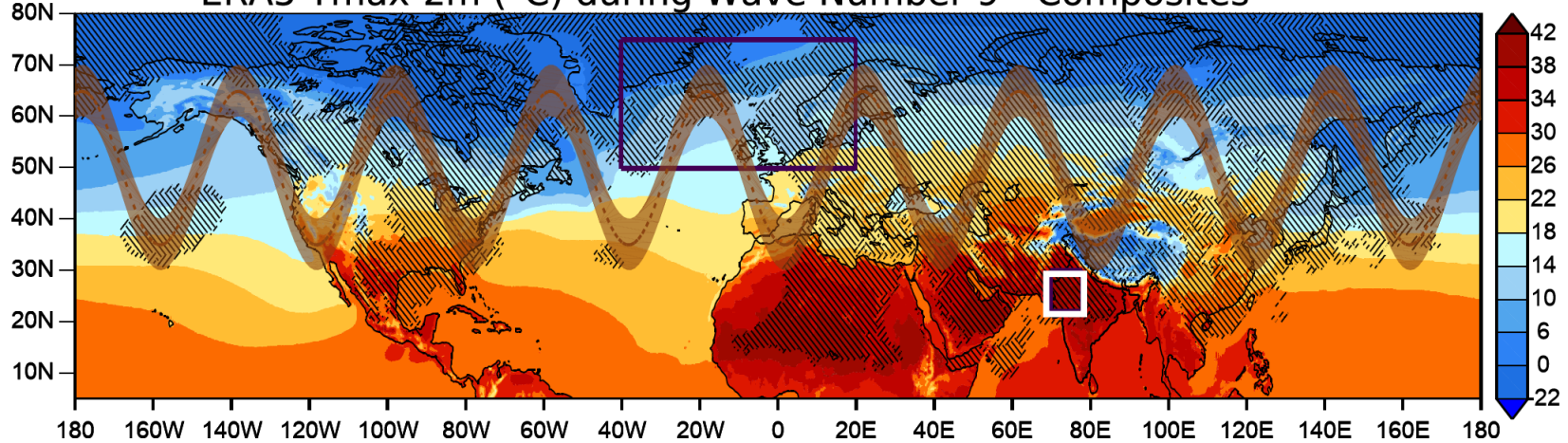
	ERA5 zg500 Granger Cause IMD Tmax		IMD Tmax Granger Cause ERA5 zg500	
Lag	F Statistic	Probability (>F)	F Statistic	Probability (>F)
1	2.7771	0.09569	0.3196	0.5719
2	2.2332	0.1073	0.5991	0.5494
3	2.7414	0.04171*	1.4882	0.2156
4	1.8635	0.1139	0.984	0.4148
5	1.2163	0.2986	1.6158	0.1522

ERA5 zg500 over North Atlantic **Granger Cause** IMD Tmax over North India **at lag-3 day, significant at 0.05 level** H0 : zg500 does not granger cause Tmax

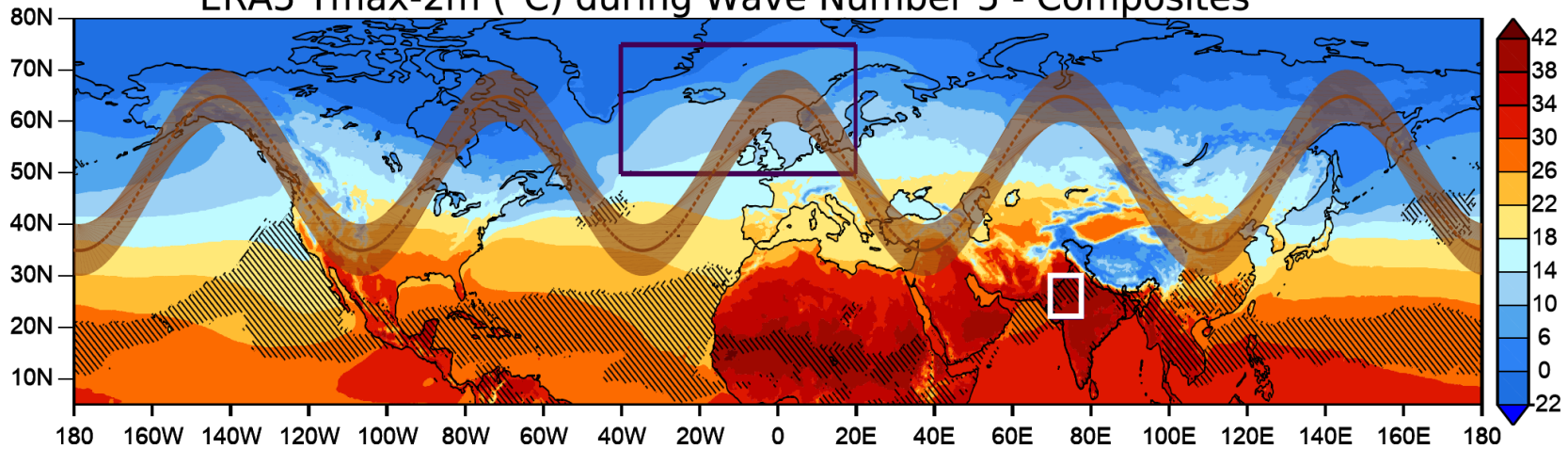
ERA5 TMAX-2M (°C) during Rossby Wave Number 9 & 5 Composites – MAMJ (1979-2018)

(After Kornhuber, Kai et al., (2020))

ERA5 Tmax-2m (°C) during Wave Number 9 - Composites

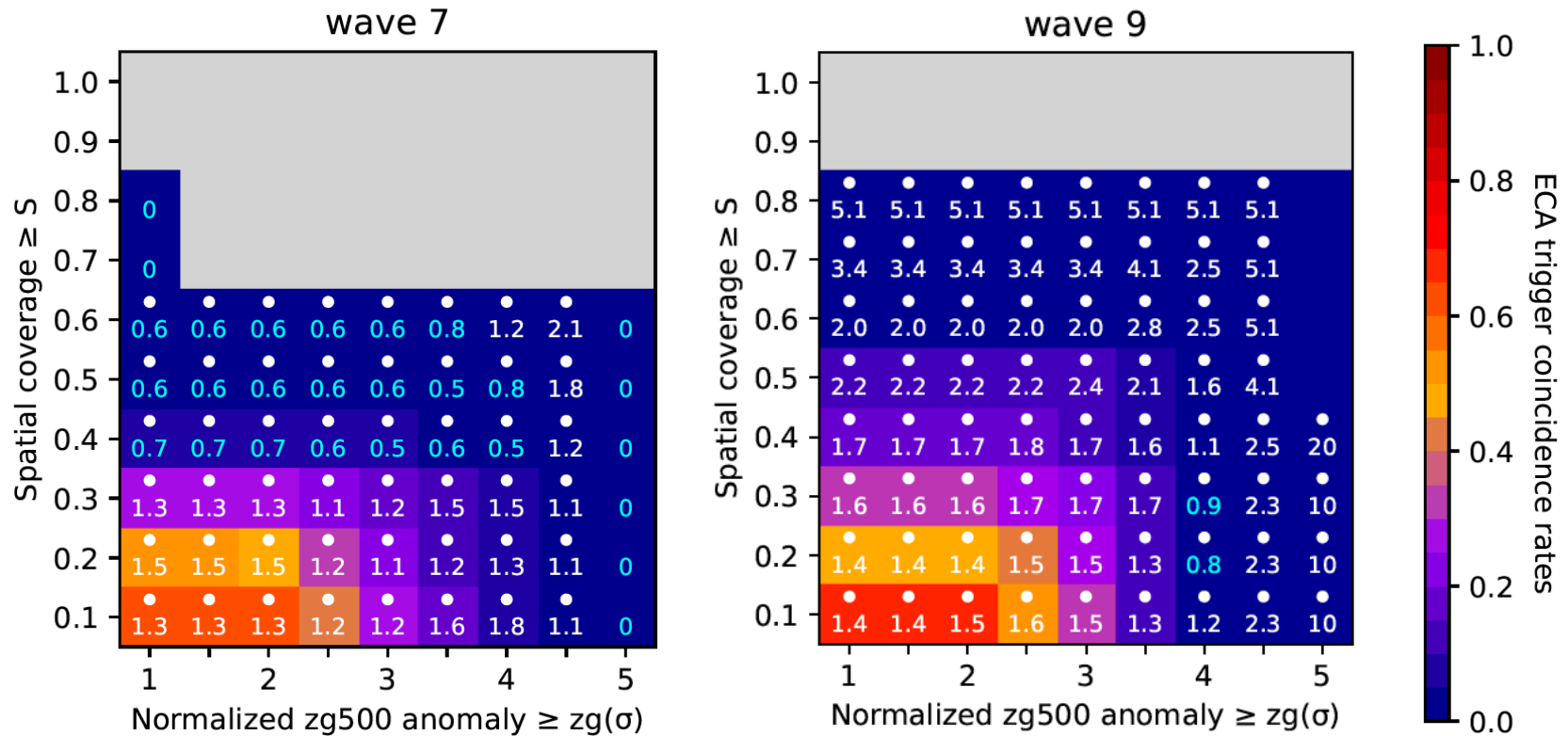


ERA5 Tmax-2m (°C) during Wave Number 5 - Composites



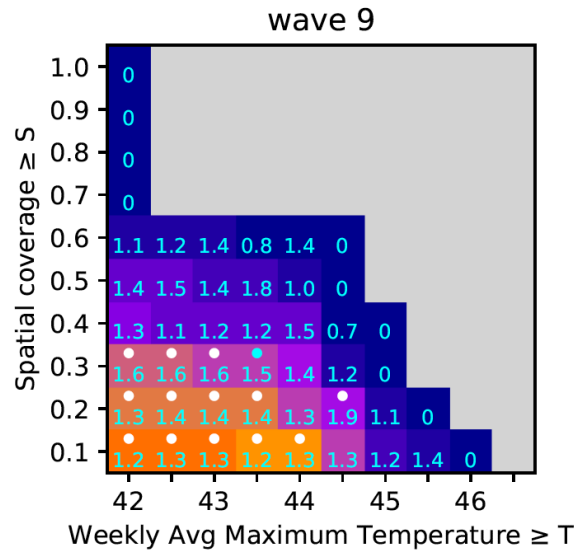
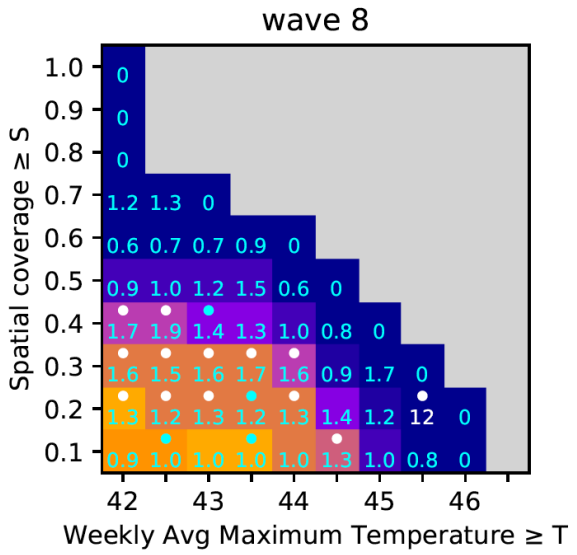
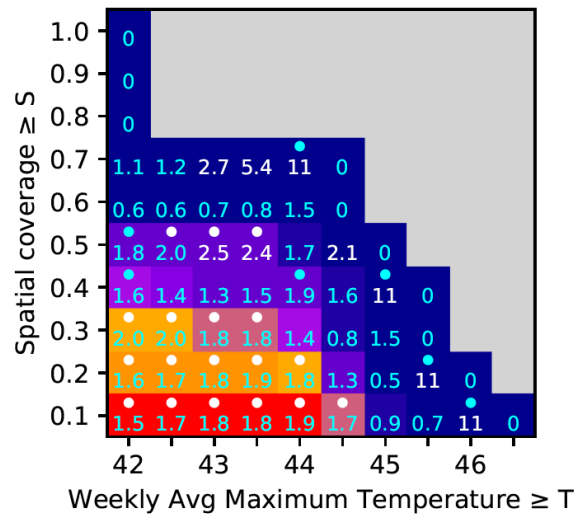
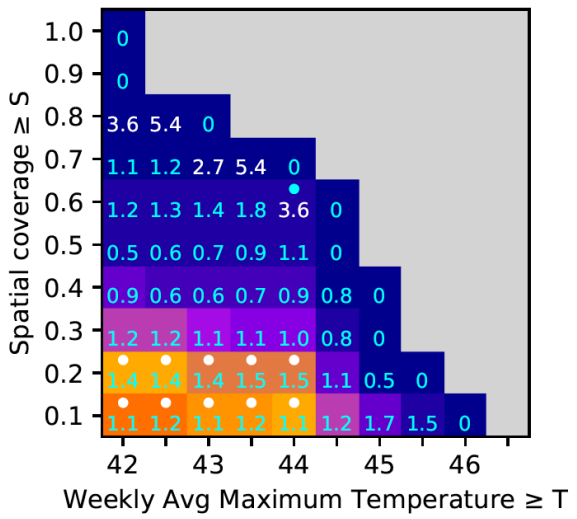
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Waves	5,6,7,8	6,7,8,9	5,6,7,8,9	6,7,8,9	5,6,7,8,9	5,6,7	5,6,7,8,9	5,6,7,8,9	5,6,7,8,9	9	5,6,7,8	6,7,8,9	5,6,9
Mortality	754	932	616	1071	1274	793	1247	1216	1677	2422	1111	384	25

ERA5 500hPa waves versus North Atlantic Normalized Zg500 Anomaly (1979-2018, MAMJ)



- ❖ Event Coincident Analysis (ECA) is a statistical method that allows quantification of the simultaneity of events contained in two series of observations, with statistical significance assessed by random shuffling.
- ❖ ECA confirms that the Rossby Wavenumbers 7 & 9, at least 20% area coverage over North Atlantic experienced higher $Zg500 > \text{std}$, which has ECA rate more than 0.5 (statistically significant at 95% level – white dots), during MAMJ of 1979 – 2018 events.
- ❖ Also, higher rate of probability to occur $Zg500$ anomaly $> \text{std}$ event over North Atlantic during respective Rossby wave number period, compared to non Rossby wave period.
- ❖ Similar kind of relationship exists for wave number 4 to 9.

ERA5 500hPa waves versus North India Heatwave+Severe Heatwave (1979-2018, MAMJ)
 wave 6



Higher probability of occurrence of weekly average Tmax > HW+SHW event over Northwest India during respective Rossby wave number period, compared to non Rossby wave period.

Wavenumber 7, 9 are the most ECA triggered (wavenumber 6, 8 are the next highest) heat wave events in northwest India.

❖ Event Coincident Analysis (ECA) confirms that the Rossby Wavenumbers 7, 8, 9, at least 30% area coverage over Northwest India experienced higher weekly mean of Heatwave + Severe Heatwave Tmax, which has ECA rate more than 0.5 (statistically significant at 95% level – white dots), during MAMJ of 1979 – 2018 events.

What can we expect in the 1.5°C or 2°C futures?

- We use model output from HAPPI (*Half a degree Additional warming, Prognosis and Projected Impacts; Mitchell et al., 2017*)
- Three experiments (10-years each):
 - historical (2006-2015), +1.5°C, and +2°C.
 - Aerosols are unchanged across experiments

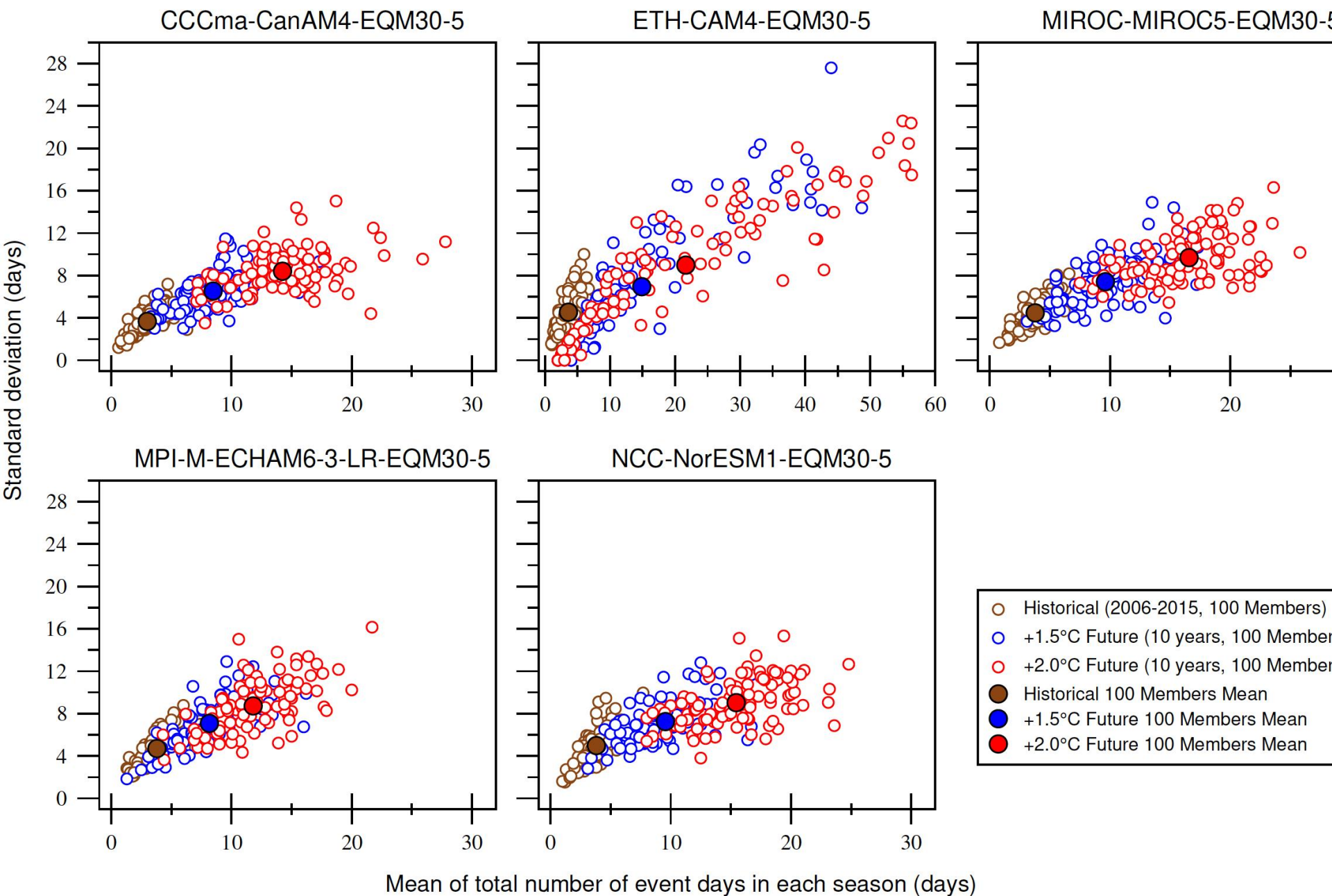
Institution	Model Name	Ensemble Members
NCC	NorESM1	125
MPI-M	ECHAM6-3-LR	100
MIROC	MIROC5	100
CCCma	CanAM4	100
ETH	CAM4	501
Total Ensemble Members		926

All model temperature and Zg500 fields were bias corrected using Empirical Quantile Mapping (eQM):
Amengual et al. 2012.

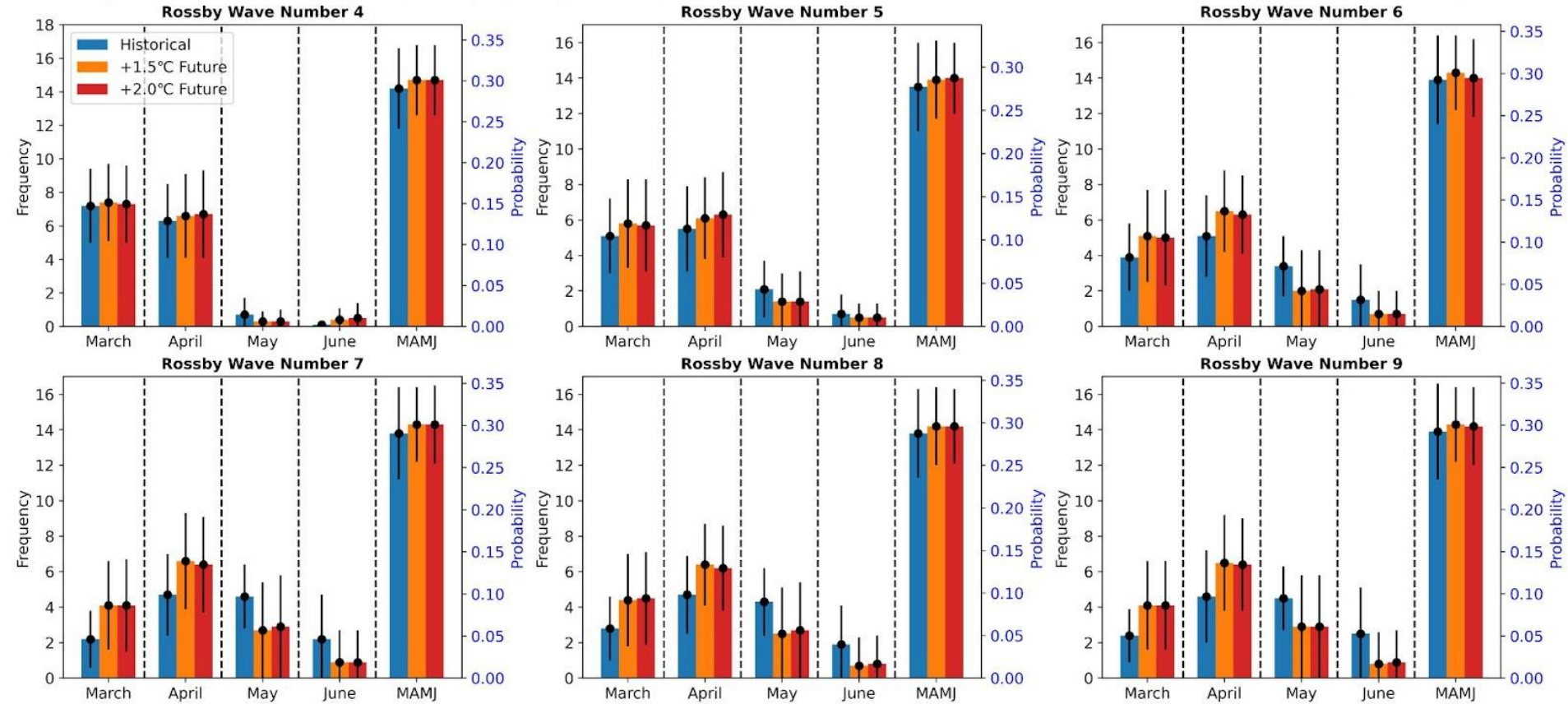
Number of Days : HAPPI MME (500 members) TMAX (North West India) preceded by Zg-500hPa (North Atlantic)

(MAMJ 10 years) All Anomalies are Normalized by its Historical Standard deviation

Event Days when Anomaly Norm > 1std

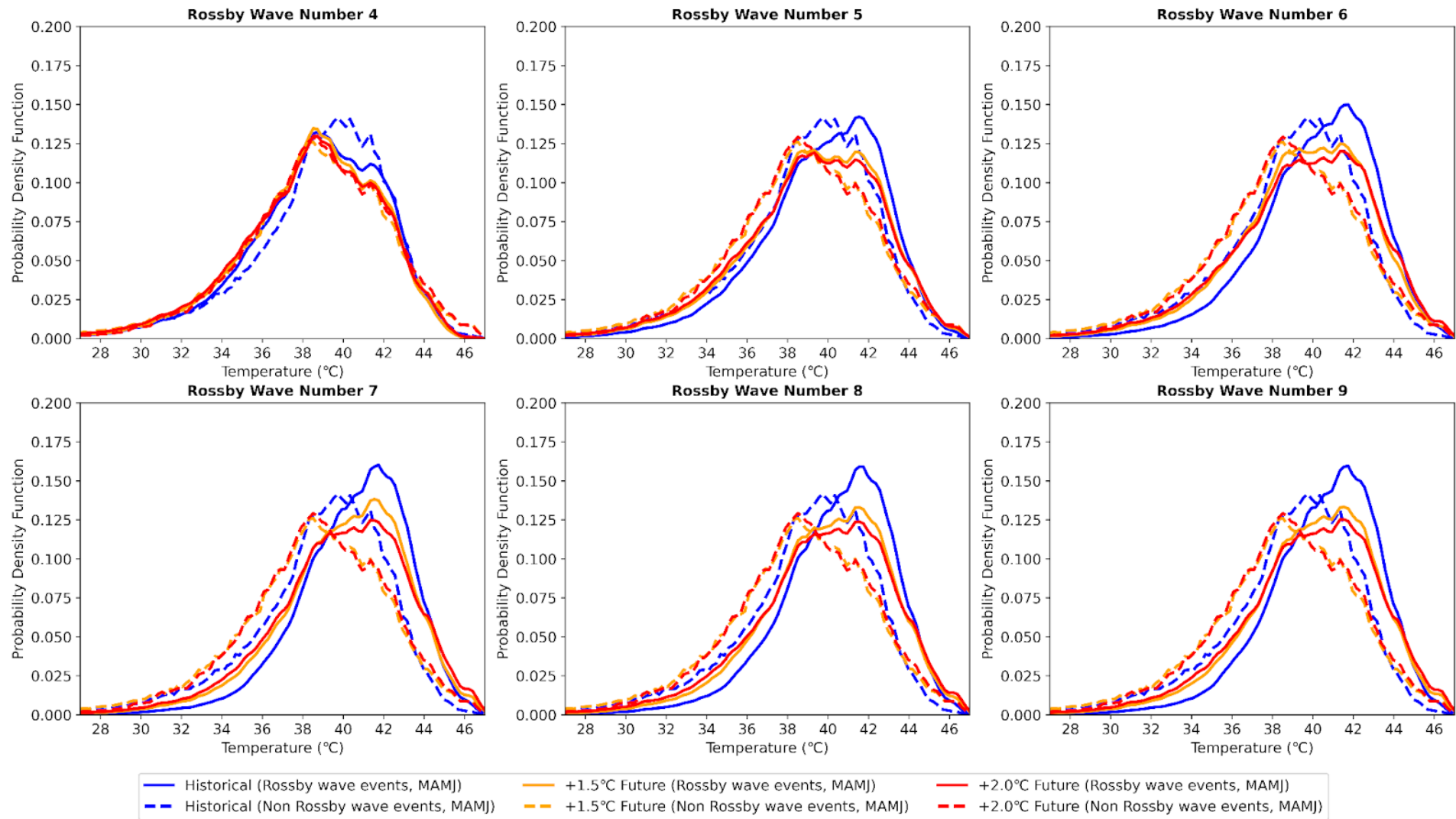


Frequency and Probability of Weekly Rossby Wave Numbers at 500 hPa - HAPPI Multi Models (MAMJ, 10 years, 500 Ensembles)



Mean Frequency (and probability) of weekly Rossby Waves (for wave numbers 4 to 9) from 5 HAPPI models (500 ensemble members) in the Historical, +1.5°C and +2°C simulations (10 years each), during individual months between March to June and the whole season. The error bars represent standard deviation obtained from 500 ensemble members, with statistical significance at 95% confidence level, by a Monte Carlo method with random shuffling of events in time ($N = 1000$).

Probability of Daily Tmax over Northwest India - Rossby Waves at 500 hPa - HAPPI 5 Models (10 years, 500 Ens)



Probability density function of daily TMAX values over Northwest India during Rossby Wave activity for wave numbers 4-9 during March to June from 5 HAPPI models with 100 ensemble members each for the Historical (blue), +1.5°C (orange) and +2°C (red) simulations. The TMAX probability density functions during Rossby Wave activity (solid lines) are to be compared against the probability density with no Rossby Wave activity (dashed lines).

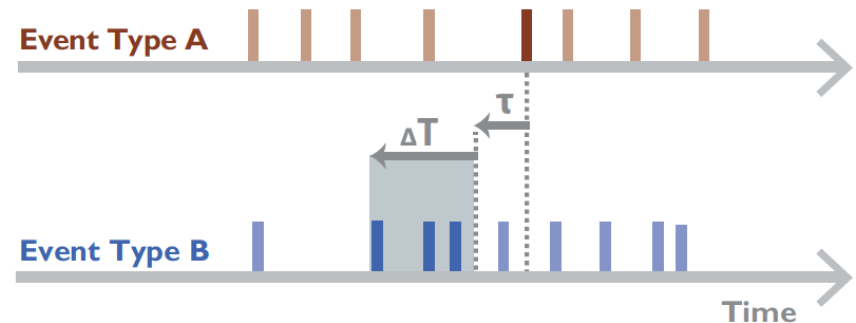
The key findings

- ❖ Atmospheric blocking (geopotential height anomalies at 500 hPa **Zg500**, using ERA5 reanalysis) over the North Atlantic region found to be statistically significant **Granger cause** surface daily maximum temperature (**TMAX**) anomalies over **north central India** with a lag of **three days** during the March to June season (1979-2018).
- ❖ Event Coincident Analysis (**ECA**) confirms that the Rossby **Wavenumbers 4 to 9 are higher ECA trigger rates for Zg500**, and Wavenumber **7, 9** are the **most ECA triggered** and wavenumber **6, 8** are the next most **ECA triggered heat events** (Heatwave + Severe Heatwave) **over northwest India**.
- ❖ Probabilities of at least **0.31, 0.324, 0.284** (statistically significant at 95% level) of teleconnection between **blocking in the North Atlantic and temperature anomalies over Northwest India** in the **historical, +1.5 °C and +2 °C** future simulations respectively.
- ❖ **Higher frequency of Rossby Waves** occurrences were also seen **during March and April** in the **+1.5°C and +2°C** future simulations **compared to historical** simulations whereas **May and June show a decline**. This will **likely trigger more heat events over Northwest India earlier (Mar and April) through blocking teleconnections** and fewer heat events in May and June. This will result in the overall season (March-June) having an unchanged frequency.
- ❖ Finally, the **probability of heat events at a lower temperature range (34°C-44°C) increase** in the **+1.5°C and +2°C** future simulations towards, **compared to historical** simulations, **consistent with the finding of increases in an earlier occurrence of Rossby waves** (during March and April).

THANK YOU

Event Coincident Analysis (ECA)

ECA is a statistical method that allows quantification of the simultaneity of events contained in two series of observations, with statistical significance assessed by random shuffling



An *instantaneous coincidence* is defined to occur if two events at t_i^A, t_j^B with $t_j^B < t_i^A$ are closer in time than a temporal tolerance or *coincidence interval* ΔT , i.e. if

$$t_i^A - t_j^B \leq \Delta T \quad (1)$$

holds. In turn, a *lagged coincidence* is defined as an instantaneous coincidence between the time shifted event at $t_i^A - \tau$, where $\tau \geq 0$ is a time lag parameter, and the event at $t_j^B < t_i^A - \tau$, i.e. if the condition

$$(t_i^A - \tau) - t_j^B \leq \Delta T \quad (2)$$

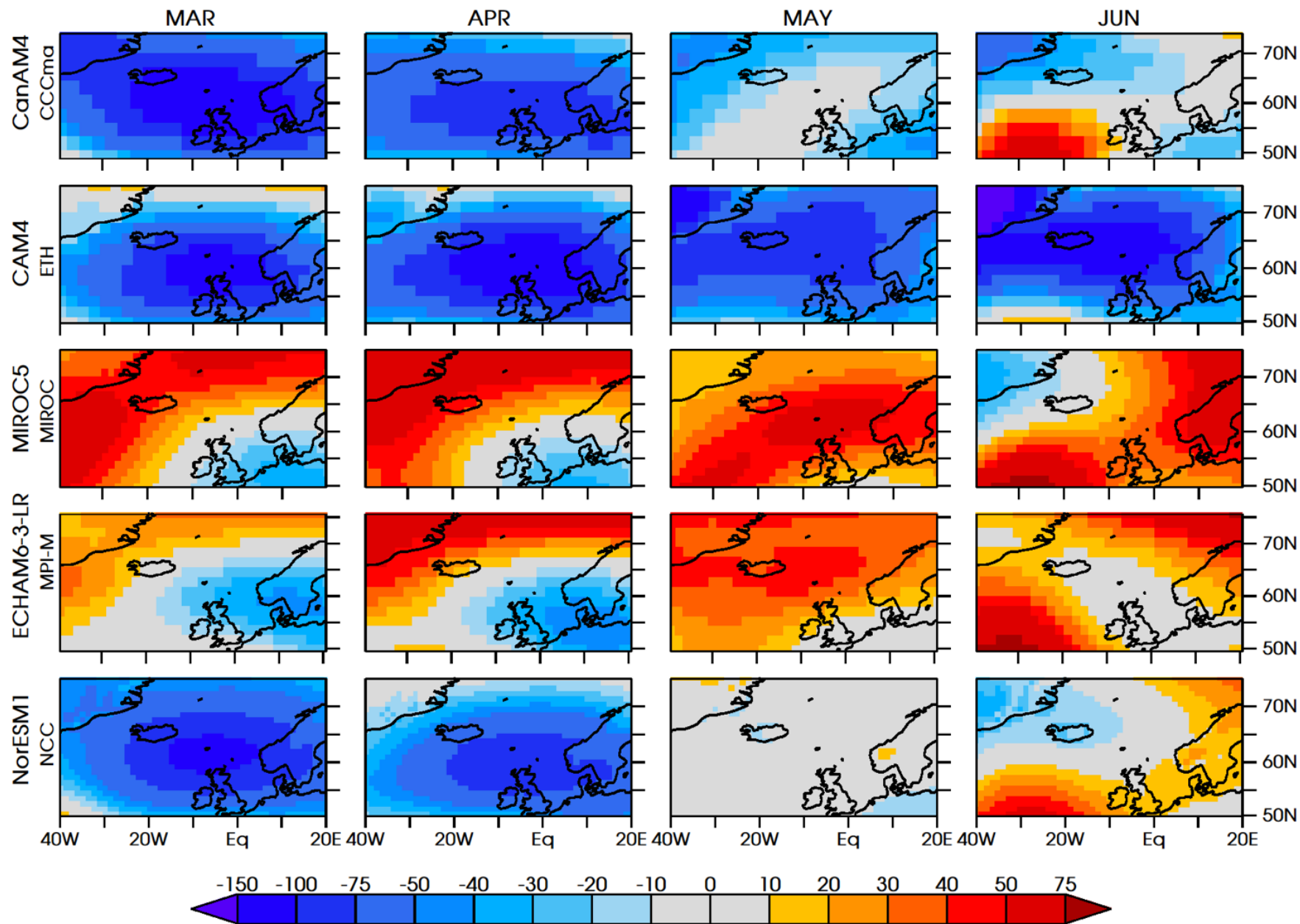
is satisfied.

The ECA triggered coincidence rate is expressed as below

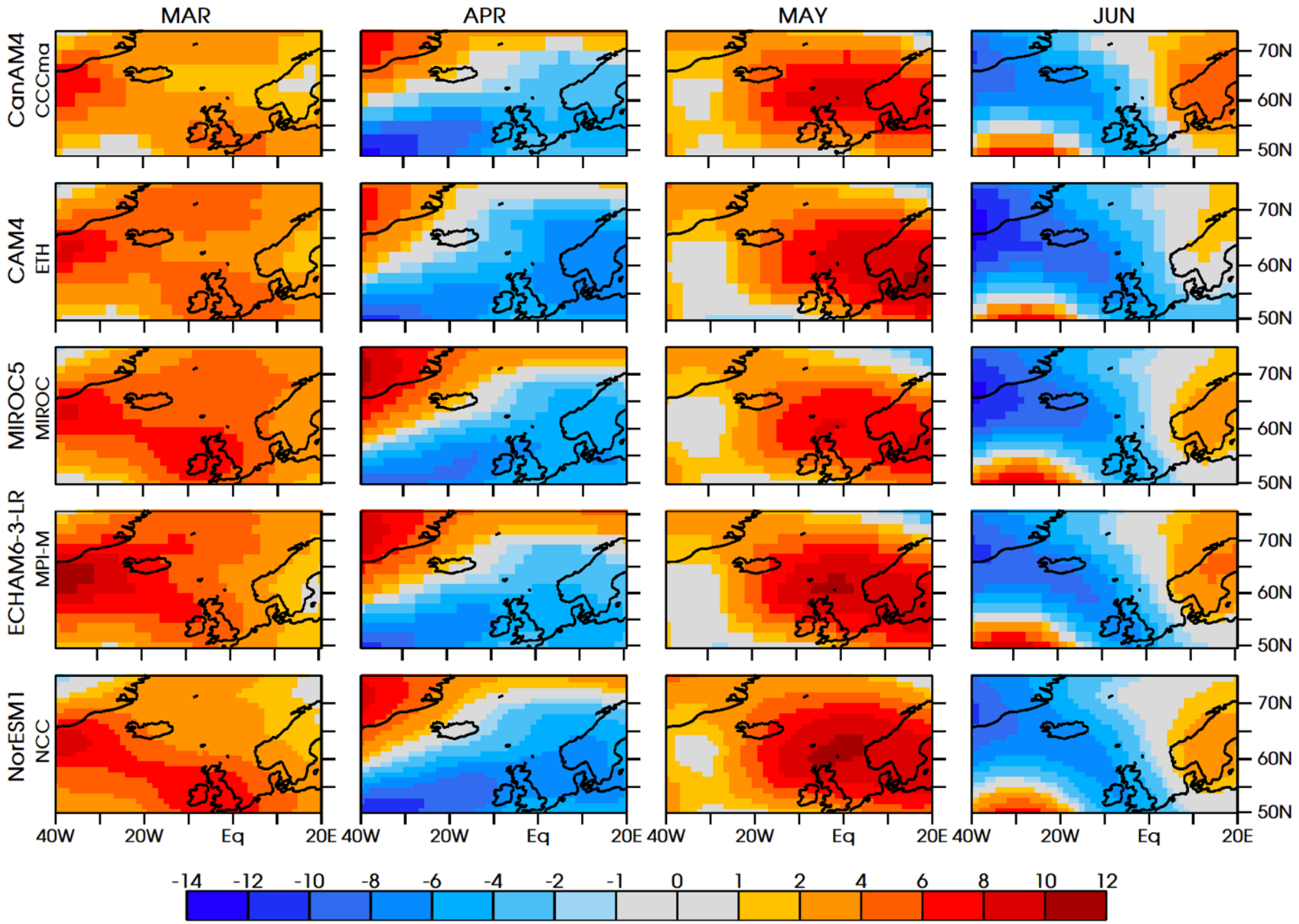
$$r_t(\Delta T, \tau) = \frac{1}{N_B} \sum_{j=1}^{N_B} \Theta \left[\sum_{i=1}^{N_A} 1_{[0, \Delta T]} \left((t_i^A - \tau) - t_j^B \right) \right]$$

Event Coincident Analysis (ECA) was performed using the CoinCalc R package (Siegmond, N 2017) by following the methodology introduced by Donges, J. et al., (2016) and the statistical significance of coincidence rates was tested using a Monte Carlo approach based on random shuffling of events in time ($N = 1,000$), employing a confidence level of 99% and 95%, respectively.

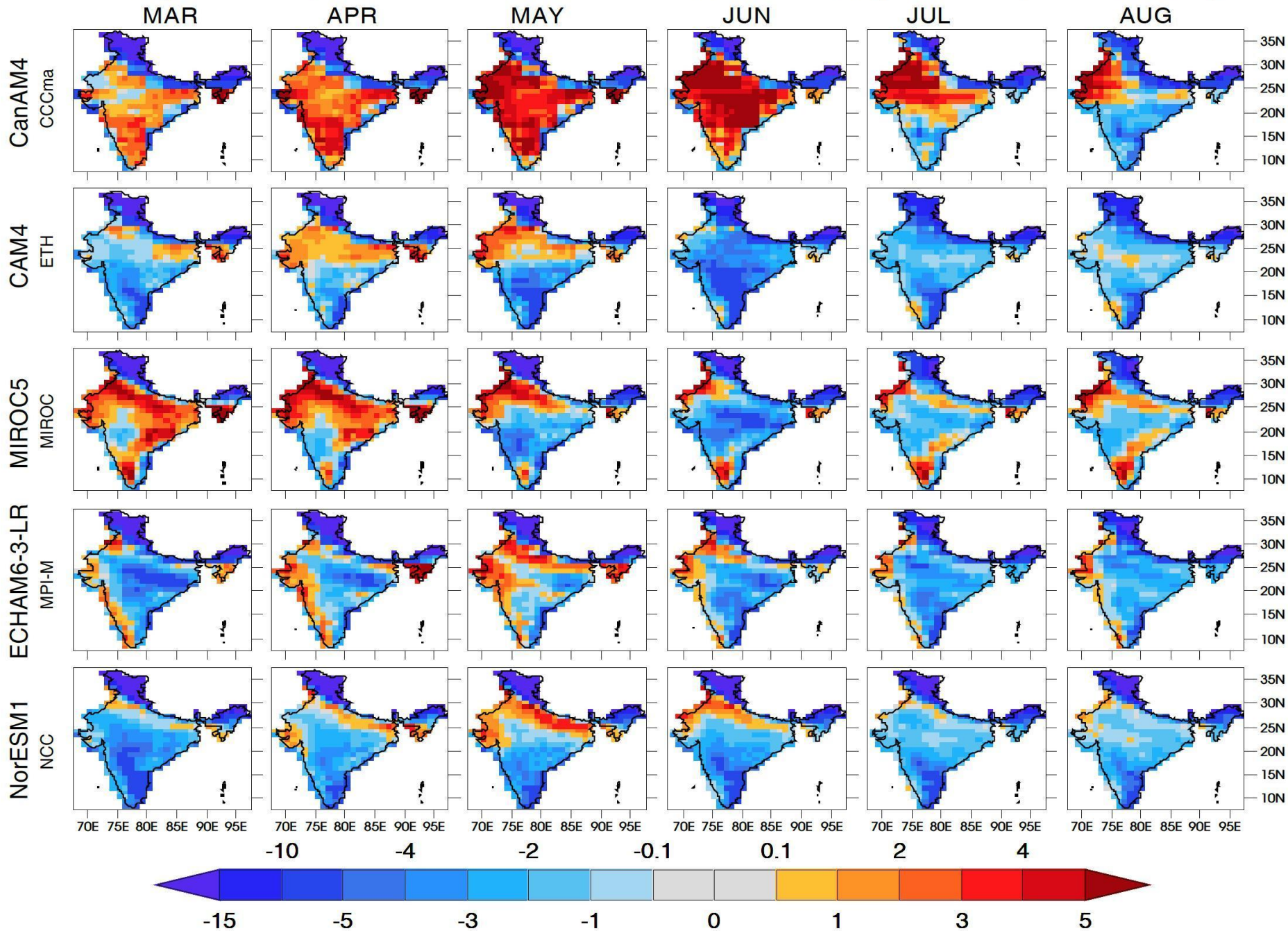
Daily Geopotential Height 500hPa MeanError ERA5 Vs HAPPI-uncorrected Historical (2006-2015, 100 members)



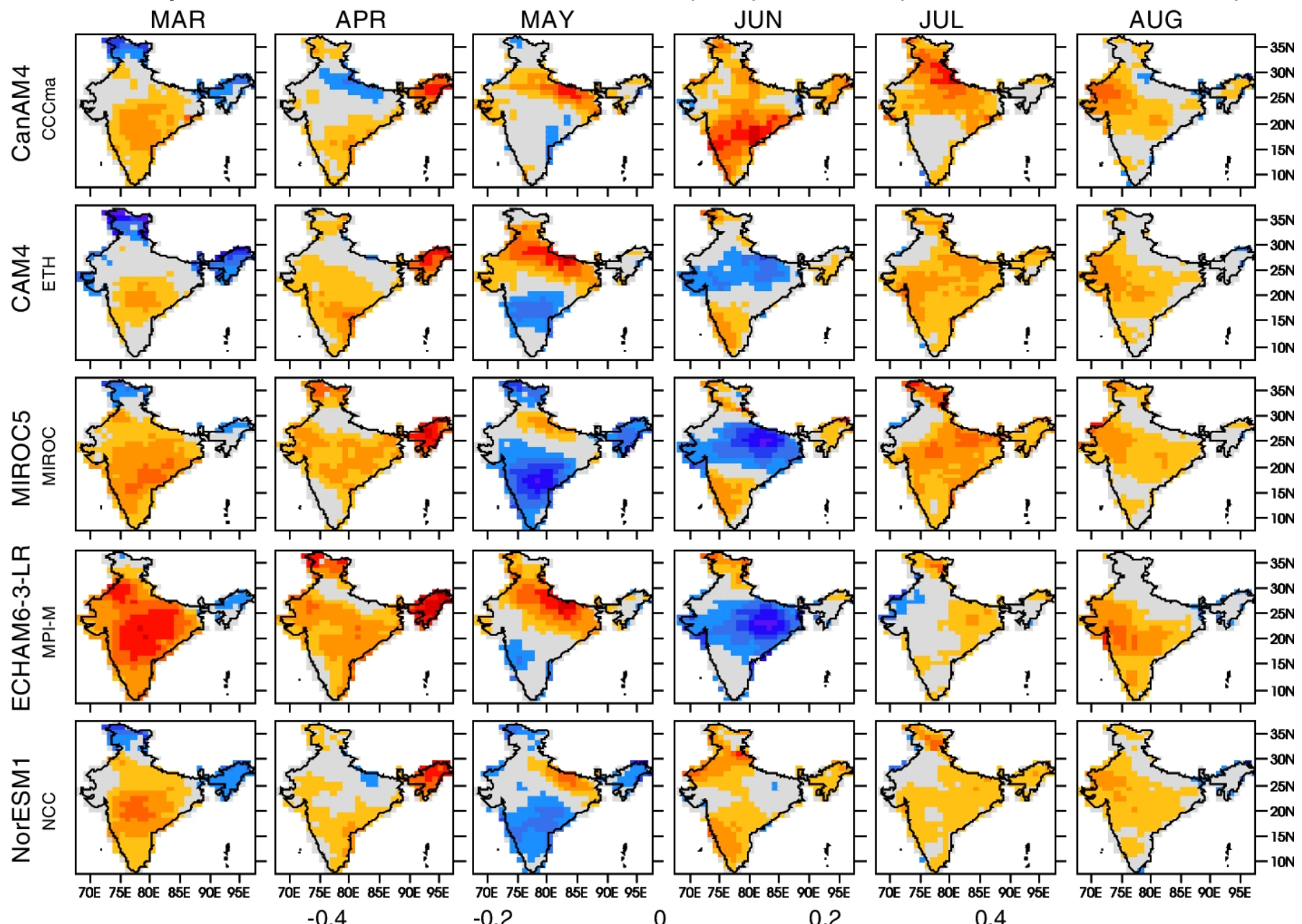
Daily Geopotential Height 500hPa MeanError ERA5 Vs HAPPI-EQM(30,5) Historical (2006-2015, 100 members)



Daily TMAX MeanError IMD Vs HAPPI-Simulated Historical (2006-2015, 100 members)

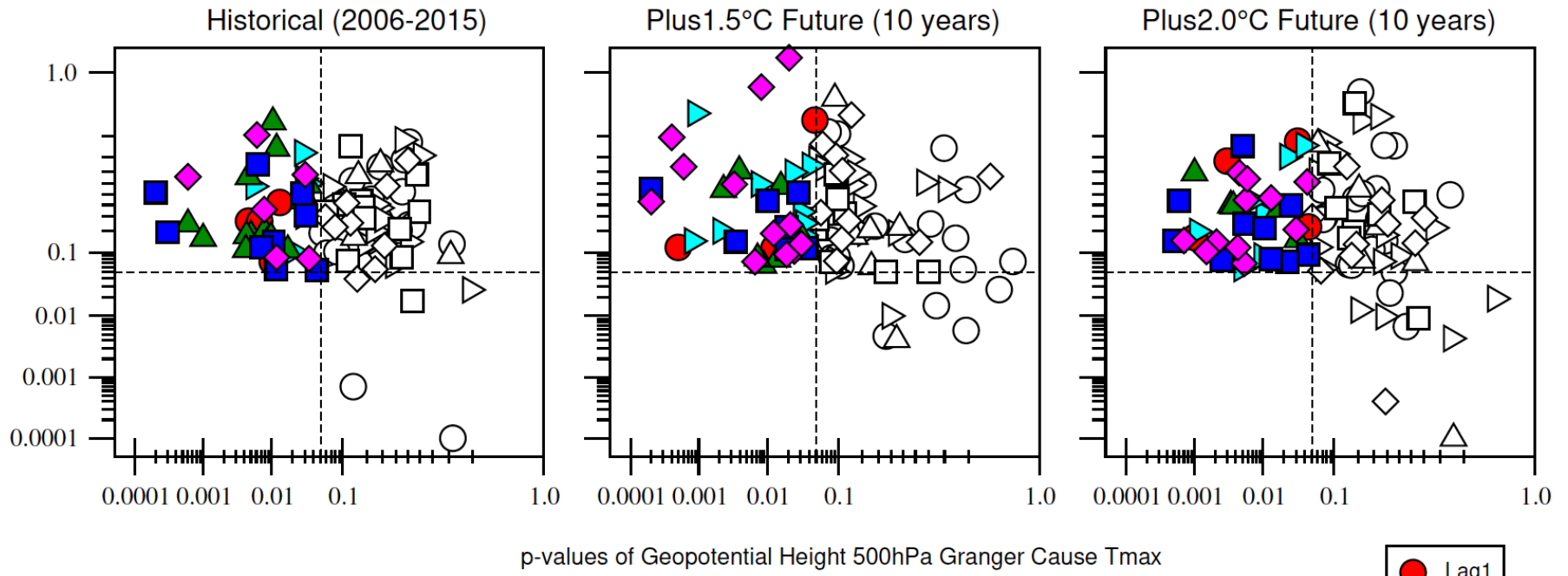


Daily TMAX MeanError IMD Vs HAPPI-EQM(30,5) Historical (2006-2015, 100 members)



HAPPI CCCma-CanAM4-EQM30-5 (100 members) Stats Geopotential Height 500hPa Versus Tmax
 (MAMJ 10 years) All Anomalies are Normalized by its Historical Standard deviation

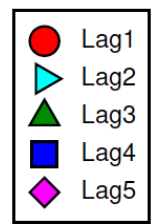
p-values of Tmax Granger Cause Geopotential Height 500hPa



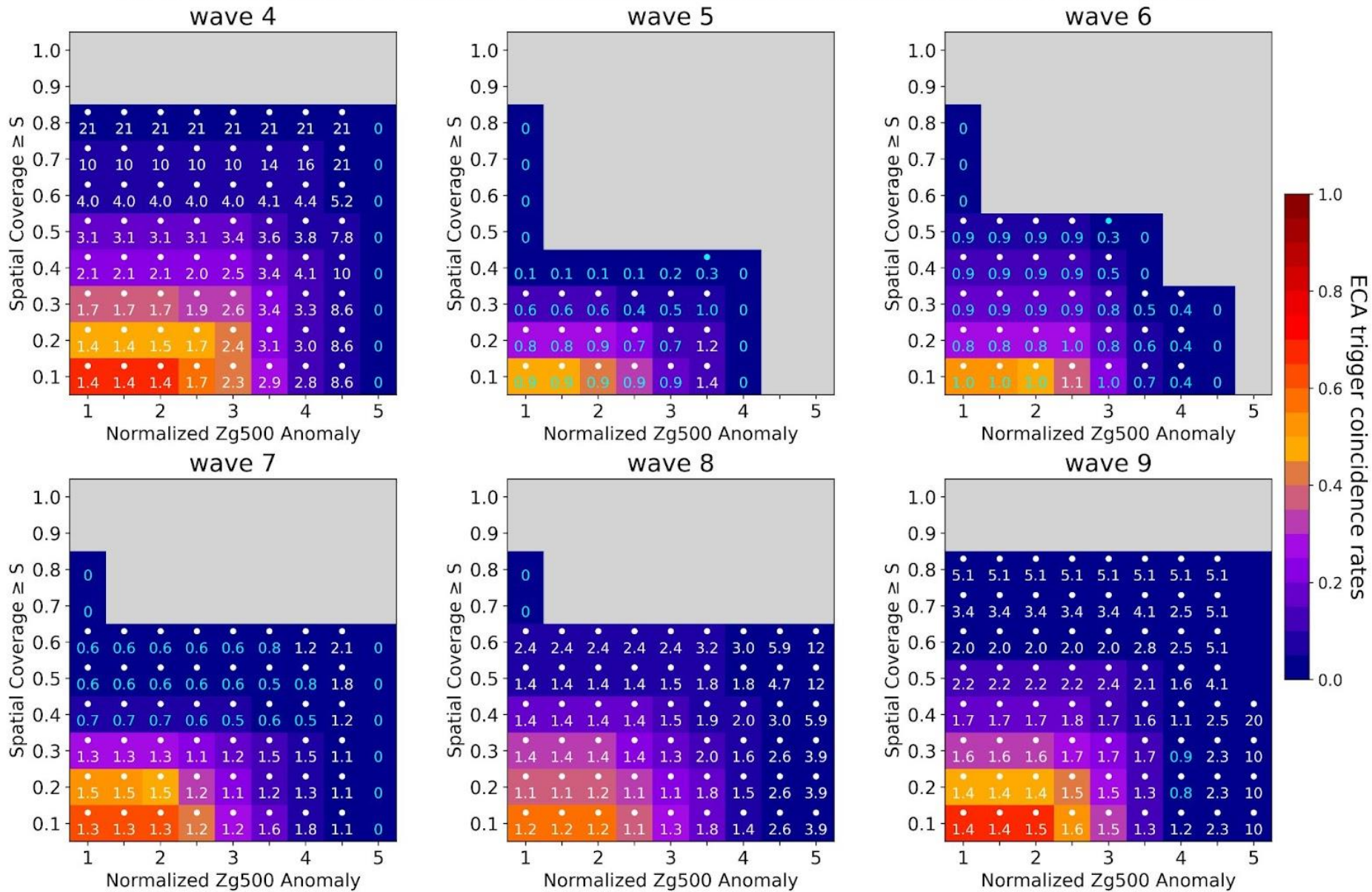
Lag1 = 4
 Lag2 = 7
 Lag3 = 14
 Lag4 = 9
 Lag5 = 6

Lag1 = 4
 Lag2 = 9
 Lag3 = 9
 Lag4 = 7
 Lag5 = 12

Lag1 = 4
 Lag2 = 8
 Lag3 = 5
 Lag4 = 12
 Lag5 = 12

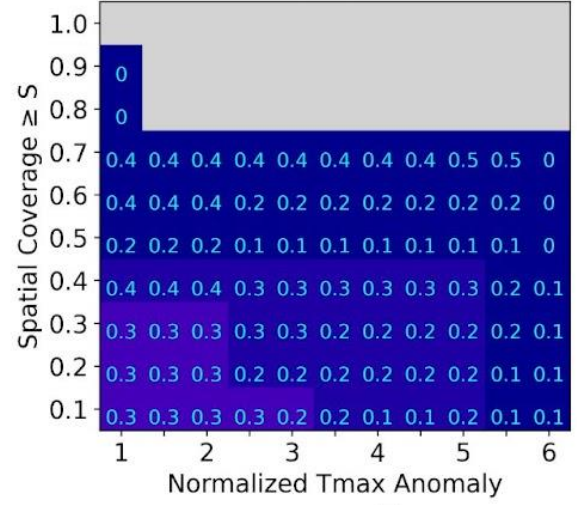


ERA5 500hPa waves versus North Atlantic Normalized Zg500 Anomaly (1979-2018, MAMJ)

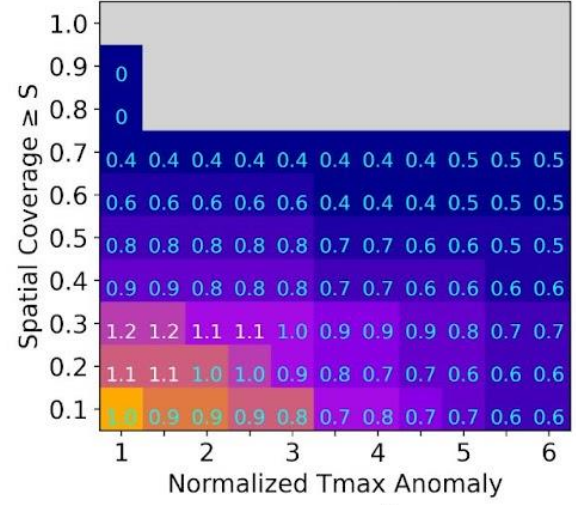


ERA5 500hPa waves versus Northwest India Normalized Tmax Anomaly (1979-2018, MAMJ)

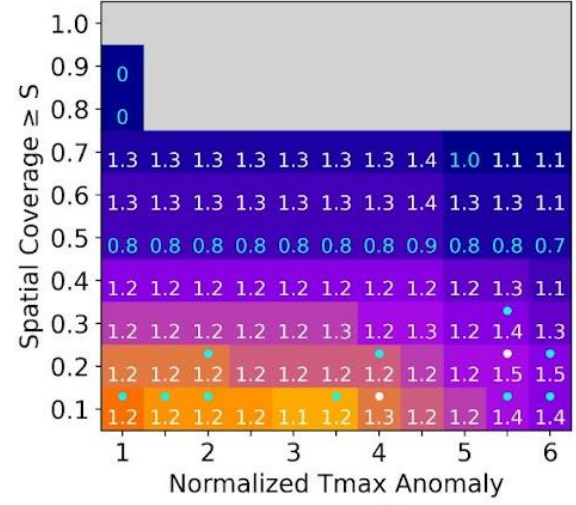
wave 4



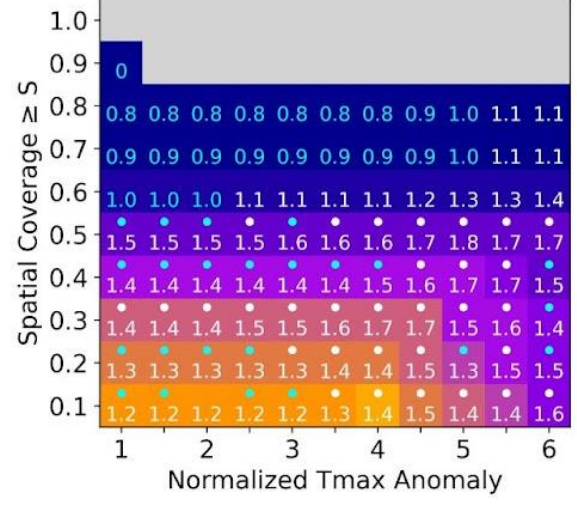
wave 5



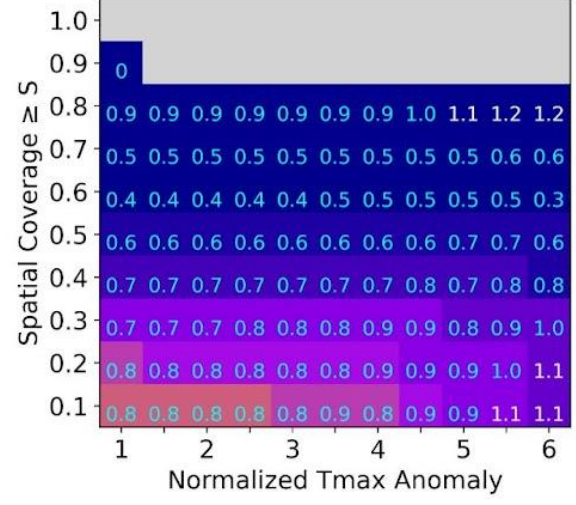
wave 6



wave 7



wave 8



wave 9

