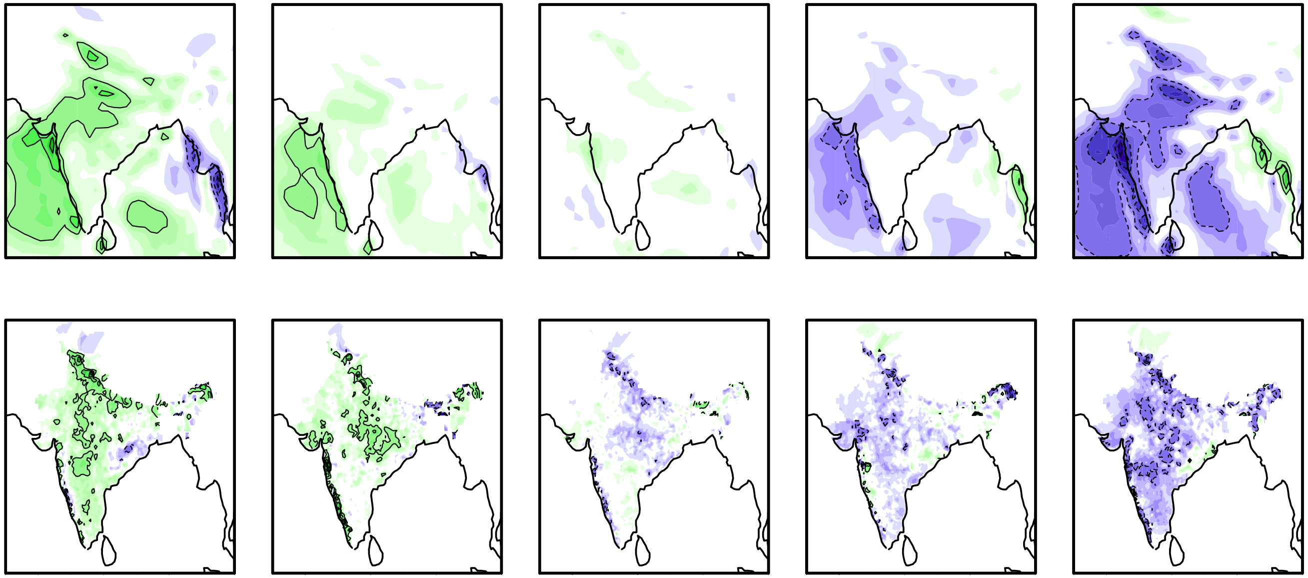
Indian monsoon teleconnections with ENSO in an ensemble of re-forecasts



GEORGE MASON UNIVERSITY

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COLA

3rd Summer School on Theory, Mechanisms and Hierarchical Modeling of Climate Dynamics: Tropical Oceans, ENSO and their teleconnections

Motivation

- The El Niño Southern Oscillation (ENSO) in the tropical Pacific Ocean has long been observed to have a significant impact on the India Summer Monsoon Rainfall (ISMR)
  i.e., El Niño → dry
  La Niña → wet

- How well is this represented in an ensemble of re-forecasts?

- Is there asymmetry in the ENSO impact?

- How is the ENSO signal manifested in terms of the active-break cycle during the monsoon season?

CFSv2 re-forecasts

- Experiments expanded from Shin et al. (2019, *Clim. Dyn.*)
- NCEP CFSv2: atmos. model GFS, T126 (1^o), 64 levels; coupled to ocean model MOMv4, as well as sea-ice and land models
- Initialized 1 Jul (and 1 Apr) each year over 62-year period (1958-2019)
- Run for 6 months; here we consider only July-Sep (JAS)
- Atmosphere initialized from CFSR at 00Z staggered over 4 days (1^{st} – 4^{th})
- Repeated with ocean initialized from 5 different ocean reanalyses

→ 20 ensemble members for 62 years, for a total of 1240 runs

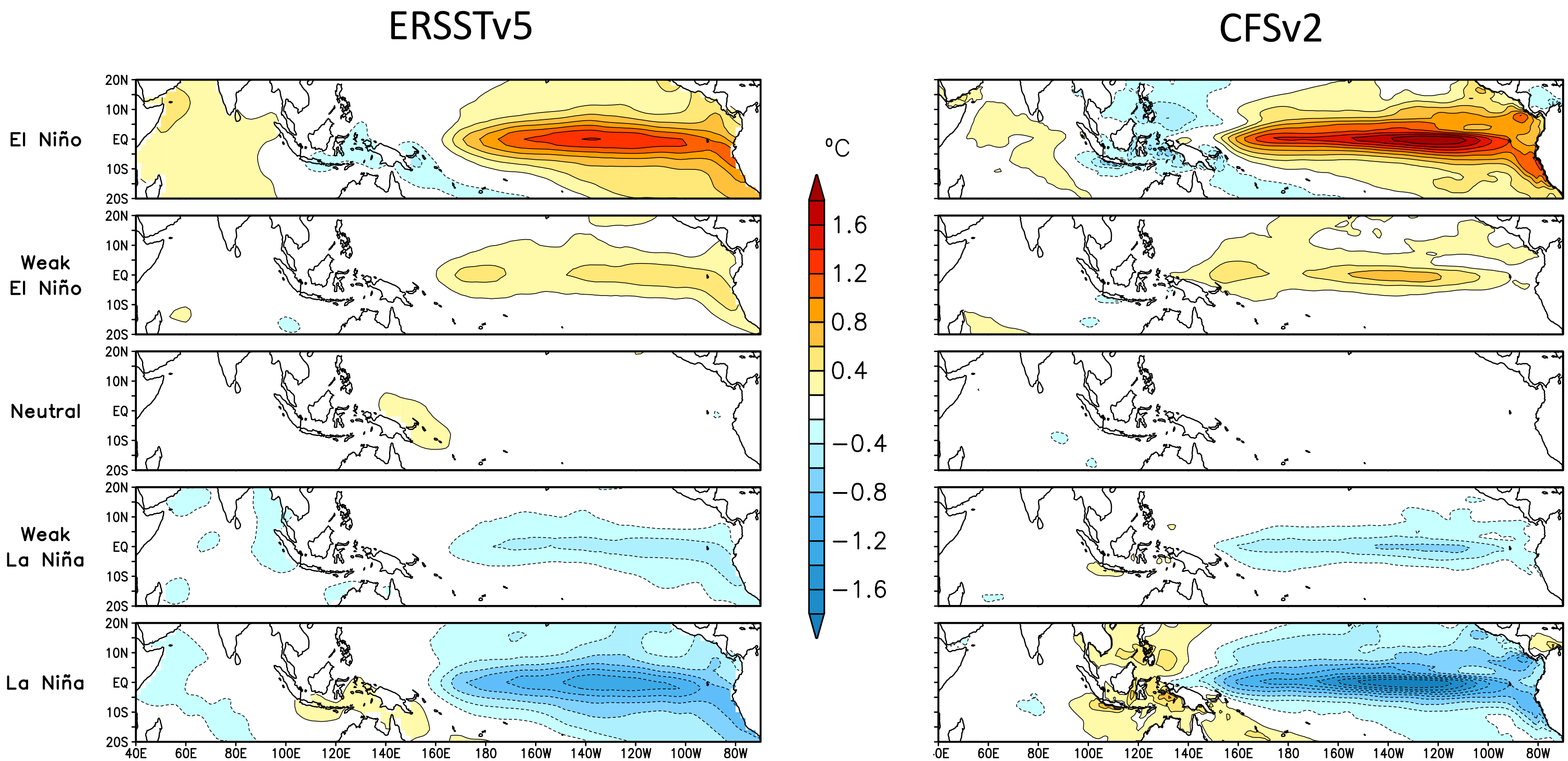
Shin, C. S., Huang, B., Zhu, J., Marx, L. & Kinter, J. L., 2019: Improved seasonal predictive skill and enhanced predictability of the Asian summer monsoon rainfall following ENSO events in NCEP CFSv2 hindcasts. *Clim Dyn* **52,** 3079–3098. https://doi.org/10.1007/s00382-018-4316-y

CFSv2 re-forecasts

- Large sample size (1240 seasons) allows for more details of ENSO-monsoon relationship to be examined:

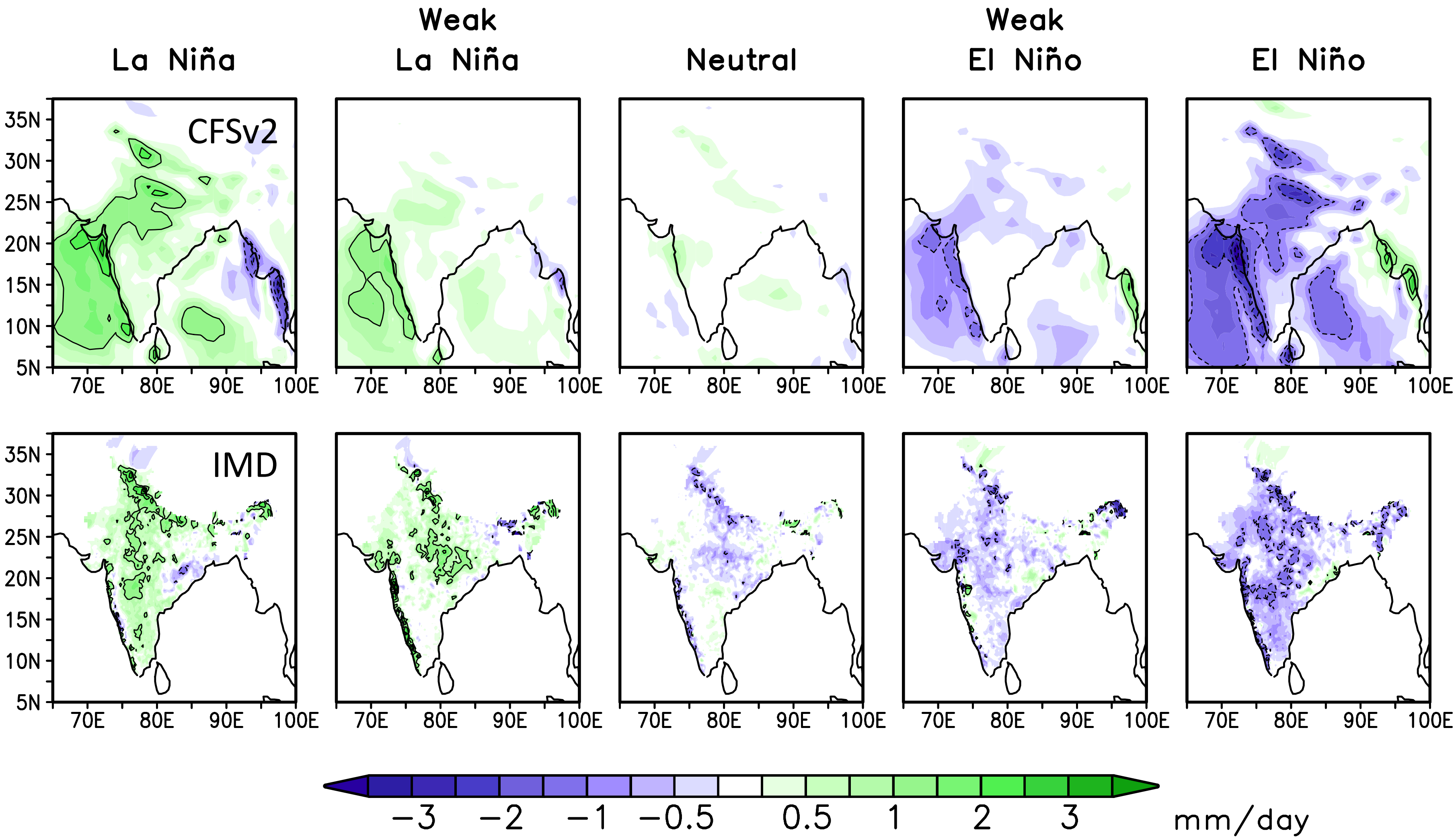
ENSO & ISMR quintiles (20% - 20% - 20% - 20% - 20%)
La Niña – weak La Niña – neutral – weak El Niño – El Niño
very wet – wet – normal – dry – very dry

- Compare with IMD rainfall (0.25^0) and ERSSTv5 for period of 1901-2021

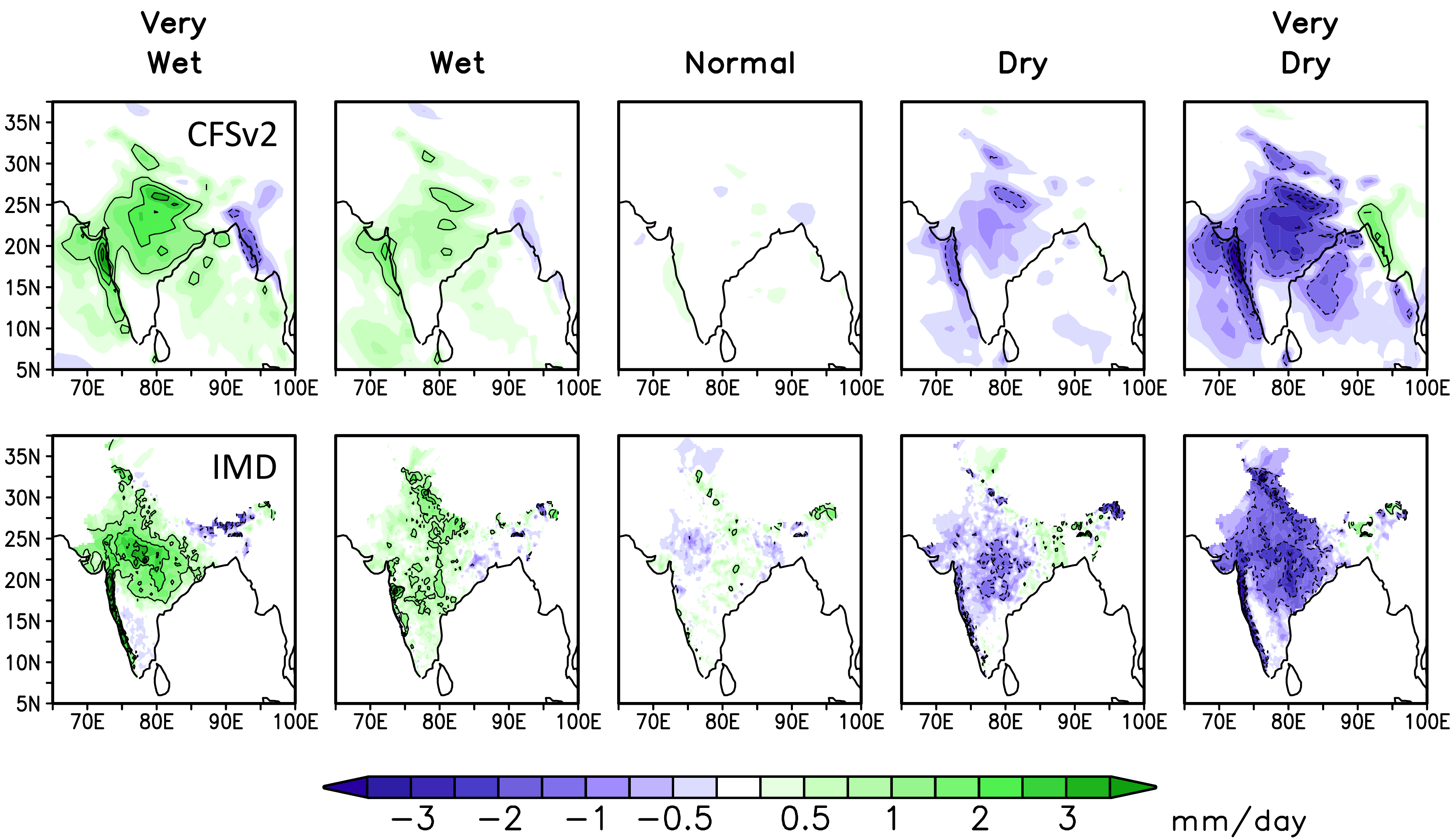


- Sea-surface temperature (SST) for different ENSO quintiles (Niño34 index)

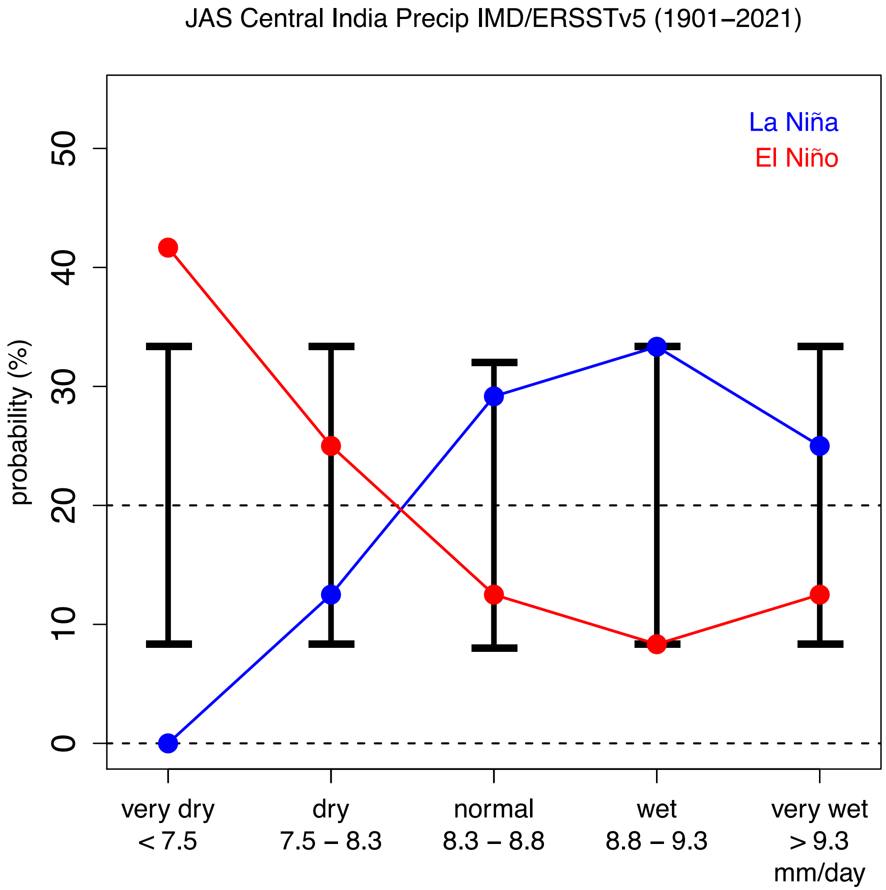
- Stronger ENSO amplitude in CFSv2

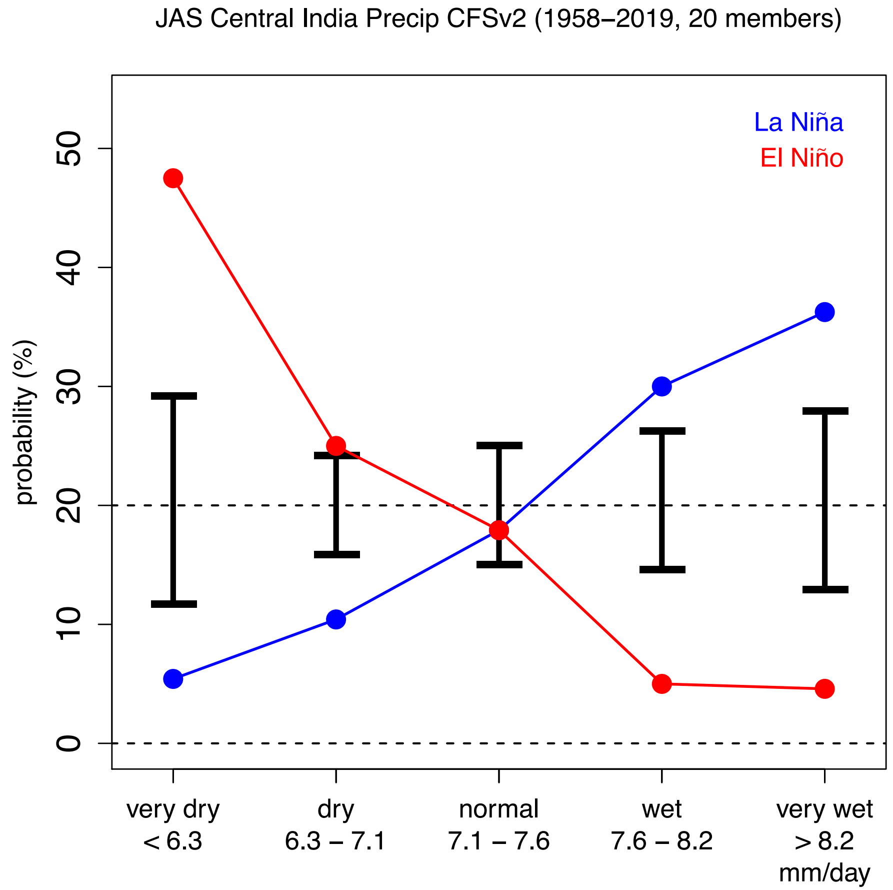


- Monsoon rainfall response to ENSO: CFSv2 (top) compared to IMD (bottom)



- Monsoon rainfall variability: CFSv2 (top) compared to IMD (bottom)





- Rainfall probability as a function of ENSO phase
- Disproportionate impact on probability of "Very Dry" (only significant change observed); less asymmetry in CFSv2

Modify PCA/EOF analysis to incorporate asymmetry

- van den Dool (2011) showed how iterative technique can be used to solve PCA (in few iterations, EOF-1 emerges following power law)

- Extend this iterative technique to allow for a separate pattern for positive and negative phases

- EOF-1 pattern gives slope of a line that minimizes mean-squared error (total least squares)

- ”Asymmetric” EOF-1 patterns give slopes of two lines that meet (share an intercept that may not necessarily be climatological mean) → continuous relationship with break point at zero, analogous to piecewise regression

Modify PCA/EOF analysis to incorporate asymmetry

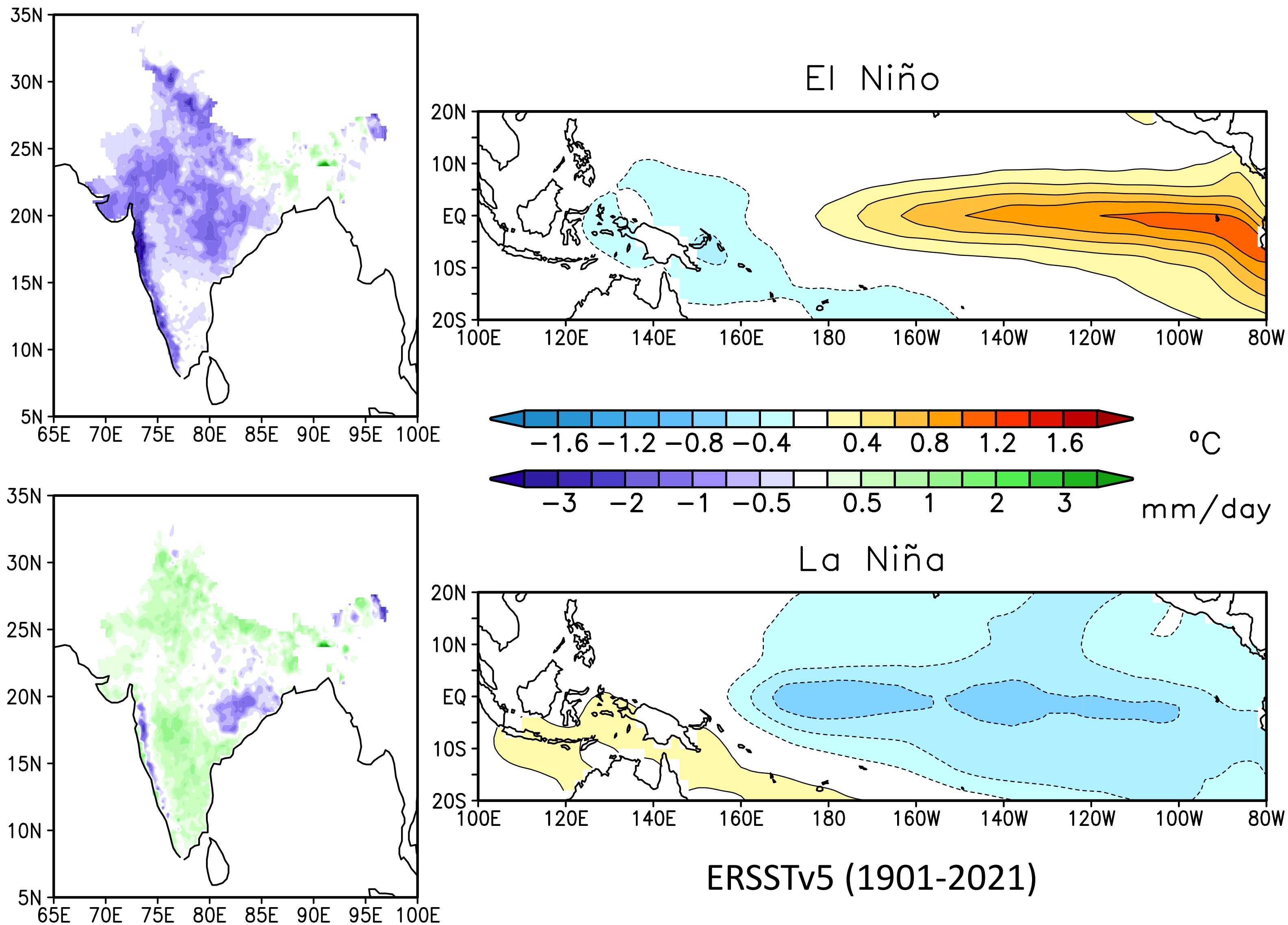
Some benefits:

- New time series (patterns) are recoverable by pattern projection (regression) with original data

- Cheap computation and provides next level of complexity (in contrast to Kernel PCA or Nonlinear PCA)

- Asymmetry in dominant mode of variability can be separated from subsequent modes (e.g., distinguishing ENSO asymmetry from ENSO flavors)

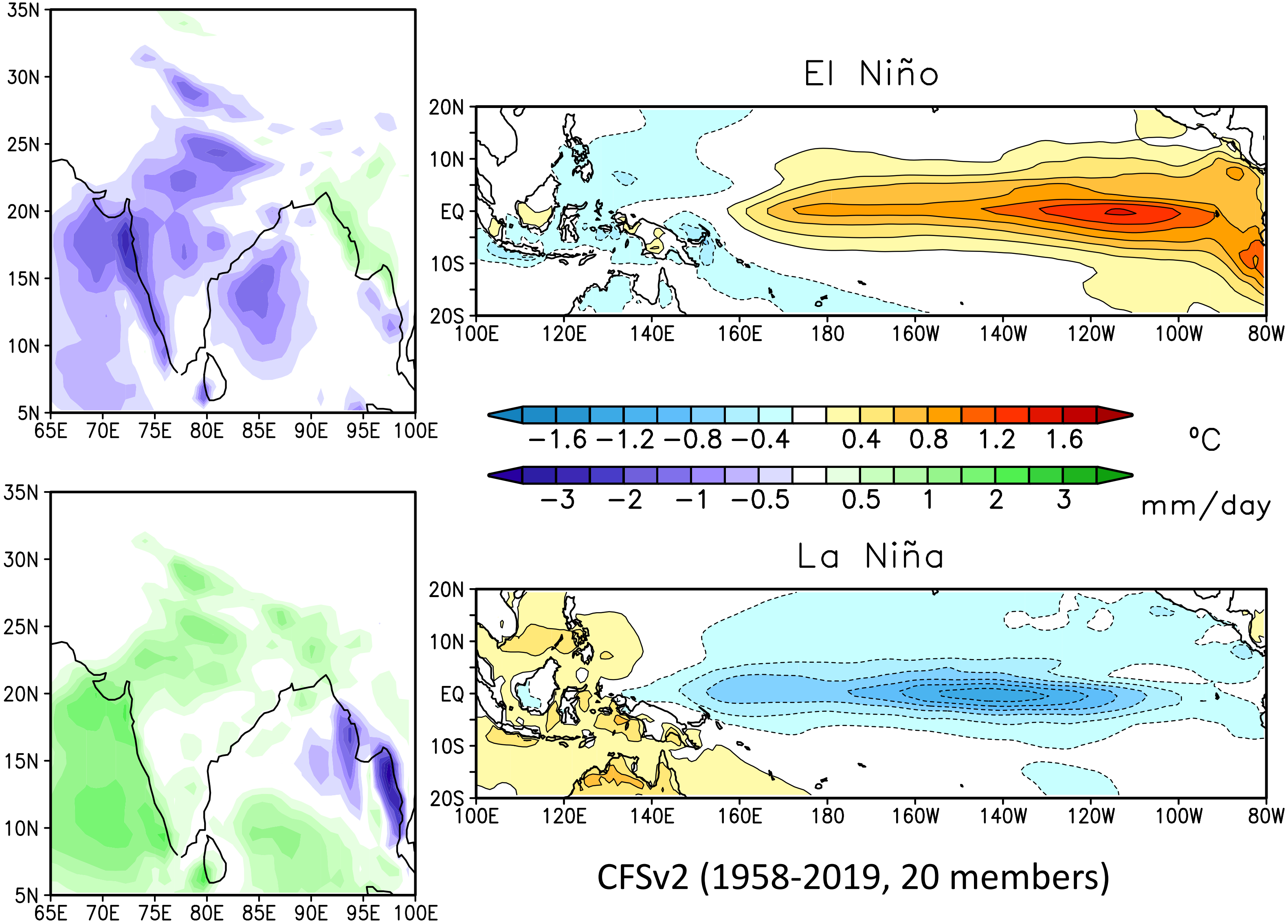
“Asymmetric” EOF-1 of JAS SST/rainfall



ERSSTv5 (1901-2021)

IMD

"Asymmetric" EOF-1 of JAS SST/rainfall



CFSv2 (1958-2019, 20 members)

ENSO impact on monsoon circulation and active-break cycle

- ENSO has a dynamical impact on monsoon rainfall via the large-scale circulation: consider 850 hPa winds (U,V) and 500 hPa vertical velocity

- ENSO forcing is slow and emerges in seasonal mean, but how is it manifested during the season, i.e. at intra-seasonal time scales?

- Straus (2021) "Preferred intra-seasonal circulation patterns of the Indian summer monsoon and active-break cycles", *Climate Dynamics*
  - Identify active-break phases in terms of "circulation regimes"
  - K-means cluster analysis of 5-day mean 850 hPa U,V over India

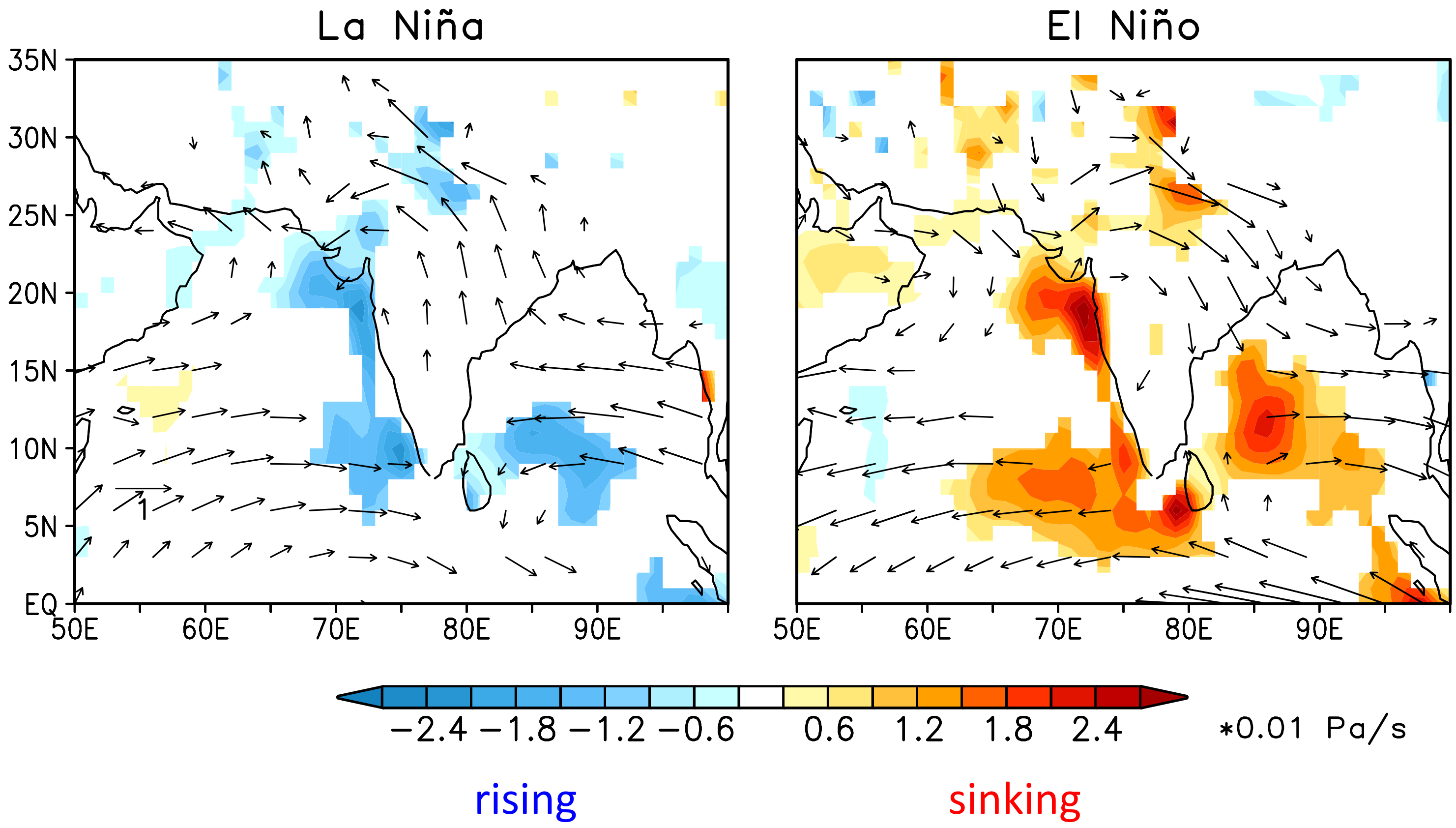
  → 4 or 5 patterns with cyclical transition path

ENSO impact on monsoon circulation and active-break cycle

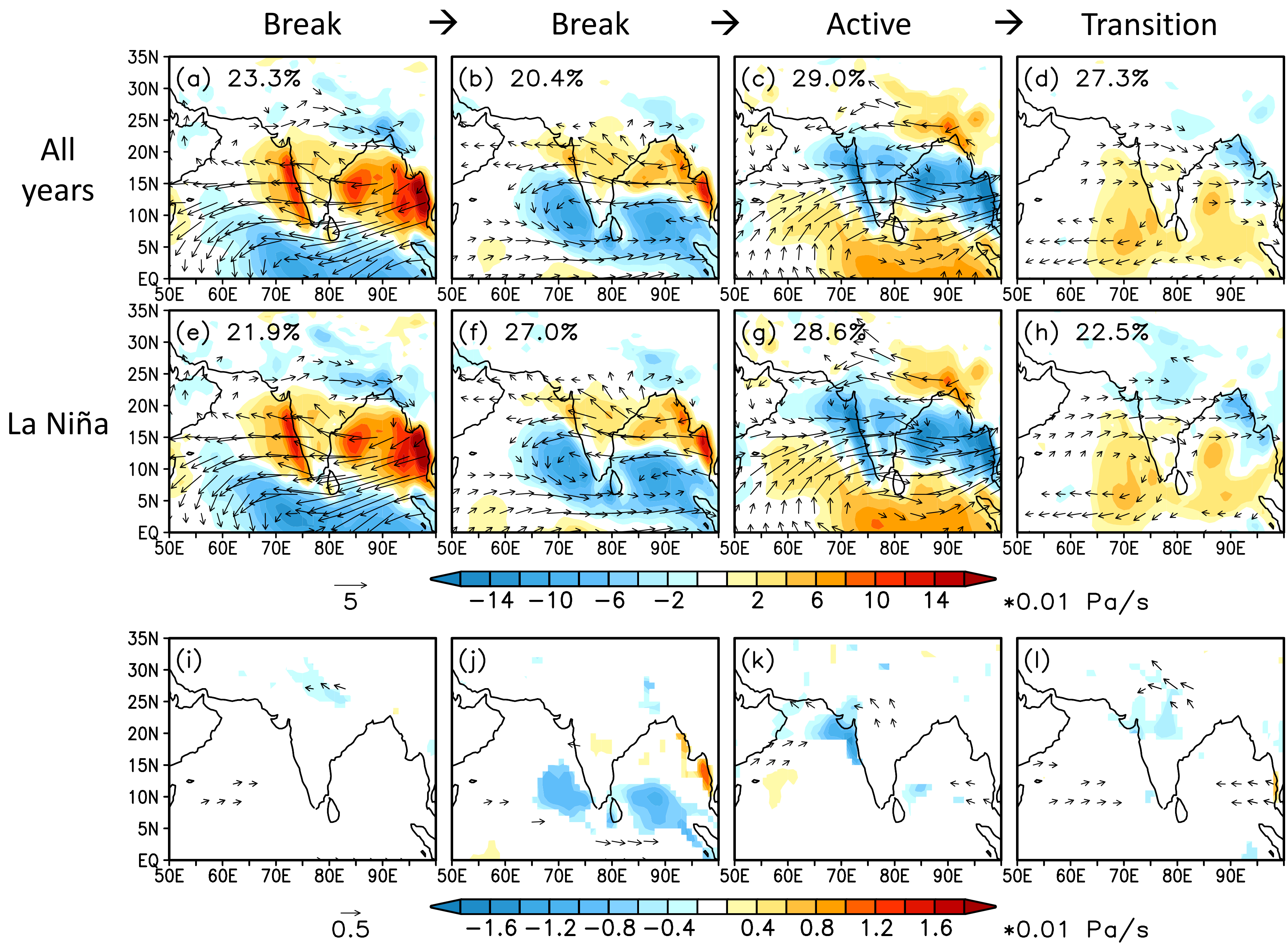
- Apply same analysis of Straus (2021) in CFSv2 re-forecasts over JAS season
- First remove climatological smooth annual cycle; truncate remaining anomalies to leading 10 EOFs (75% of variance)
- Compute cluster analysis (using k=4) over all years and reconstruct patterns using all EOFs (also consider composites of 500 hPa vertical velocity ω)

- How does ENSO impact active-break phases?
- Can answer this question by taking cluster averages conditional on ENSO quintiles and examining differences from clusters using all years

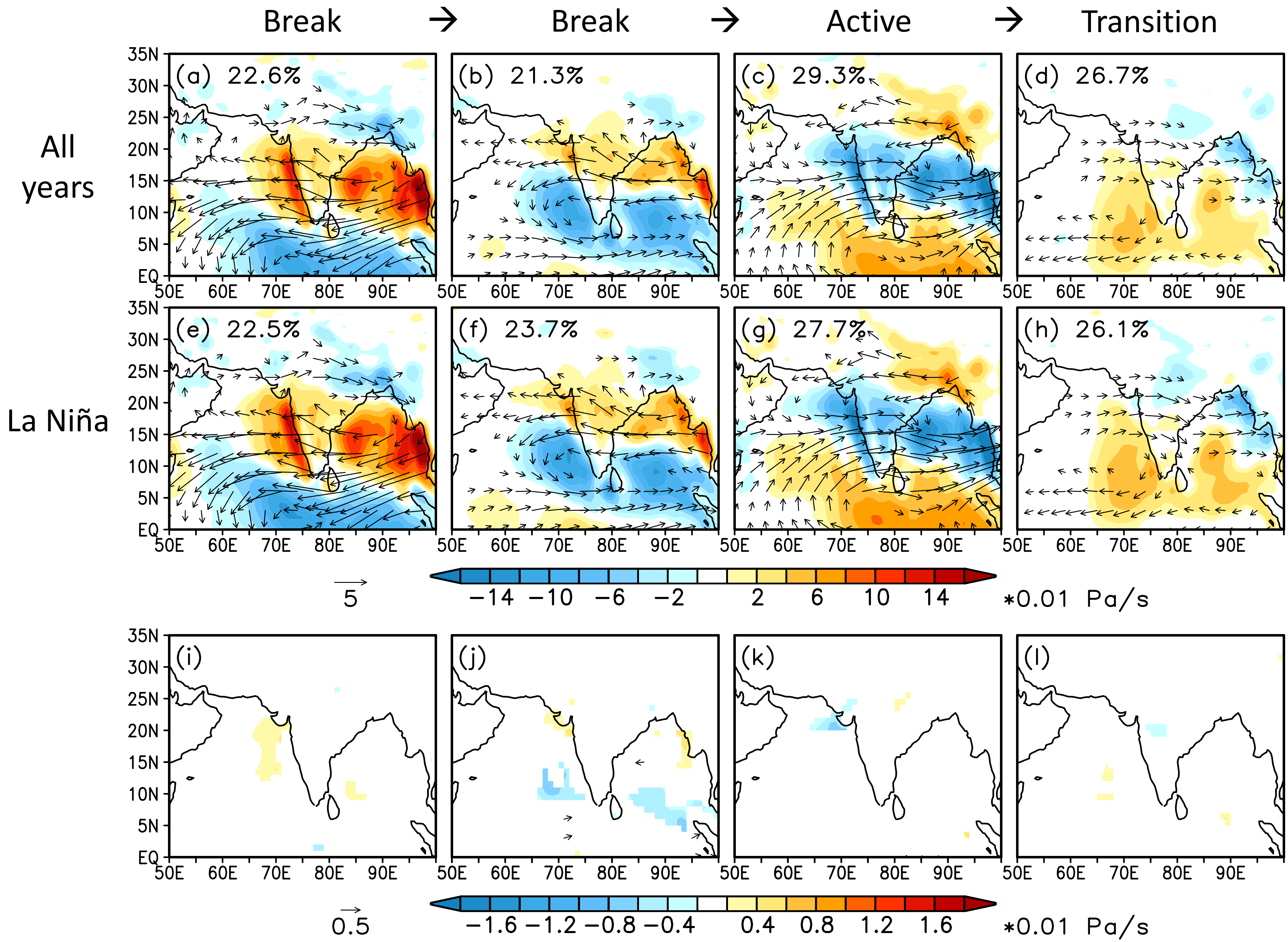
- Significance in differences determined from bootstrapping procedure



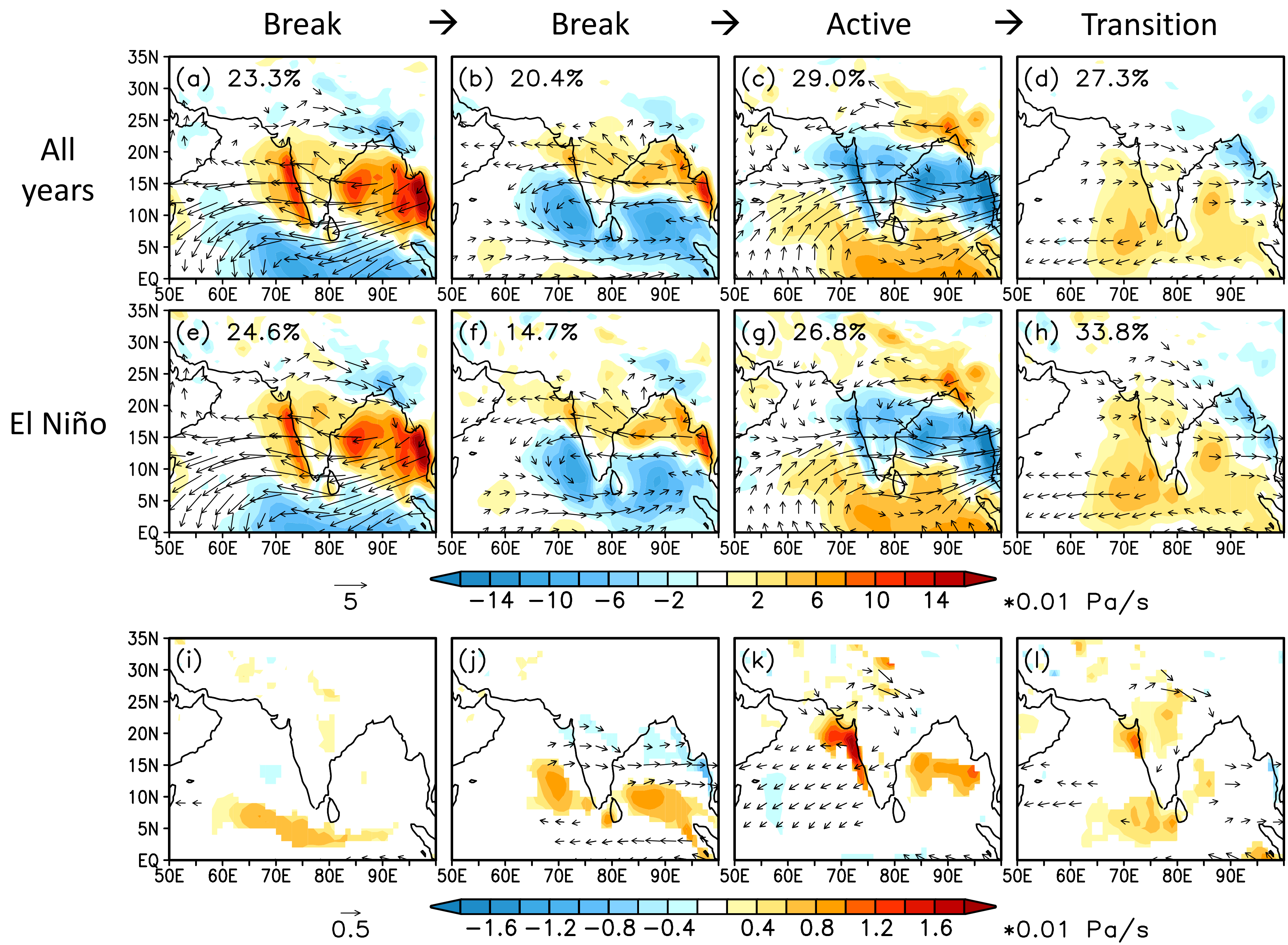
- JAS mean monsoon circulation response to ENSO in CFSv2
- La Niña – more ascent, winds SE (W) over Central India (Arabian Sea)
- El Niño – more descent, winds NW (E) over Central India (Arabian Sea)



Break → Break → Active → Transition
All years
La Niña
(a) 23.3%
(b) 20.4%
(c) 29.0%
(d) 27.3%
(e) 21.9%
(f) 27.0%
(g) 28.6%
(h) 22.5%
(i)
(j)
(k)
(l)
35N 30N 25N 20N 15N 10N 5N EQ
50E 60E 70E 80E 90E
5
−14 −10 −6 −2 2 6 10 14
*0.01 Pa/s
0.5
−1.6 −1.2 −0.8 −0.4 0.4 0.8 1.2 1.6
*0.01 Pa/s



La Niña signal removed prior


Break → Break → Active → Transition
All years
El Niño
(a) 23.3%
(b) 20.4%
(c) 29.0%
(d) 27.3%
(e) 24.6%
(f) 14.7%
(g) 26.8%
(h) 33.8%
(i)
(j)
(k)
(l)
35N 30N 25N 20N 15N 10N 5N EQ
50E 60E 70E 80E 90E
5
−14 −10 −6 −2 2 6 10 14
*0.01 Pa/s
0.5
−1.6 −1.2 −0.8 −0.4 0.4 0.8 1.2 1.6
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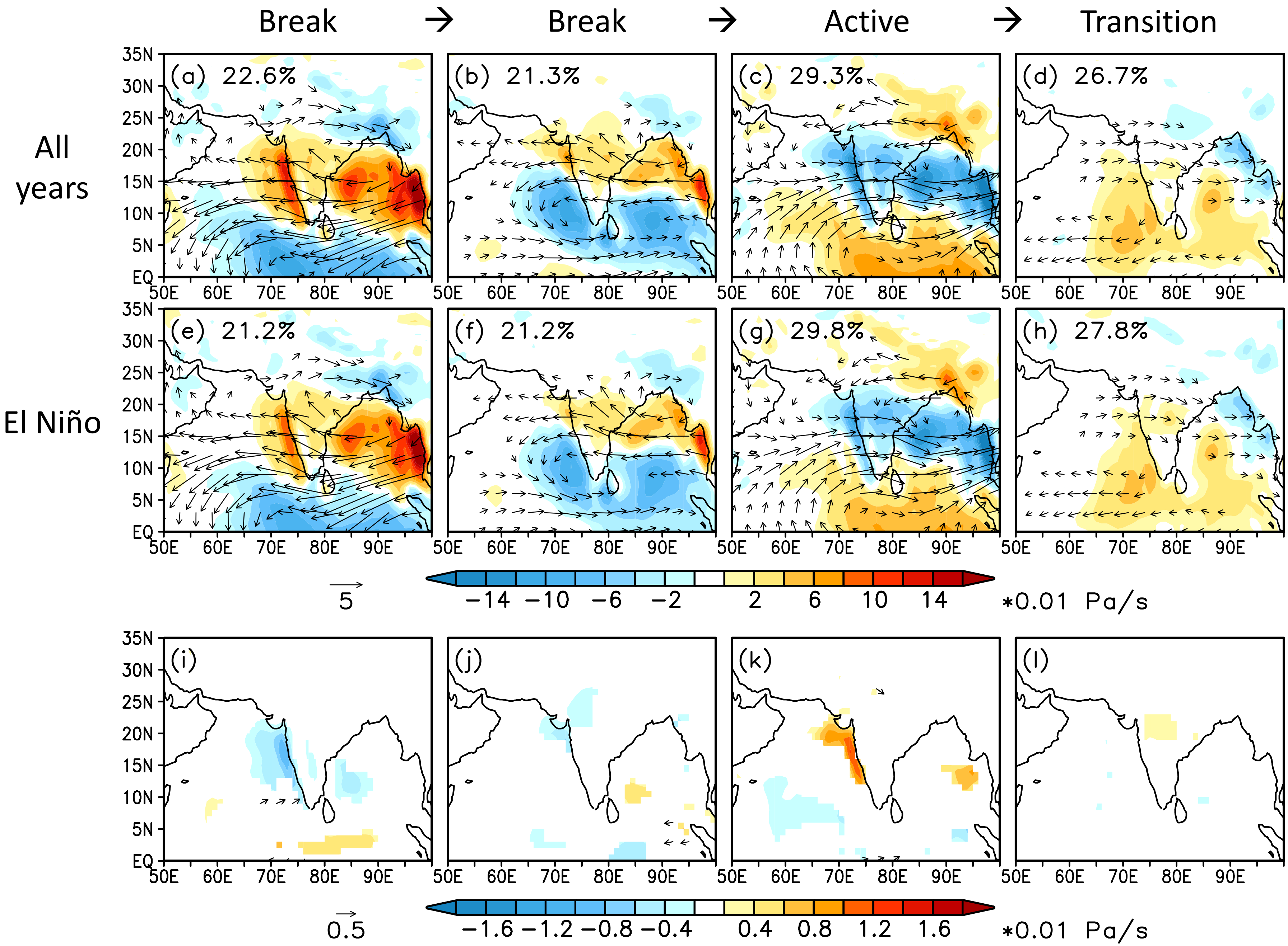


El Niño signal removed prior

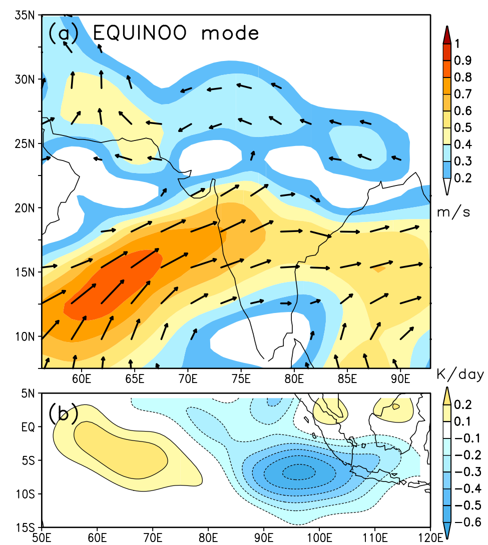
Monsoon Teleconnection Diabatic Heating Experiments

Swenson, E. T., D. M. Straus, and D. Das, 2022: Indian monsoon teleconnections and the impact of correcting tropical diabatic heating. *J. Atmos. Sci.*, **79**, 1445-1458, doi: 10.1175/JAS-D-21-0231.1

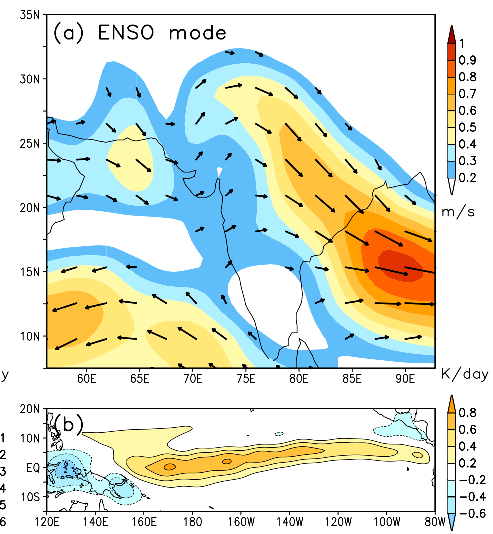
- Corrected tropical heating in CFSv2 in 38 years of re-forecasts using "added heating" technique that preserves model feedbacks

- Improved skill in local tropical winds and SST (especially over Indian Ocean)
- Large improvement in skill in East Asian monsoon
- Improved monsoon teleconnections

- EQUINOO forced response limited to Bay of Bengal; no response in Somali Jet
- Either model unable to simulate response OR observed teleconnection IS NOT a response to tropical heating



Equatorial Indian Ocean Oscillation (EQUINOO)



ENSO

Summary and Conclusions

- Examined ENSO impact on Indian Monsoon in large set of CFSv2 re-forecasts
- El Niño has a stronger impact on monsoon than La Niña
- Largest signal found in likelihood of very dry summer
- Observed ENSO signal exhibits asymmetry in both Pacific SST and rainfall over India

- Circulation patterns associated with intra-seasonal active-break cycle are quite robust and mostly independent of ENSO
- ENSO signal over central India most evident during transitional phase and preceding active phase
- Upward motion (active convection) over Arabian Sea and Bay of Bengal is enhanced/reduced during La Niña/El Niño
- If slow ENSO signal is removed prior, only evidence of a modified active-break cycle is over Arabian Sea during El Niño

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