Automated identification of South Asian monsoon low pressure systems: Historical variations across reanalysis products

Vishnu S[1], William Boos[1], Paul Ullrich[2], and Travis O'Brien[3]

[1]University of California
[2]University of California, Davis
[3]Lawrence Berkeley National Laboratory

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Abstract

Synoptic-scale cyclonic vortices produce abundant rainfall in South Asia, where these low pressure systems (LPS) are traditionally categorized as monsoon lows, monsoon depressions, and more intense cyclonic storms. The India Meteorological Department has tracked monsoon depressions for over a century, finding a large decline in the number of those storms in recent decades; their tracking methods, however, seem to have changed over time and do not include monsoon lows, which can produce intense rainfall despite their weak winds. This study presents a fast and objective tracking algorithm that can identify monsoon LPS in high-resolution datasets with a variety of grid structures. A sensitivity analysis has been performed to select a set of atmospheric variables and their corresponding thresholds for optimal tracking of LPS. Approximately 250 combinations of variables and thresholds are used to identify LPS over roughly a decade (the training period) in each of four atmospheric reanalyses, and these combinations are ranked using a skill score that compares the reanalyses with each other and with a preexisting track dataset that was compiled by subjective identification of LPS. This procedure finds the streamfunction of the 850 hPa horizontal wind to be the best variable for tracking LPS. The streamfunction is smoother than the vorticity field and represents the complete non-divergent component of the wind even when the flow is not geostrophic, unlike the geopotential height or sea level pressure. Using this tracking algorithm, LPS statistics are then computed in five reanalysis products that each span at least 40 years, with a primary goal being to determine whether the large decrease in monsoon depressions seen in the India Meteorological Department track dataset since the 1970s can be found in any reanalysis. This trend assessment is particularly relevant for the ERA5 reanalysis, which extends back to 1950 and which contains explicit climate forcings. In addition to secular trends, this study assesses the decadal variation of LPS, as well as interannual changes in LPS activity that are associated with the El Niño-Southern Oscillation and the Indian Ocean Dipole.

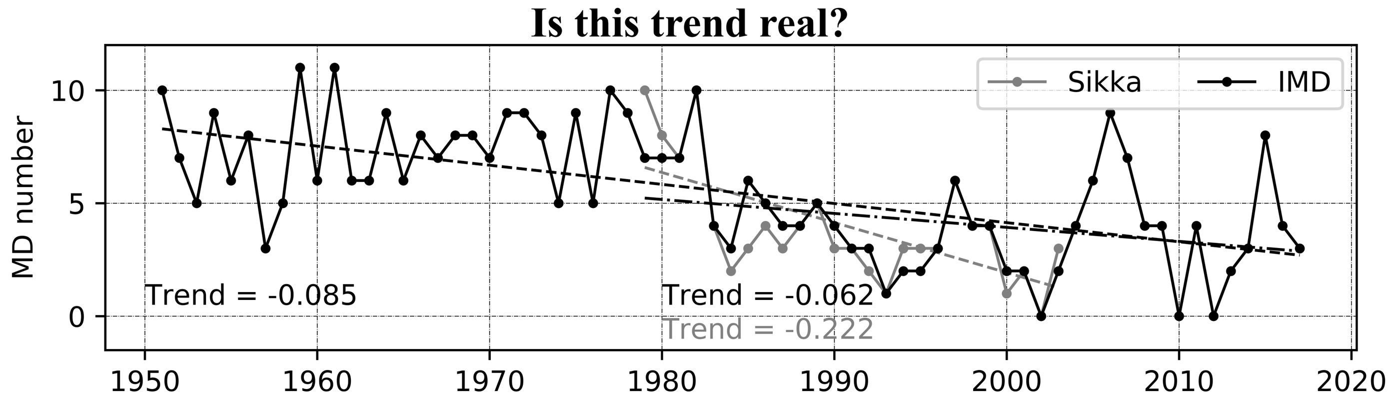
Automated identification of South Asian monsoon low pressure systems: Historical variations across reanalyses

Vishnu Sasidharan Nair# (Berkeley), William Boos (Berkeley), Travis O'Brien (LBL), Paul Ullrich (Davis) #vishnus@berkeley.edu

Introduction & Objective

- Monsoon Low Pressure Systems (LPS) are cyclonic vortices that produce a large fraction of South Asia's rainfall
- Intense LPS are called Monsoon Depressions (MDs).
- The India Meteorological Department (IMD) record shows a large downward trend in the number of MDs, but their tracking methods have changed over time and do not include weaker LPS (Lows).

Is this trend real?



Goal: devise a fast, objective, optimal tracking algorithm that can identify monsoon LPS in ensembles of high-resolution data

Tracking tools & criteria

- We use **TempestExtremes**, an automated Lagrangian pointwise feature tracker (Ullrich and Zarzycki, 2016).
- **Training:**
  - Identify LPS tracks in 4 reanalyses (ERA-Interim, JRA55, CFSR, MERRA2) for 1990-2003, selecting tracking criteria to match overall statistics of an existing hand-analyzed LPS dataset (Sikka, 2006)

Candidate variables
Mean sea level pressure
Geopotential at 850hPa
Streamfunction at 850hPa
Relative vorticity at 850hPa

- Consider 4 geophysical variables x 8 intensity thresholds x 2 radii thresholds x 8 relative humidity thresholds
- Additionally, 8 relative humidity thresholds (at 850 hPa) are considered to differentiate heat lows from moist LPS.

- We use the Critical Success Index (CSI), the ratio of the number tracks that match between the test dataset and reference datasets to the number of unique tracks in both datasets

$$CSI(dataset, reference) = \frac{Matches}{Matches + NonMatches}$$

- A single tracking algorithm is selected using a **combined CSI** that weights agreement across reanalyses with agreement with the reference dataset

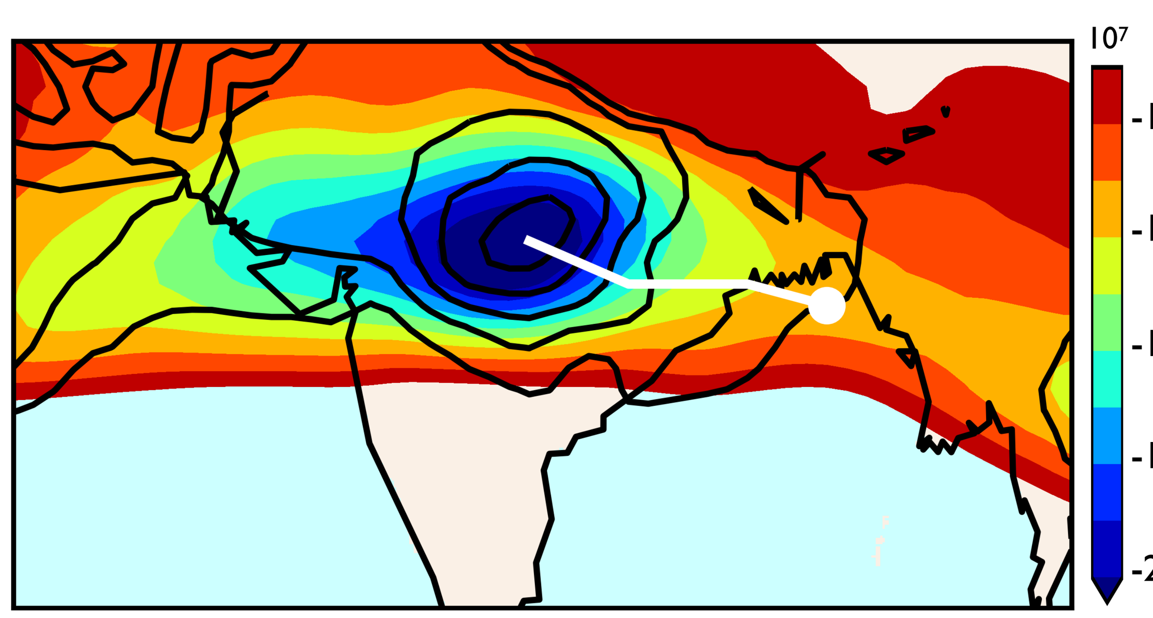
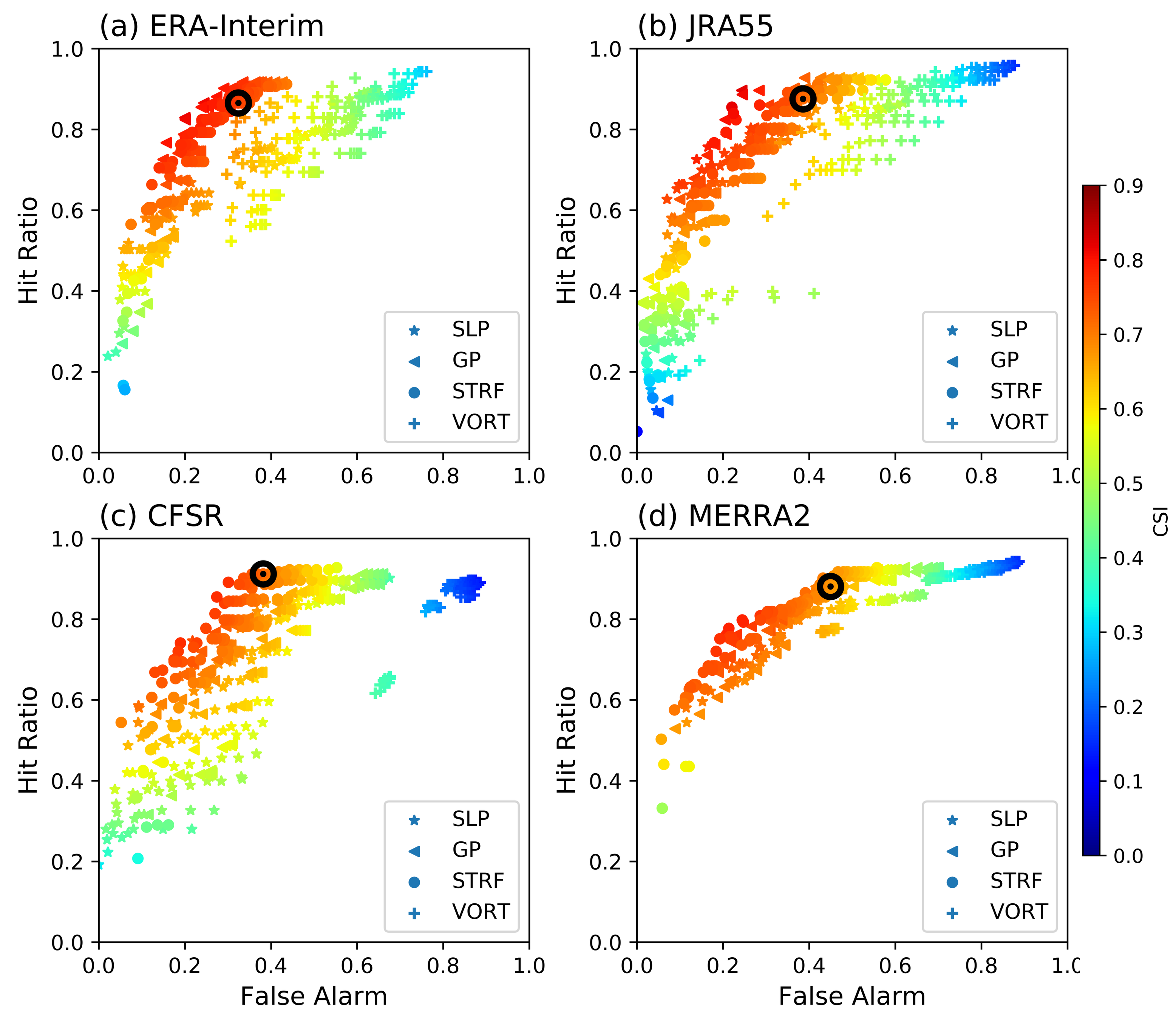


Figure 1: A sample LPS track, overlaid on 850 hPa stream-function (colors) and mean sea level pressure (contours). White dot denotes genesis location.

Selecting an optimal tracking algorithm



- The CSI metric (colors) rewards "hits" while penalizing "false alarms"
- The optimal metric tracks 850 hPa streamfunction minima and requires RH > 85%. It correctly matches about 90% of LPS in the reference dataset
- Interannual correlation coefficients of track counts between reanalyses vary from about 0.5 - 0.7 (not shown)

Figure 2: CSI metric (colors) as a function of hit ratio and false alarm ratio for each of 512 algorithms applied to 4 reanalyses, referenced to the hand-analyzed (Sikka) dataset. Black circle marks the optimal algorithm chosen based on the combined CSI.

Data & algorithm availability

- Tracks from 5 reanalyses are available on request (will post online after paper acceptance): ERA5, ERA-Interim, CFSR, MERRA2 (all 1979-2018), and JRA55 (1958-2018)
- Tracking algorithm and TempestExtremes software are available and can be used to extract LPS from any model, including CMIP models.
- We have also extracted tracks from the Indian Monsoon Mission model, CFS-IITM.

Interannual modes of variability

- The number of LPS is higher during strong monsoon years and during La Niña, but there is no significant change in counts in Indian Ocean Dipole events.

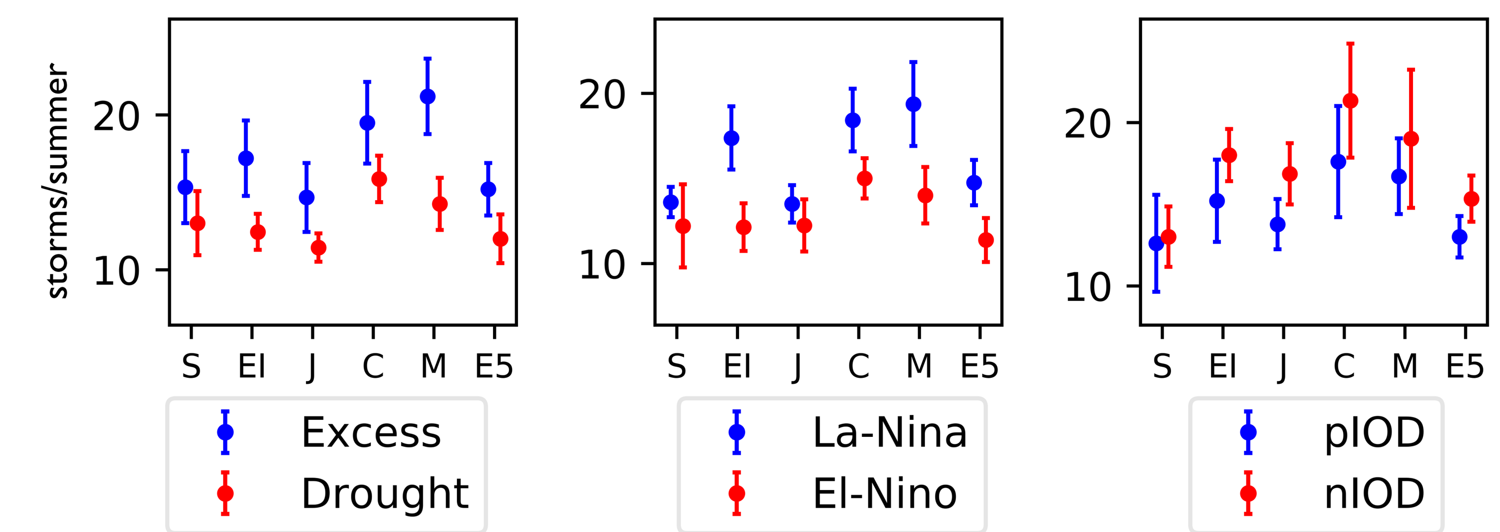


Figure 3: LPS counts in excess vs. drought South Asian summers (left), El Niño vs. La Niña (middle), and positive vs. negative Indian Ocean Dipole events. Vertical bars show 95% confidence interval. Axes abbreviations are S: Sikka (hand-analyzed reference dataset), EI: ERA-Interim, J: JRA55, C: CFSR, M: MERRA2, E5: ERA5.

Can we find a historical trend in any of the reanalyses?

No detectable long-term trend

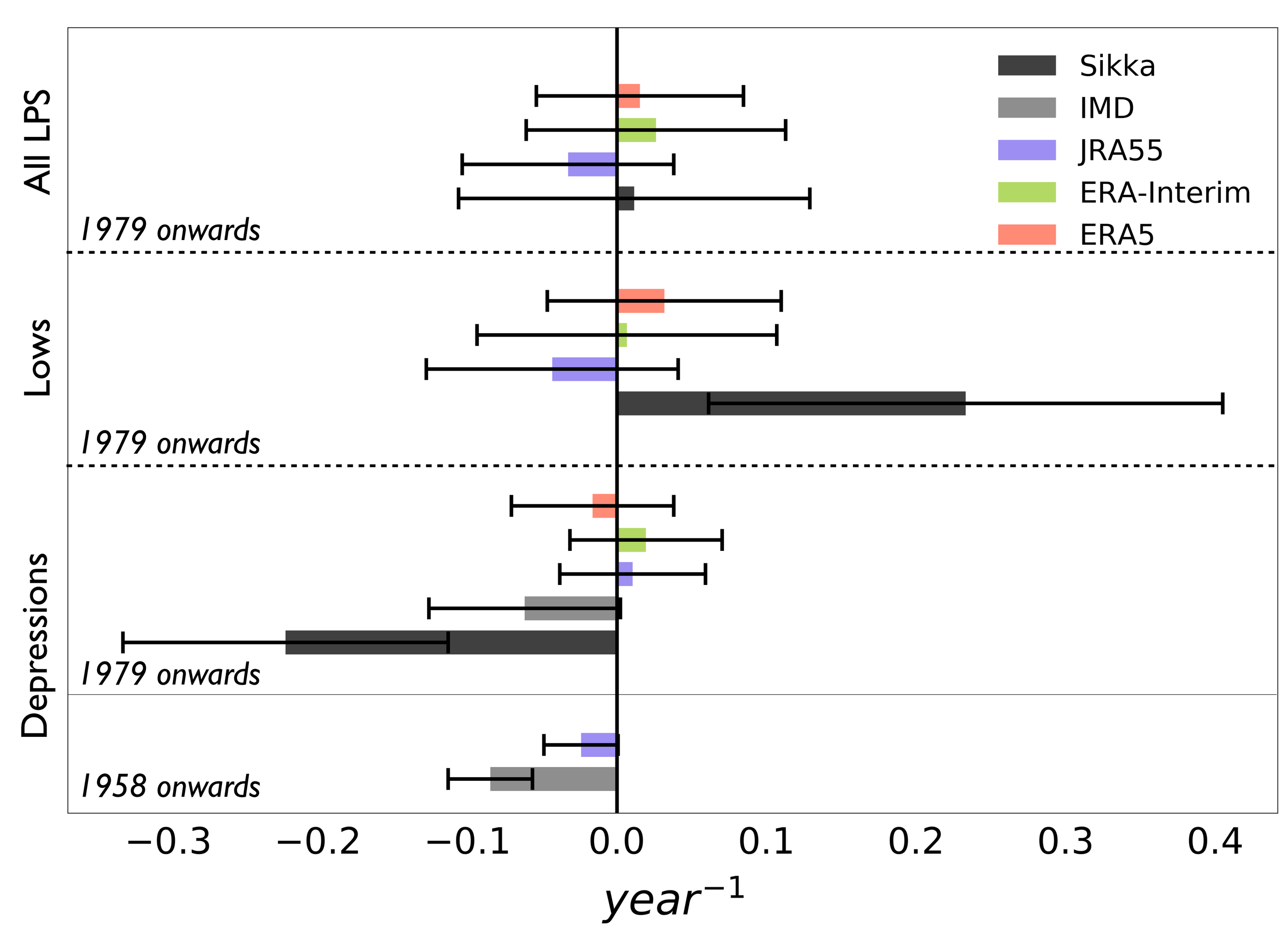


Figure 4. Trend in LPS, Lows, and Depressions in all datasets. Error bars represent the 95% confidence interval for these trends. Sikka dataset ended in 2003.

- No trend in Depression counts exists in any of the 5 reanalyses between 1979-2018.
- In JRA55, a weak downward trend in Depression counts exists over the longer period 1958-2018, but its error bar is large enough to include zero.

Are we seeing a poleward shift in genesis?

- Prior studies (Sandeep et al. 2018) found a poleward shift in the genesis distribution in GCM simulations of the next century.
- Something that looks like a poleward shift appears over the past 40 years, but the change in the mean latitude of genesis is not statistically detectable.

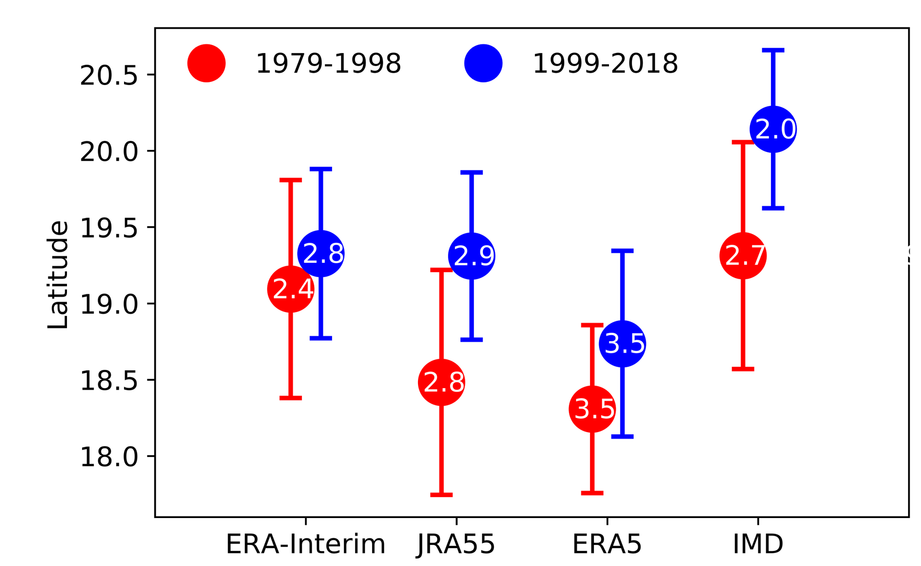


Figure 6. Mean latitudinal position of Depression genesis in the two epochs. Error bars show the 95% confidence interval. Values in circles are mean seasonal counts.

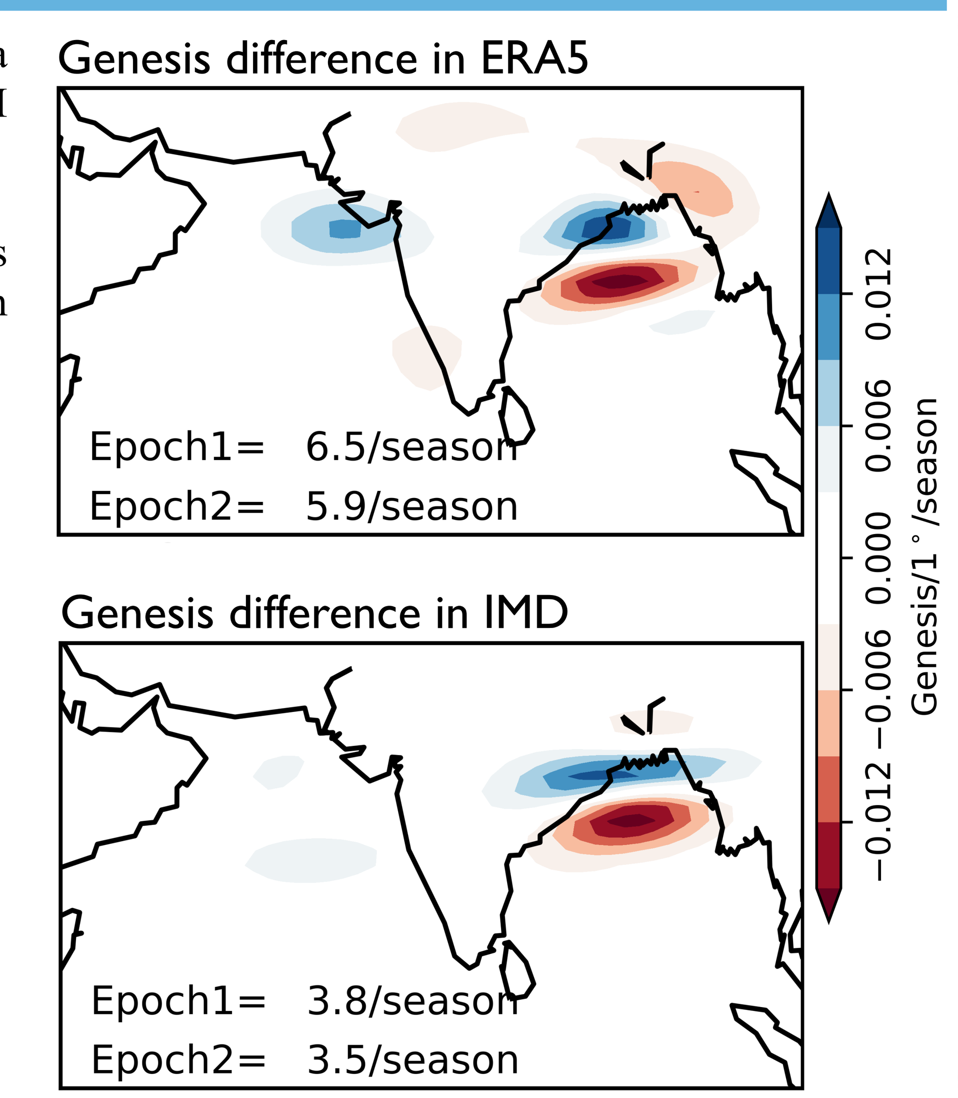


Figure 5: Change in genesis frequency of Depressions between epoch 1 (1979–1998) and epoch 2 (1999–2018).