Influence of climate forcing agents on the regional hydrological cycle trends in a changing climate

25-29 SEPTEMBER 2023 TRIESTE, ITALY
ICRC-CORDEX 2023
International Conference on Regional Climate

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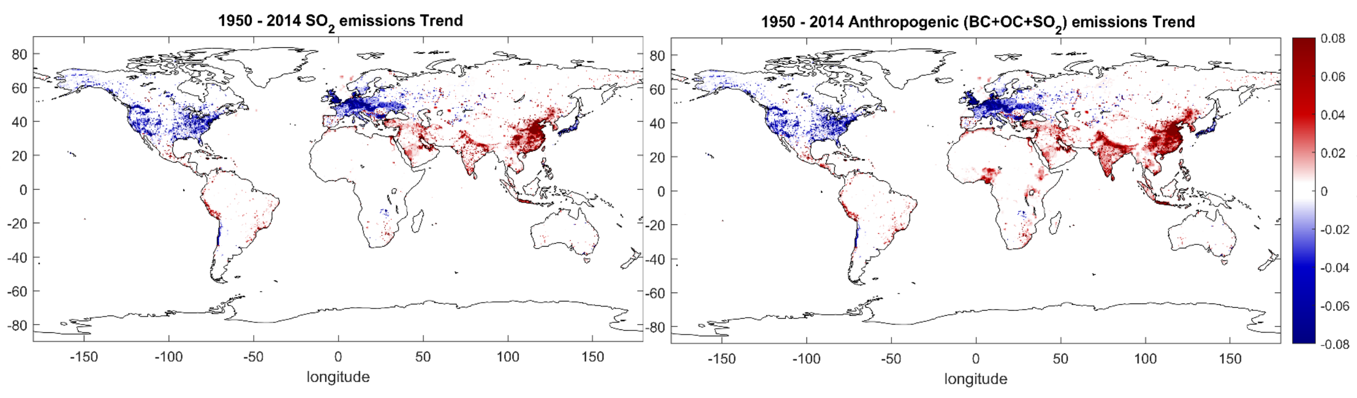
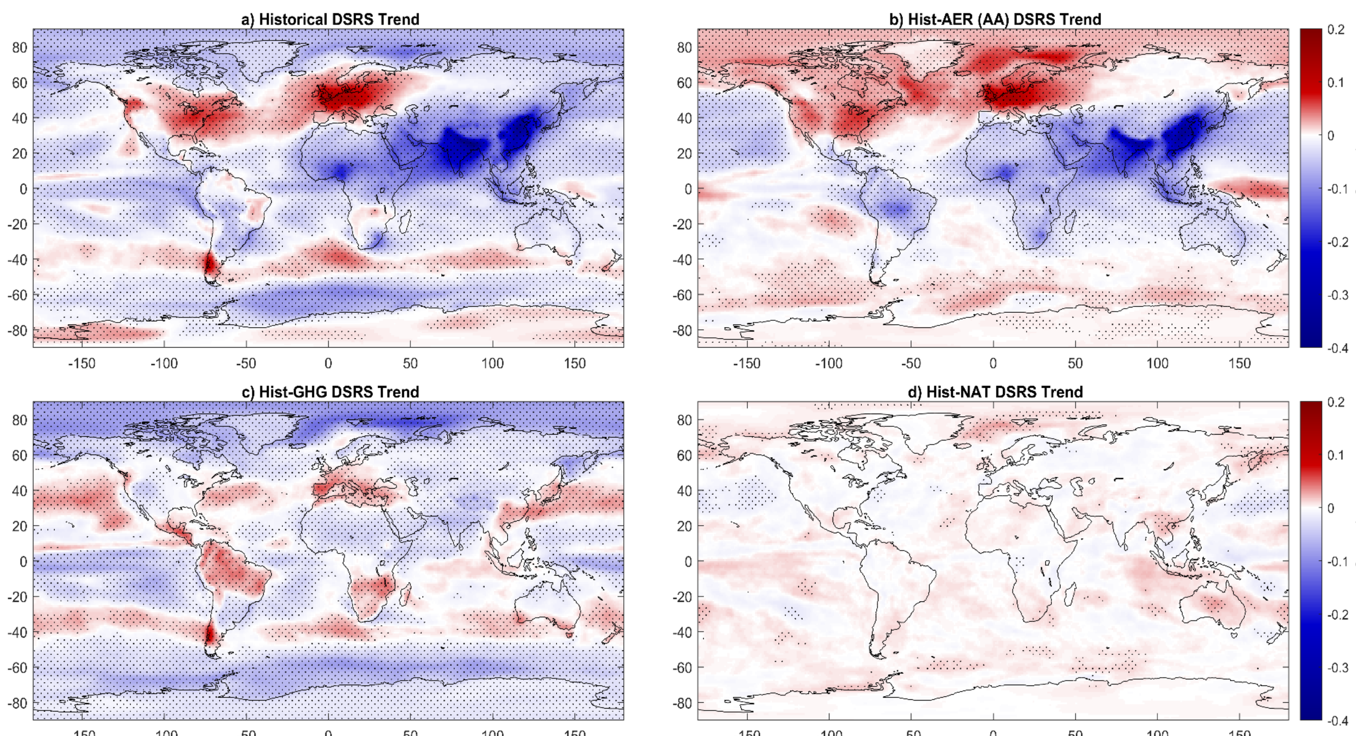
Abstract

Over the past few decades, the global hydrological cycle has been significantly impacted by factors such as Greenhouse Gases (GHGs), Anthropogenic Aerosols (AA), and climate variability. Notably, the trends in monsoon precipitation in the northern hemisphere are closely tied to the presence of GHGs and AA. This study aims to comprehensively analyze the regional evapotranspiration trends. The investigation is carried out by exploring the relationship between downward solar radiation and evapotranspiration using simulations from the CMIP6 General Circulation Models. The study covers historical data as well as separate experiments only involving GHGs, AA, and Natural Forcings spanning from 1850 to 2014. Analysis of regional trends in downward solar radiation highlights significant reductions in India and East China, particularly from the 1960s onwards. The focus is placed on these regions to assess alterations in the hydrological cycle. The trend analysis of evapotranspiration and precipitation over south and east Asia from the 1950s to 2010s showed a drying trend in Eastern China, while India had an increase in annual total evapotranspiration and rainfall in the same period. These opposing responses in these two regions are due to, more so than the greenhouse gas effect AA emissions having considerable control over Eastern China's precipitation. In contrast, the greenhouse effect has strong controls on the Indian land region's hydrological cycle exceeding the forcing brought on by the AA emissions. The models are categorized using a hierarchical tree clustering technique to analyze the model's internal uncertainty, revealing that certain models exhibit energy-limited biases. These biases lead to heightened evapotranspiration responses to insolation changes. These tendencies might be responsible for inducing aridity in the studied areas, consequently leading to an increase in simulated climate extremes.



Trend in Anthropogenic a) sulfur dioxide (SO_2) emissions and b) BC+OC+ SO_2 emissions in g m^{-2} year^{-1} over the period 1950 – 2014

Spatial pattern of temporal trends of downwards solar radiation at surface

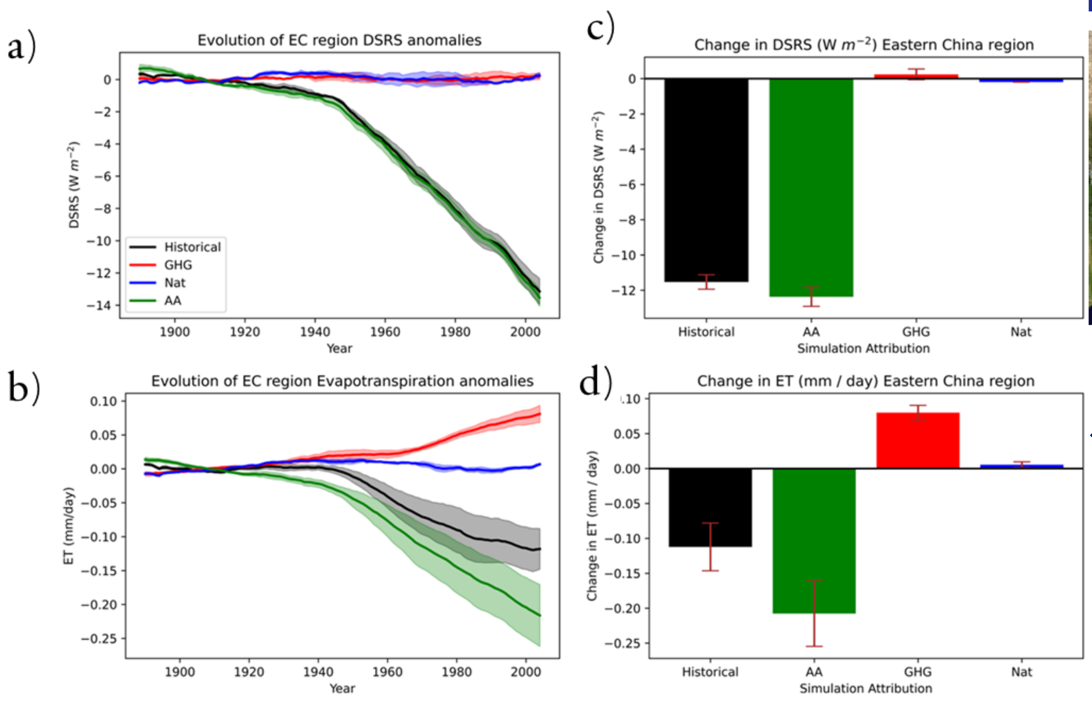


Global climate models used in this study

MODEL	Institutions	Ensemble members	References
ACCESS-CM2	CSIRO, Australian Research Council Centre of Excellence for Climate System Science, Australia	r1i1p1f1, r2i1p1f1, r3i1p1f1	Bi et al. (2020)
ACCESS-ESM1-5	Australian Community Climate and Earth System Model, Australia	r1i1p1f1, r2i1p1f1, r3i1p1f1	Ziehn et al. (2020)
BCC-CSM2-MR	Beijing Climate Center, China	r1i1p1f1, r2i1p1f1, r3i1p1f1	Shi et al. (2020)
CanESM5	Canadian Centre for Climate Modeling and Analysis, Canada	r1i1p1f1, r2i1p1f1, r3i1p1f1	Swart et al. (2019)
CNRM-CM6-1	Centre National de Recherches M´et´eorologiques, France	r1i1p1f2, r2i1p1f2, r3i1p1f2	Voldoire et al. (2019)
FGOALS-g3	Chinese Academy of Sciences, China	r1i1p1f1, r2i1p1f1, r3i1p1f1	Li et al. (2020)
GISS-E2-1-G	Goddard Institute for Space Studies, United States	r1i1p1f1, r2i1p1f1, r3i1p1f1	Kelley et al. (2020)
HadGEM3-GC31-LL	Met Office Hadley Centre, United Kingdom	r1i1p1f3, r2i1p1f3, r3i1p1f3	Kuhlbrodt et al. (2018)
IPSL-CM6A-LR	Institut Pierre Simon Laplace, France	r1i1p1f1, r2i1p1f1, r3i1p1f1	Boucher et al. (2020)
MIROC6	Japanese modeling community, Japan	r1i1p1f1, r2i1p1f1, r3i1p1f1	Tatebe et al. (2019)
MRI-ESM2-0	Meteorological Research Institute, Japan	r1i1p1f1, r2i1p1f1, r3i1p1f1	Yukimoto et al. (2019)
NorESM2-LM	Norwegian Earth system model Climate modeling Consortium, Norway	r1i1p1f1, r2i1p1f1, r3i1p1f1	Seland et al.(2020)

From all the model attribution simulations

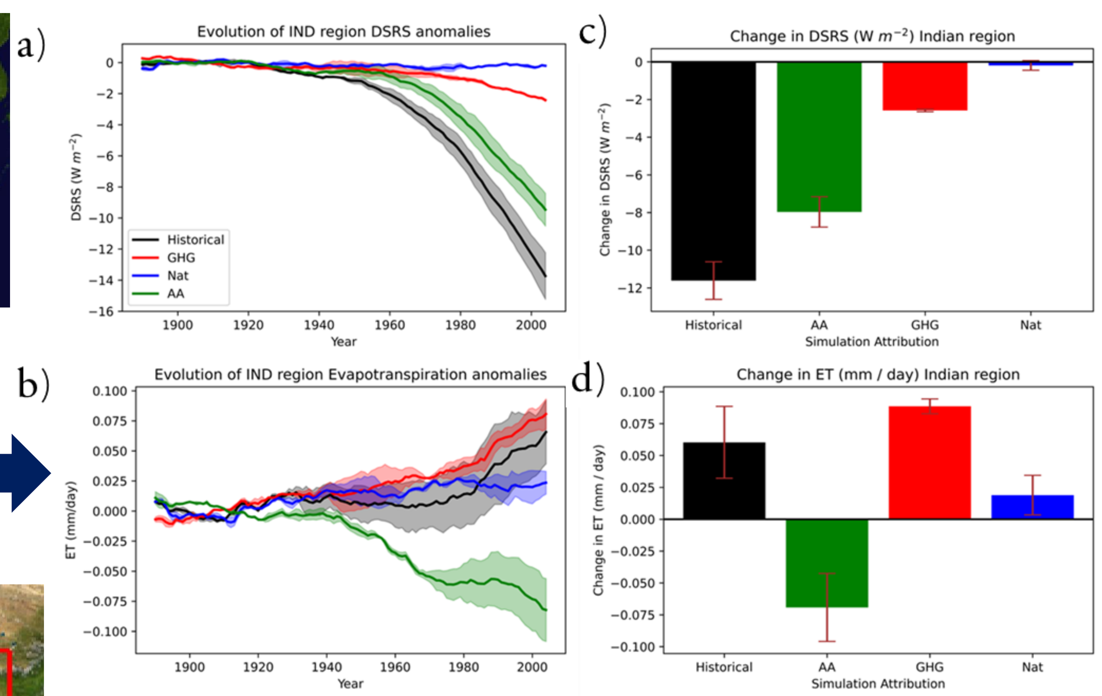
1. **Historical,**
2. **Anthropogenic Aerosols (AA) only,**
3. **GHG only,**
4. **Nat only are used for the study**



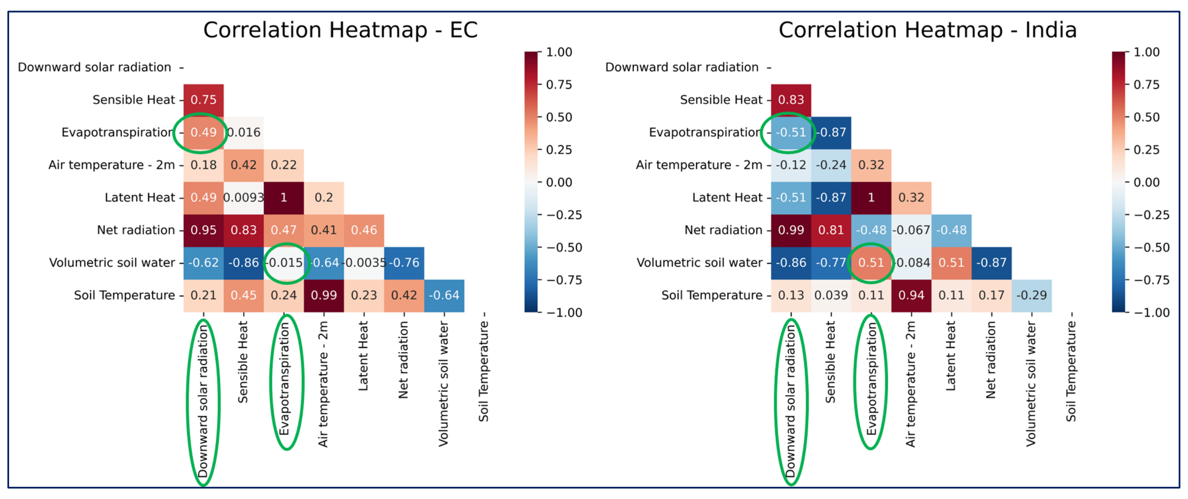
Eastern China

India

Evolution of Annual a) Downward solar radiation at surface, b) Evapotranspiration anomalies on the historical period over Eastern China land region and Changes in c) Downward solar radiation at the surface, d) Evapotranspiration between [1901-1920] and [1995-2014] in four ensembles of attribution simulations from 12 models



Evolution of Annual a) Downward solar radiation at surface, b) Evapotranspiration anomalies on the historical period over India land region and Changes in c) Downward solar radiation at the surface, d) Evapotranspiration between [1901-1920] and [1995-2014] in four ensembles of attribution simulations from 12 models

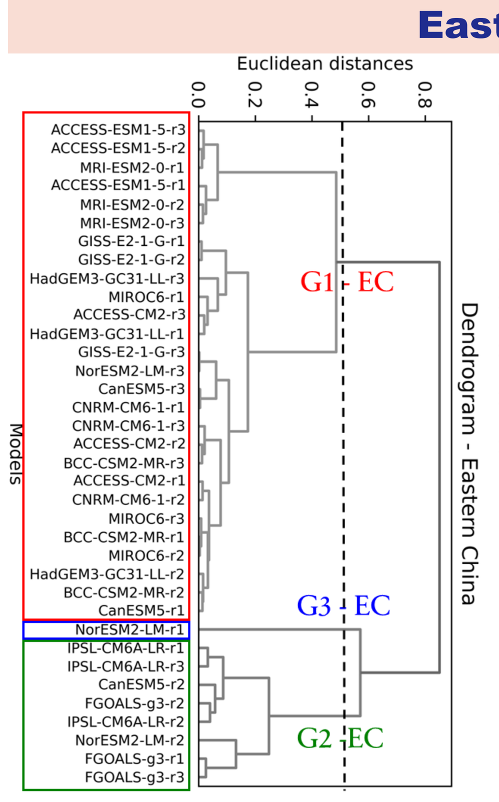


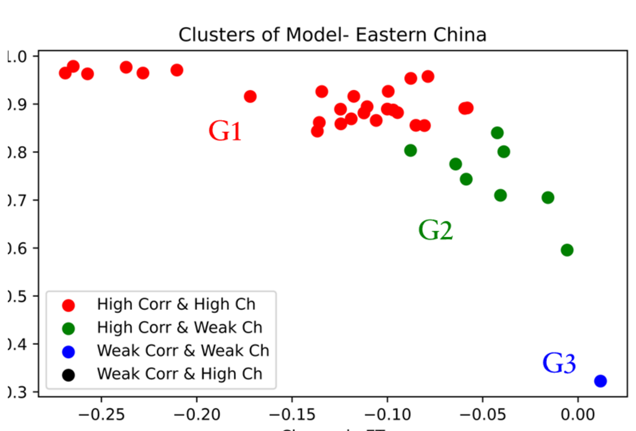
Relation between various soil-atmospheric parameters from ERA-5 for 1959-2014 period

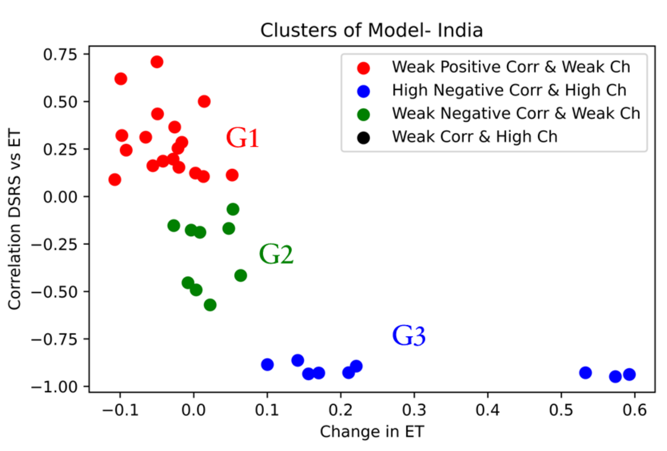
Classification of the models to study the uncertainty in the evapotranspiration evolution

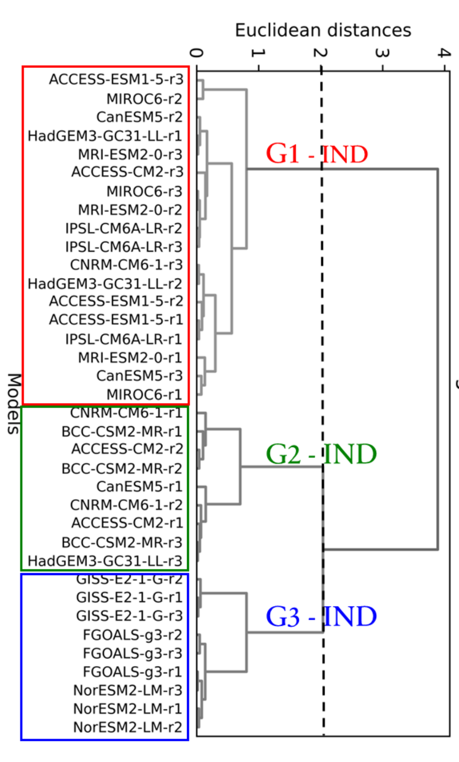
- The CMIP6 models have been classified according to two metrics with a ML technique i.e. hierarchical tree clustering algorithm
- Metrics
  1) Decadal correlation in between ET and DSRS for the [1991-2010] period
  2) Changes in ET between [1901-1920] and [1995-2014]

Eastern China





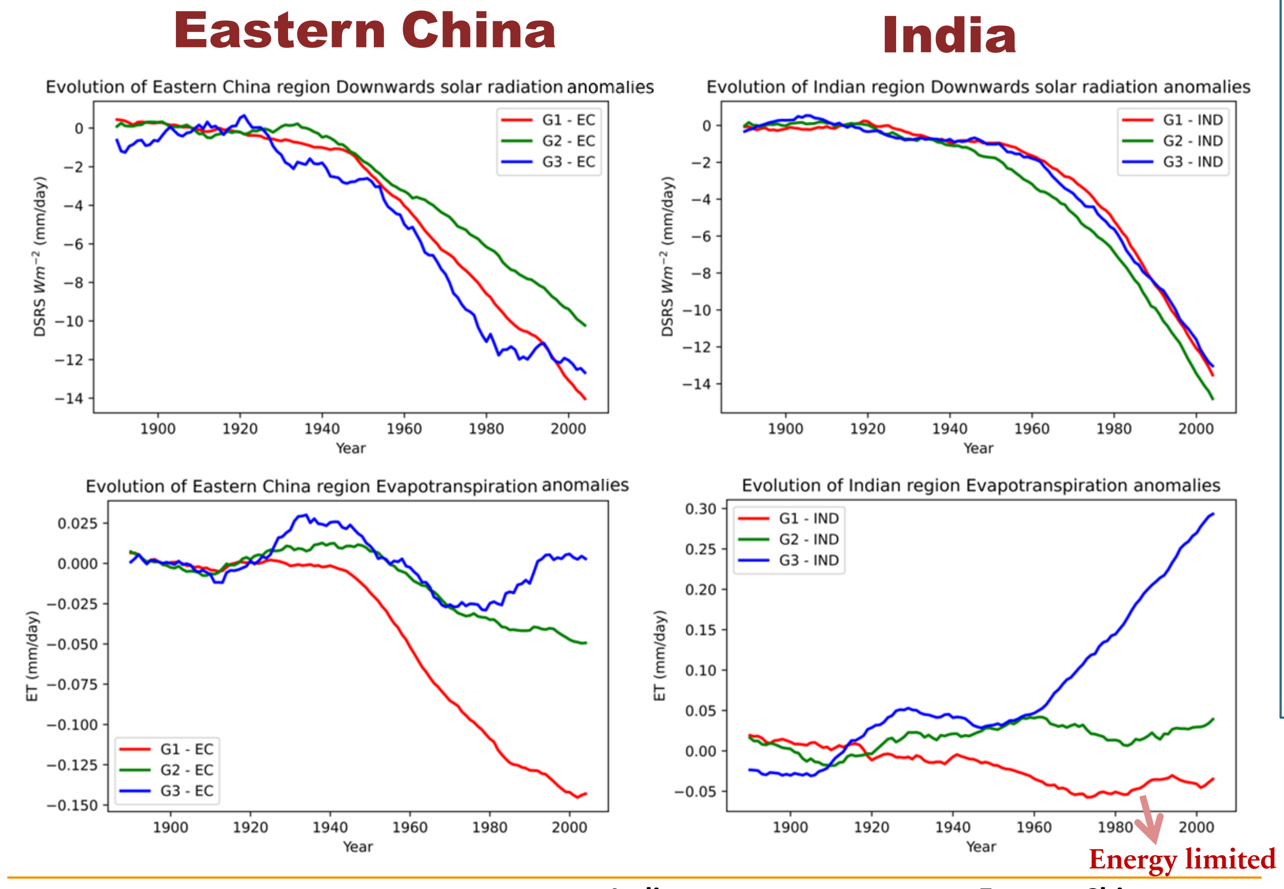




India

Eastern China

India



SPI	SPI category	India			Eastern China		
		G1 -IND	G2-IND	G3-IND	G1-IND	G2-IND	G3-IND
≥ 2.00	Extremely wet	16	18	19	14	18	22
1.50 – 1.99	Severe wet	21	25	23	30	31	27
1.00 – 1.49	Moderately wet	74	70	57	60	55	47
0 – 0.99	Mildly wet	215	223	228	223	229	218
– 0.99 – 0	Mild drought	233	225	234	220	223	247
–1.40 – –1.00	Moderate drought	63	66	66	71	65	62
–1.99 – –1.50	**Severe drought**	**34**	**31**	**23**	**34**	**31**	**32**
≤ – 2.00	Extreme drought	10	12	13	12	15	11

Findings

- The trend analysis of evapotranspiration and precipitation for the 1950s to 2010s showed a drying trend in Eastern China following the DSRS trend, while in India they had an increasing trend opposing the DSRS trend in the same period.
- These opposing responses in these two regions are due to, more so than the greenhouse gas effect, AA emissions have considerable control over Eastern China's ET and precipitation.
- In contrast, the greenhouse effect has strong controls on the Indian land region's hydrological cycle exceeding the forcing brought on by the AA emissions.
- From the agglomerative hierarchical clustering , some models simulate strong aerosols and GHGs-driven changes in evapotranspiration and also precipitation on the historical period, while other models show virtually no impact.
- These opposed responses are largely determined by two seemingly independent properties of the models:
  - The magnitude of the impact of anthropogenic aerosols on solar radiation and whether evapotranspiration is predominantly water or energy limited.

Contact Information

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