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A Causality-guided Approach for Predicting Future Changes in Extreme Rainfall over China Using Known Large-scale Modes

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Motivation & Overview

- To develop suitable tools for climate services in China to predict extreme regional precipitation
  → Representation of **extremes** in ESM/AOGCMs ➔ **Not good**
  → Representation of **large-scale modes** in ESM/AOGCMs ➔ **Good**
- Use statistical model, i.e. transfer function, to improve the representation of extremes

Large-scale modes ➔ Transfer function ➔Extremes!

- Causality-guided approach to select predictors
  → **Causality-guided statistical model (CGSM)**
- Focus on extreme Mei-yu rainfall (MYR) and extreme tropical cyclone rainfall (TCR).
- Data: ERA5, CN05.1, CMIP6 (historical/SSP585)

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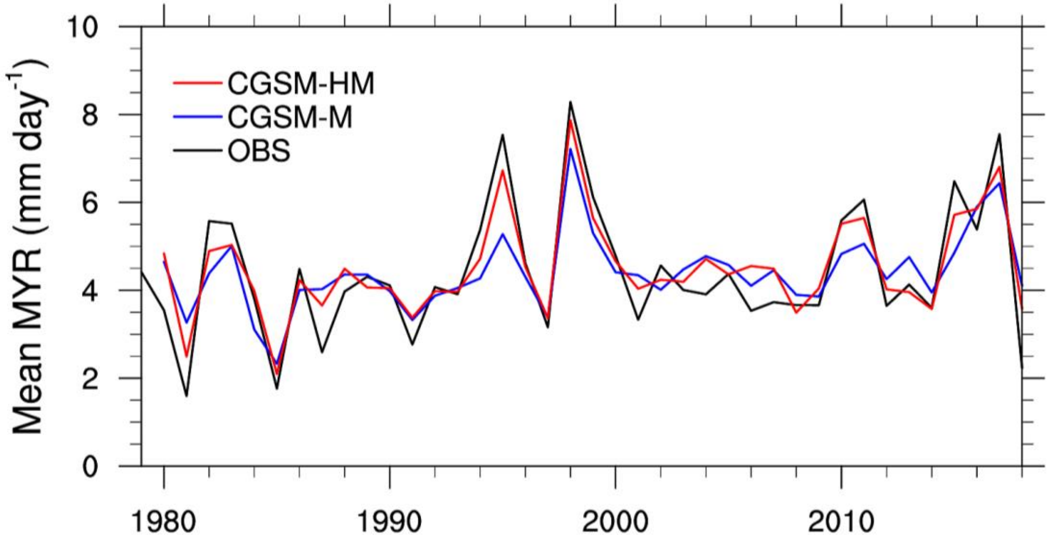
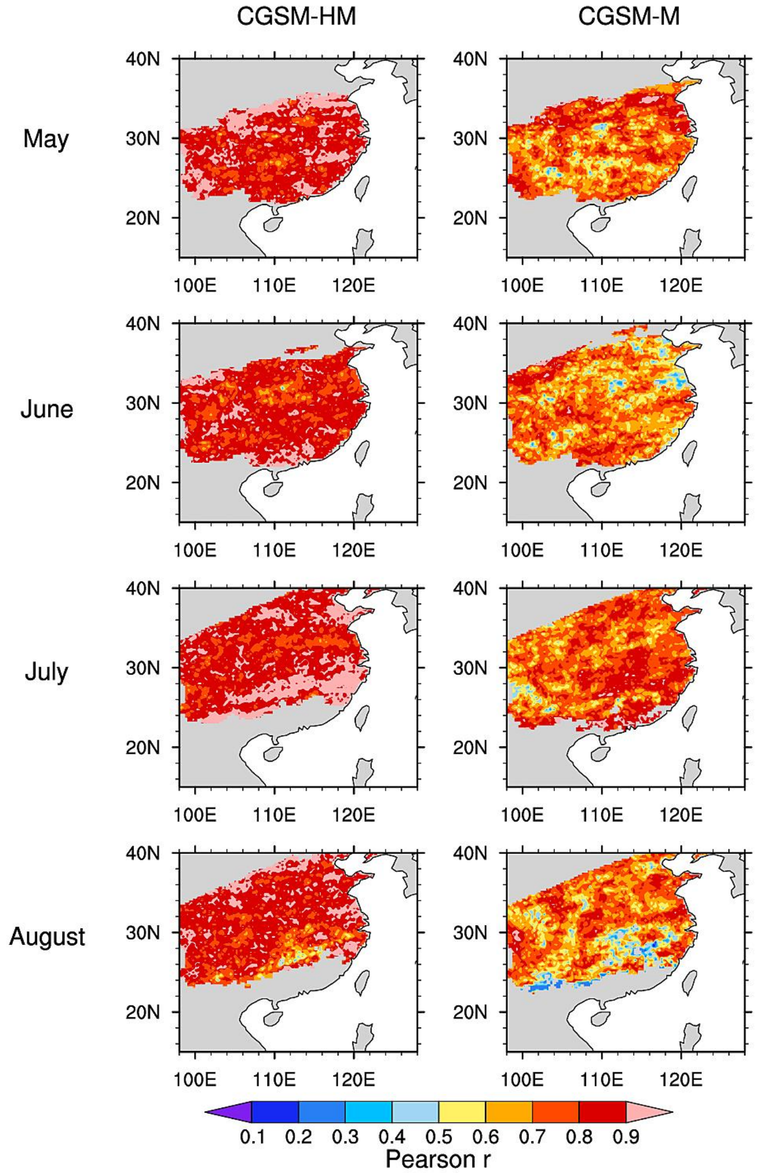
Results Part 1: CGSM for extreme Mei-Yu Rainfall (MYR)

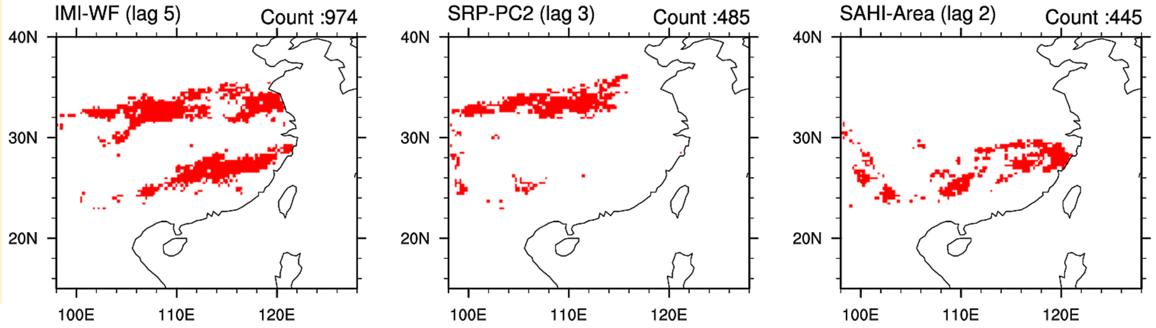
- For MYR, we have constructed CGSM based on
- monthly indices (CGSM-M) and
- half-monthly indices (CGSM-HM)
  - → Results show CGSM-HM has **better** performance than CGSM-M
  - → **Importance of sub-monthly variability.**
  - → In agreement with Ding et al. 2021.
- **Spatial coherences** of the choice of predictors using causality-guided approach.



Mean MYR in Middle/lower YV
Fig 7. Ng et al. 2022, ***Adv Atmo Sci***



Correlation between OBS and CGSM
Fig 4. Ng et al. 2022, ***Adv Atmo Sci***



Top 3 Frequently chosen predictors in the CGSM-HM for 2nd half of June
Fig 8. Ng et al. 2022, ***Adv Atmo Sci***

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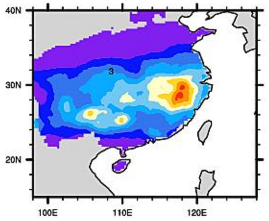
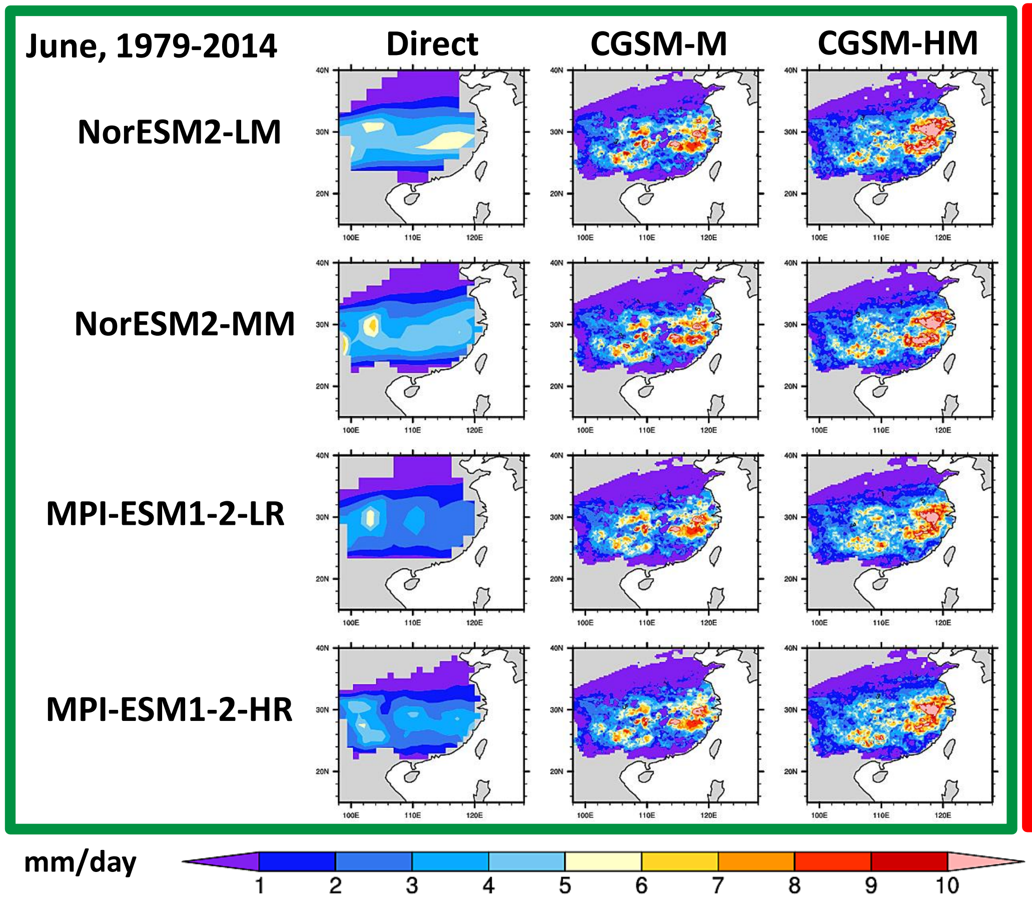
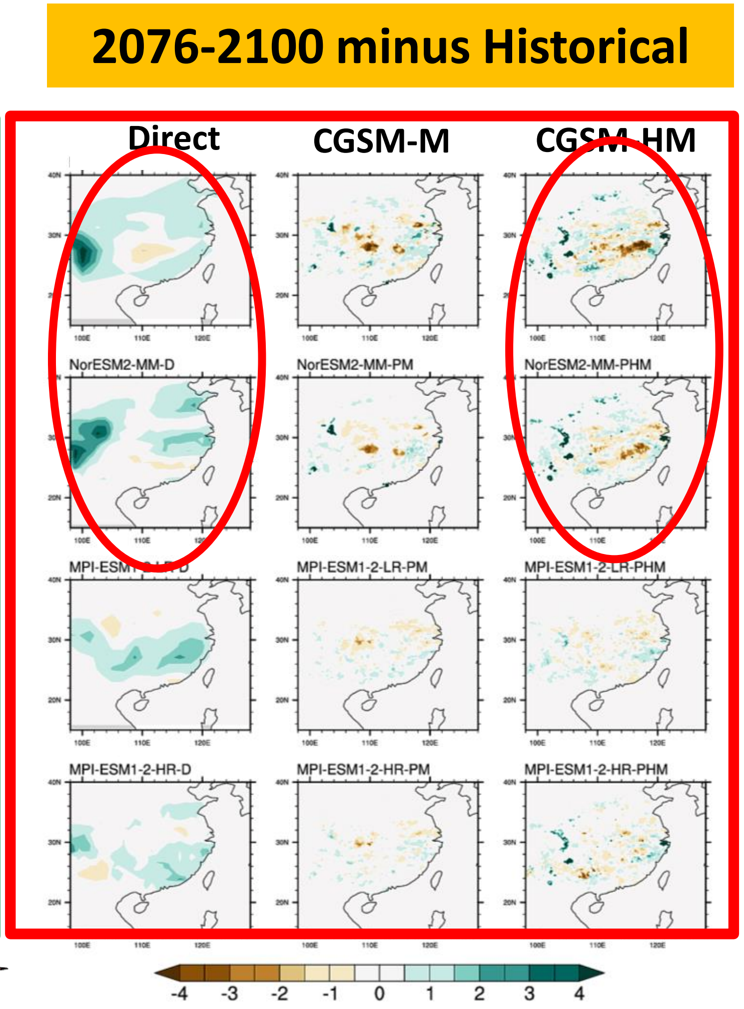
Application to ESMs–Example 1: MYR

CN05.1 (1979-2018)







- **CMIP6-historical**
  - → Direct outputs do not capture the OBS climatological pattern.
  - → Using CGSM, we can recover the OBS climatological pattern across all models.
    - ➢ Finer structure than direct outputs
    - ➢ More realistic than direct outputs
- **CMIP6-SSP585 (2076-2100)**
  - → Direct outputs do not agree on the spatial patterns of future changes, even with for the same model family.
    - ➢ NorESM2
      - × Large positive MYR changes in upstream Yangtze river .
    - ➢ MPI-ESM1-2
      - × Smaller positive MYR changes in the similar region.
  - → CGSM agree on the spatial patterns of the future changes for the same model family.

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Results Part 2: CGSM for extreme Tropical Cyclone Rainfall (TCR)

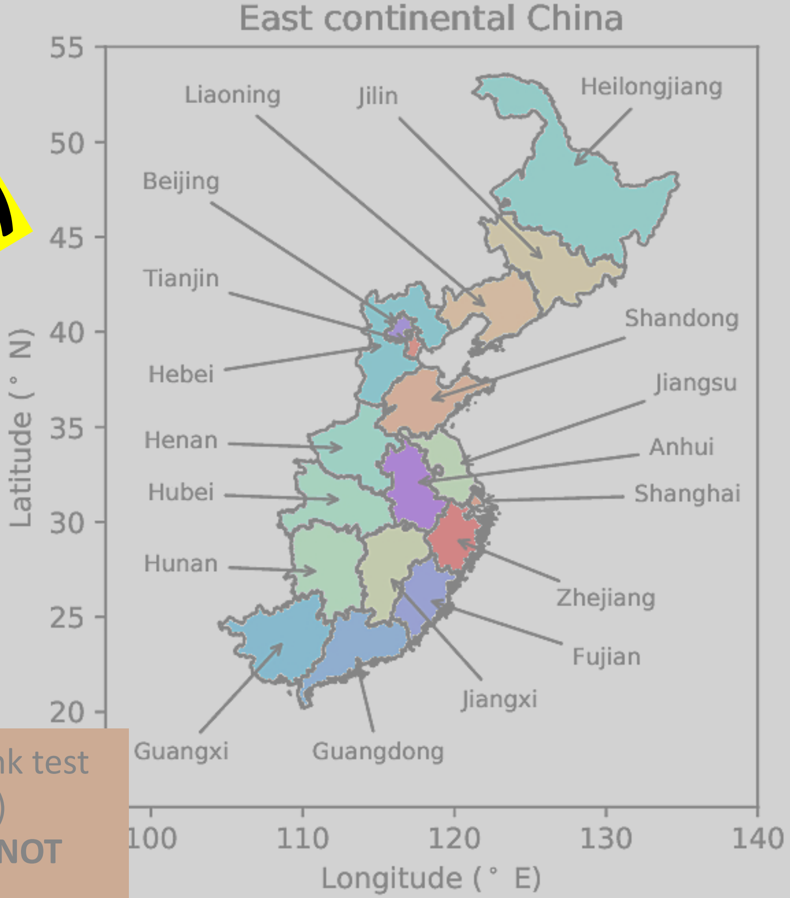
- Construct model per **province** per **month**
- Due to rarity of TCR, provincial TCR timeseries contains a lot of **zero entries**.
  - → Challenging to construct statistical model
  - → **Two-step models (TSMs)**
    - ➢ **Logistic regression model (LRM)**
      - × Determine zero and non-zero entry
    - ➢ **Multiple linear regression (MLR)**
      - × Model non-zero TCR.
  - → For the same month and province, LRM and MLR do **NOT** have the same set o[illegible] predictor
    - ➢ Indicates the underlying mechanisms are different
    - ➢ This is expected.

Ng et al. 2022 (in prep)

	Month			
Province	7	8	9	10
Guangdong	0.76	0.74	0.78	0.64
Guangxi	0.82	0.70#	0.51	0.68
Fujian	0.77	0.63	0.56	0.43#
Jiangxi	0.69	0.70	0.66	[illegible]
Hunan	0.67	0.65	[illegible]	[illegible]
Zhejiang	0.73	[illegible]	[illegible]	[illegible]
Anhui	[illegible]	[illegible]	[illegible]	
Hubei	[illegible]	[illegible]	0.16*	
Jia[illegible]	[illegible]	0.89	0.56	0.20*
[illegible]	[illegible]	0.81	0.52	0.14*
[illegible]ng	0.73	0.65	0.69	
[illegible]anghai	0.51	0.57	0.32	
Hebei		0.83		
Liaoning	0.03*	0.77		
Jilin	0.66	0.54		
Heilongjiang	0.27*	0.73		

= Wilcoxon signed-Rank test (significant at 0.05 level)
* = Pearson correlation **NOT** significant at 0.05.

Overall performance of TSM, Pearson' Correlation



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Summary

- The causality approach shows **good performance** in detecting useful predictors for constructing statistical models (transfer functions).
- Application of CGSM to predict MYR/TCR in **Earth System Models**
  - ➔ CGSM can **recover** the observed pattern of MYR, while direct ESM simulations cannot.
    - ➔ ESM "*realistic*" LSMs have generally more predictive capacity for extreme precipitation than directly simulated extreme precipitation
    - ➔ This confirms the validity of our approach to use the better simulated LSMs as predictor from ESMs
  - ➔ Similar argument applies to TCR, as ESMs struggle to simulate TC in general (due to resolution).

➢ High potential for ESM-based diagnostics of extreme (e.g., Mei-yu/Tropical cyclone) precipitation for **Applications in Climate Services**

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Publication:
Ng, K. S., G. C. Leckebusch, and K. I. Hodges, 2022: A Causality-guided statistical approach for modeling extreme Mei-yu rainfall based on known large-scale modes – A pilot study. *Adv Atmos Sci. 10.1007/s00376-022-1348-3*

References

- **Ng, K. S., G. C. Leckebusch, and K. I. Hodges, 2022: A Causality-guided statistical approach for modeling extreme Mei-yu rainfall based on known large-scale modes – A pilot study. *Adv Atmos Sci. 10.1007/s00376-022-1348-3***
- Befort, D. J., K. I. Hodges, and G. C. Leckebusch, 2016: East Asian rainfall in CMIP5 models: Contribution of Tropical Cyclones and Mei-yu front to spatio-temporal rainfall variability. *AGU Fall Meeting 2016, San Francisco, A23J-0365.*
- Befort, D. J., K. Hodges, and G. C. Leckebusch, 2017: A new approach for estimating projected future changes in extreme rainfall over East Asia and its uncertainties including information about model performance on different scales. *AGU Fall Meeting 2017, New Orleans, A53C-1476.*
- Ding, Y., Y. Liu, and Z.-Z. Hu, 2021: The Record-breaking Meiyu in 2020 and Associated Atmospheric Circulation and Tropical SST Anomalies. *Adv Atmos Sci. 10.1007/s00376-021-0361-2*
- Eyring, V., S. Bony, G. A. Meehl, C. A. Senior, B. Stevens, R. J. Stouffer, and K. E. Taylor, 2016: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geosci. Model Dev.*, ***9, 1937-1958. 10.5194/gmd-9-1937-2016***
- Hersbach, H., and Coauthors, 2020: The ERA5 global reanalysis. *Q J Roy Meteor Soc,* ***146, 1999-2049. 10.1002/qj.3803***
- Hodges, K., A. Cobb, and P. L. Vidale, 2017: How Well Are Tropical Cyclones Represented in Reanalysis Datasets? *J Climate,* ***30, 5243-5264. 10.1175/JCLI-D-16-0557.1***
- Ng, K. S., and G. C. Leckebusch, 2021: A new view on the risk of typhoon occurrence in the western North Pacific. *Nat. Hazards Earth Syst. Sci.*, ***21, 663-682. 10.5194/nhess-21-663-2021***
- O'Neill, B. C., and Coauthors, 2016: The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. *Geosci. Model Dev.*, ***9, 3461-3482. 10.5194/gmd-9-3461-2016***
- Runge, J., P. Nowack, M. Kretschmer, S. Flaxman, and D. Sejdinovic, 2019: Detecting and quantifying causal associations in large nonlinear time series datasets. *Science Advances,* ***5, eaau4996. 10.1126/sciadv.aau4996***
- Runge, J., 2020: Discovering contemporaneous and lagged causal relations in autocorrelated nonlinear time series datasets. *Proceedings of the 36th Conference on Uncertainty in Artificial Intelligence (UAI), P. Jonas, and S. David, Eds., PMLR,* ***1388--1397.***
- Wu, J., and X.-J. Gao, 2013: A gridded daily observation dataset over China region and comparison with the other datasets. *Chinese Journal of Geophysics (in Chinese),* ***56, 1102-1111. 10.6038/cjg20130406***

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