Use of machine learning techniques for identification of robust teleconnections to East African rainfall variability

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Research Supported by NASA Applied Science Program SERVIR

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Motivation – NASA SERVIR Applied Science Team

Leveraging Coupled Climate Model Projections for SERVIR Applications Science

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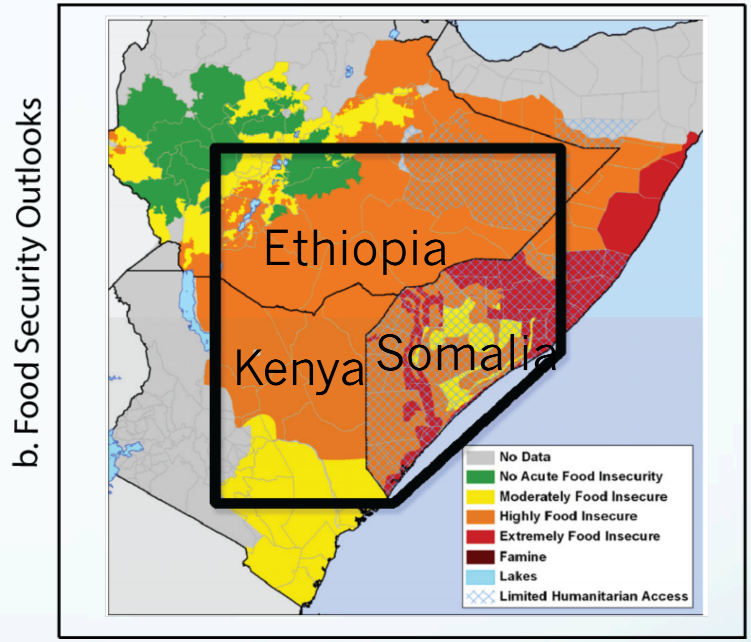
- The NASA/USAID SERVIR AST is focused on providing enhanced products, outlooks and projections (e.g.):
    - Agricultural modeling
    - Hydrologic modeling,
    - Air quality and landslide risk, among other

- Tailored for several hub regions
    - East Africa
    - Mesoamerica
    - Hindu Kush-Himalayan



- *Providing assessment of seasonal and climate model forecasts for these regions and development of scenarios for impact modeling*
    - *Requires downscaling in time and space (daily, ~10km)*
- *(Wed) Poster 516, Climate Scenarios for the NASA/USAID SERVIR Project: Challenges for Multiple Planning Horizons*

East Africa is a focus area of several efforts. There is a need for early warning of potential hazards for planning.

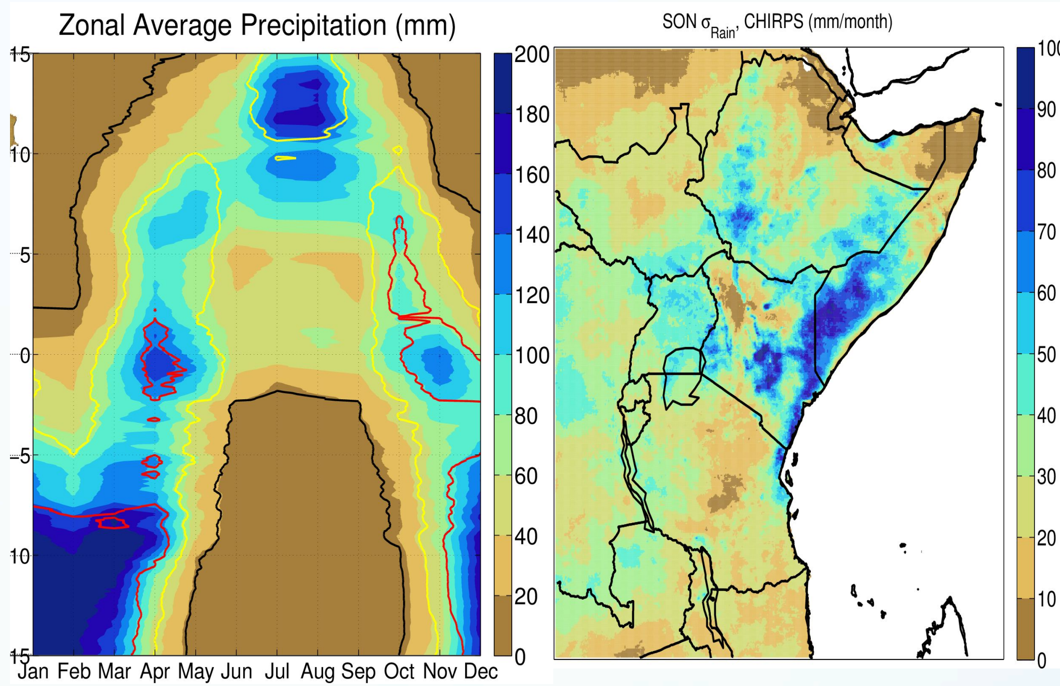
Motivation – East African Rainfall Variability

<u>Equatorial East Africa (5S-5N)</u>

- Two rainy seasons
  - MAM “long” rains
  - OND “short” rains

- Interannual variability of seasonal rainfalls appears to be more coherent for short rains rather than long rains

- Peaks in interannual variability are strongest over Uganda, Kenya, and southern Somalia.



<u>Most studies of interannual variability have focused on seasonal mean variability.</u>

- What can we learn about the characteristics of subseasonal variability in relation to seasonal mean variability?

- Can we appeal to machine learning approaches for providing a framework to examine patterns of subseasonal variability other than statistics of daily weather?

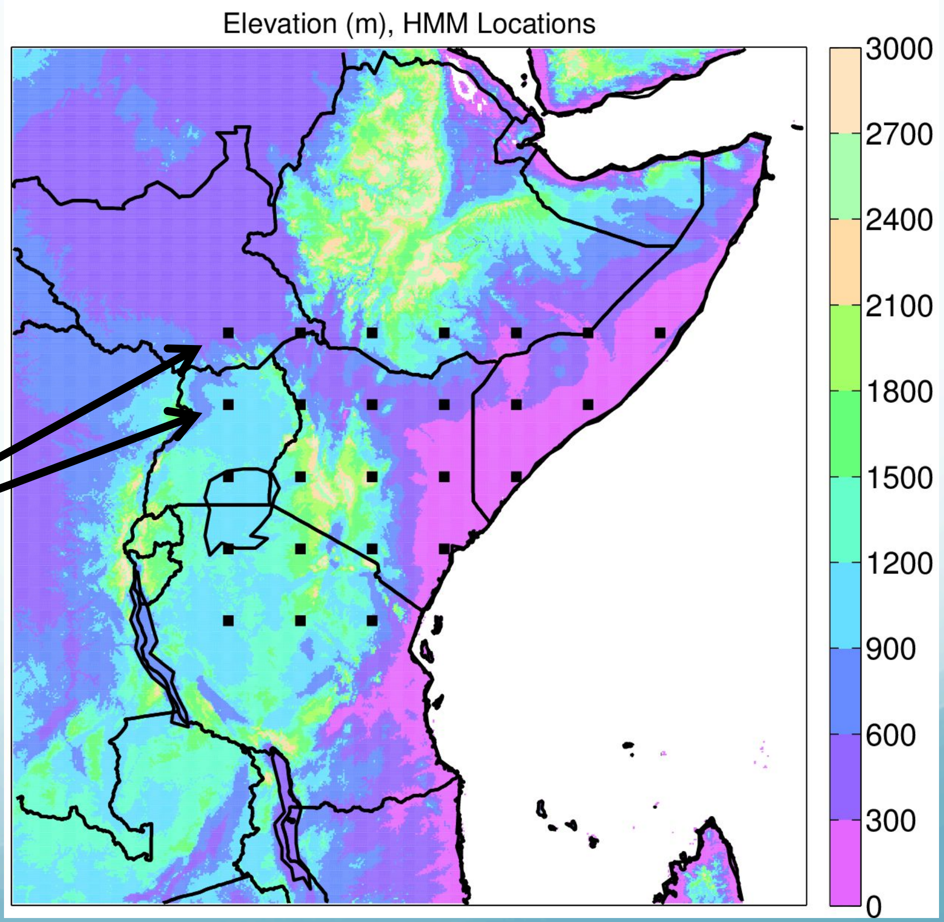
Approach - Datasets

MERRA – Weather/Climate Composites
- 1/3 x 2/3 resolution
- 1979 – NRT
- U,V – 850mb, 250mb
- Omega – 500mb
- Moisture convergence

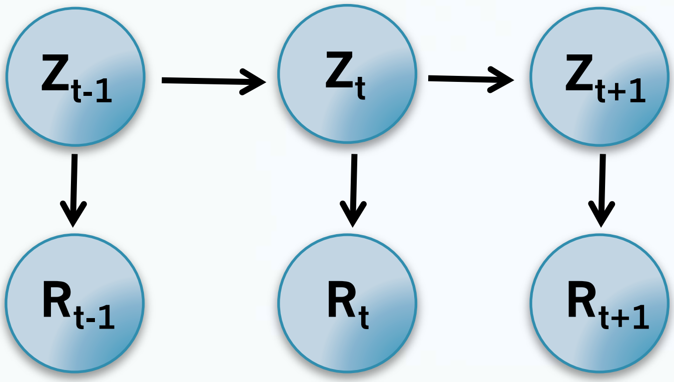
Climate indices
- Wheeler-Hendon MJO Index

Primary Domain – East Africa
- 5S – 5N , 32.5E – 47.5E
- 25 stations (~2.5° apart)
- Coastal lowlands and interior highlands
- Focus on short rains (SOND)

CHIRPS – Rainfall
- ~5km resolution
- Merged IR/Model/Station
- 1981 – Near Real Time (NRT)

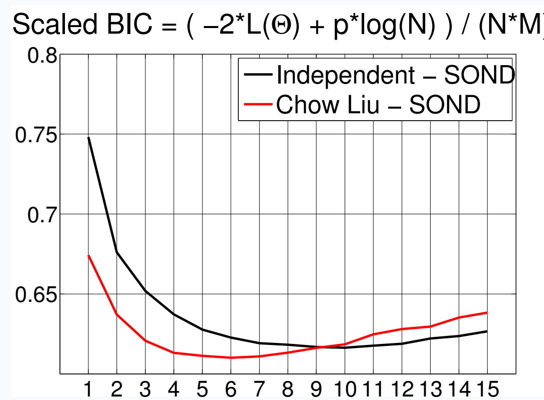


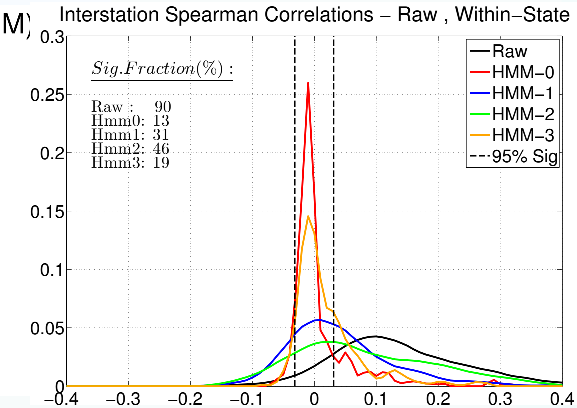
Approach – Hidden Markov Modeling



- Directed graphical model that expresses the probability density of a sequence of observed variables (**R_t**) as the result of a Markov sequence of unobserved or latent states (**Z_t**)

- Links to machine learning
  - Clustering: identification of potential hidden structures from observations
  - Classification: assignment of sequence of vectors to a most likely sequence of hidden states (Viterbi algorithm)

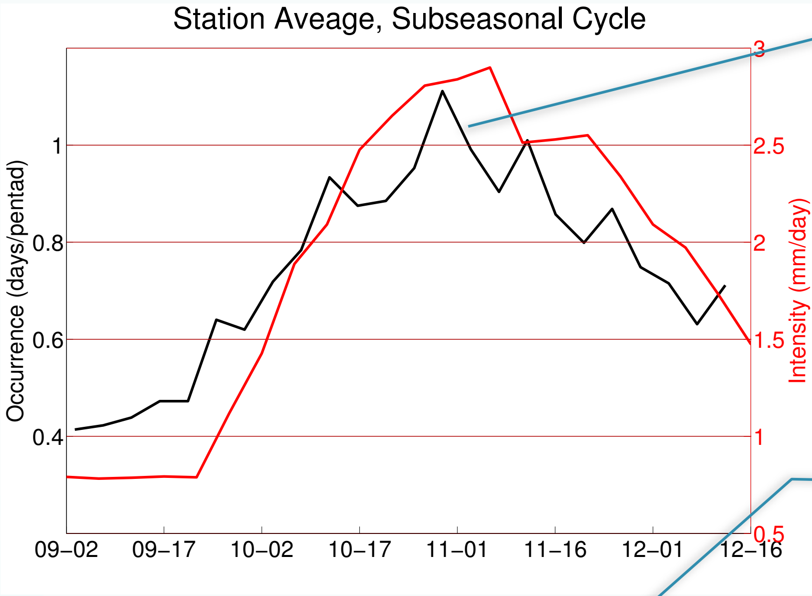




HMM Model Training

- Use MVNHMM Toolbox (S. Kirshner)
- 4 states chosen for this analysis
- Use of Conditional Independence model
  - Only marginal improvement found by taking into account within-state dependence
- Interstation correlations reduced significantly by conditioning on states

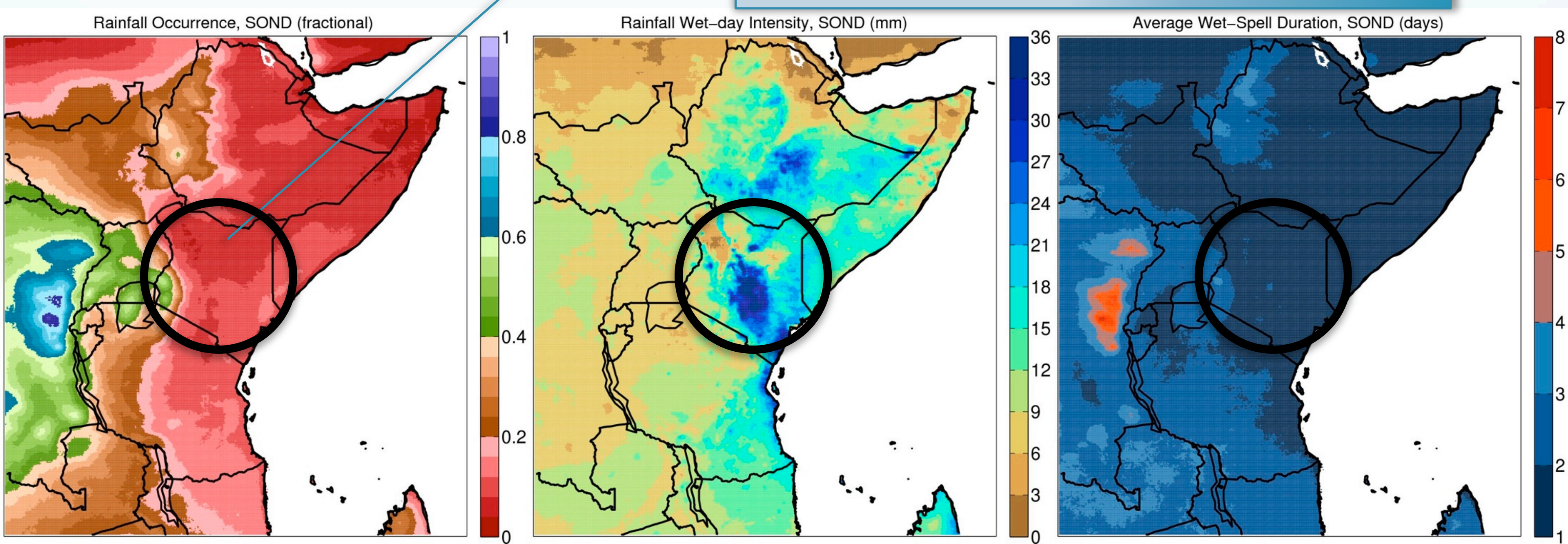
Subseasonal Variability – Traditional View



Rainfall occurrence and wet-day intensity covary strongly over the SOND period typically peaking in late October.

Distribution of Daily Rainfall

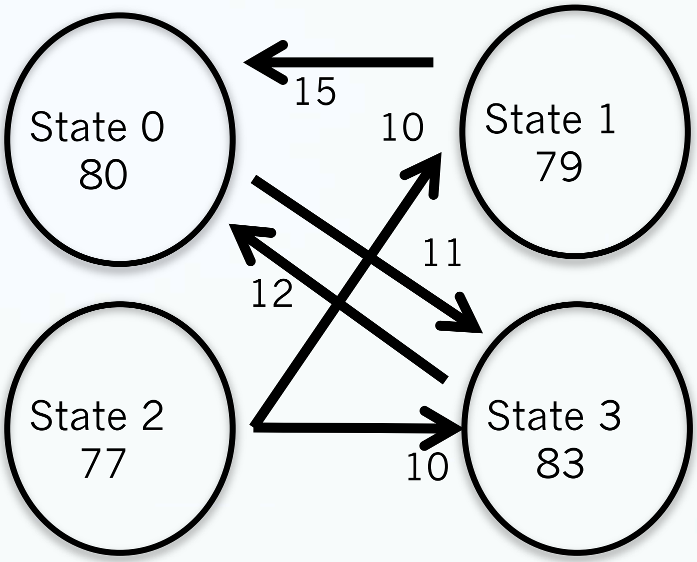
1) Infrequent
2) Intense
3) Short duration

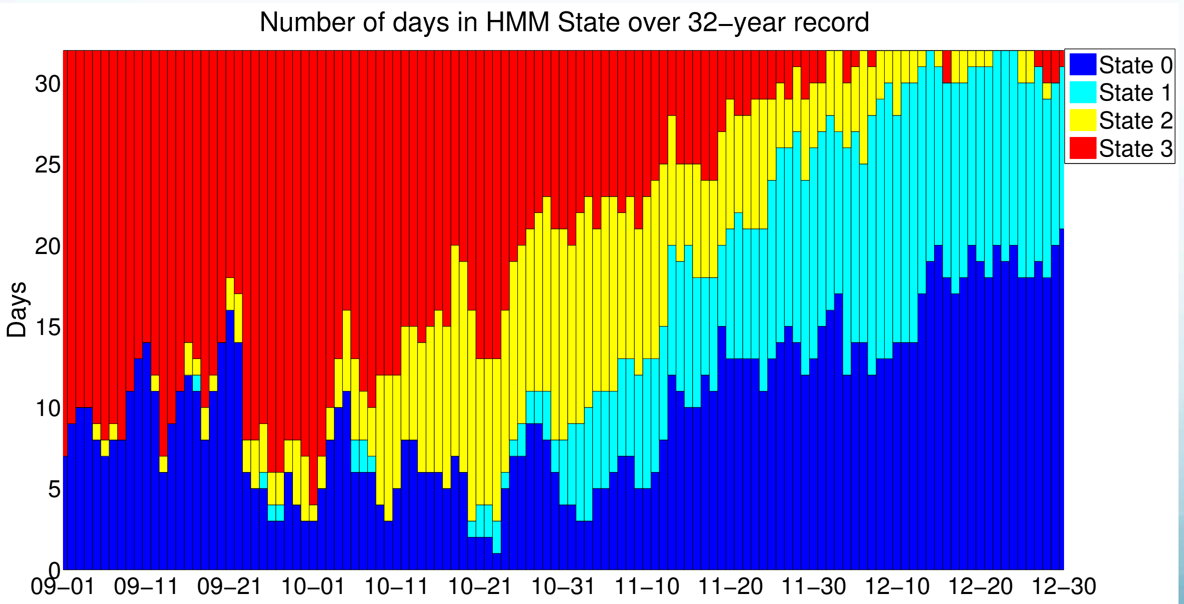


Subseasonal Variability – HMM View

Transition Probabilities (4 states):

- Very likely to remain in a particular state (persistence)
- Very unlikely to go from State 2 to State 0 directly (<3%)
- Non-stationary over the SOND period





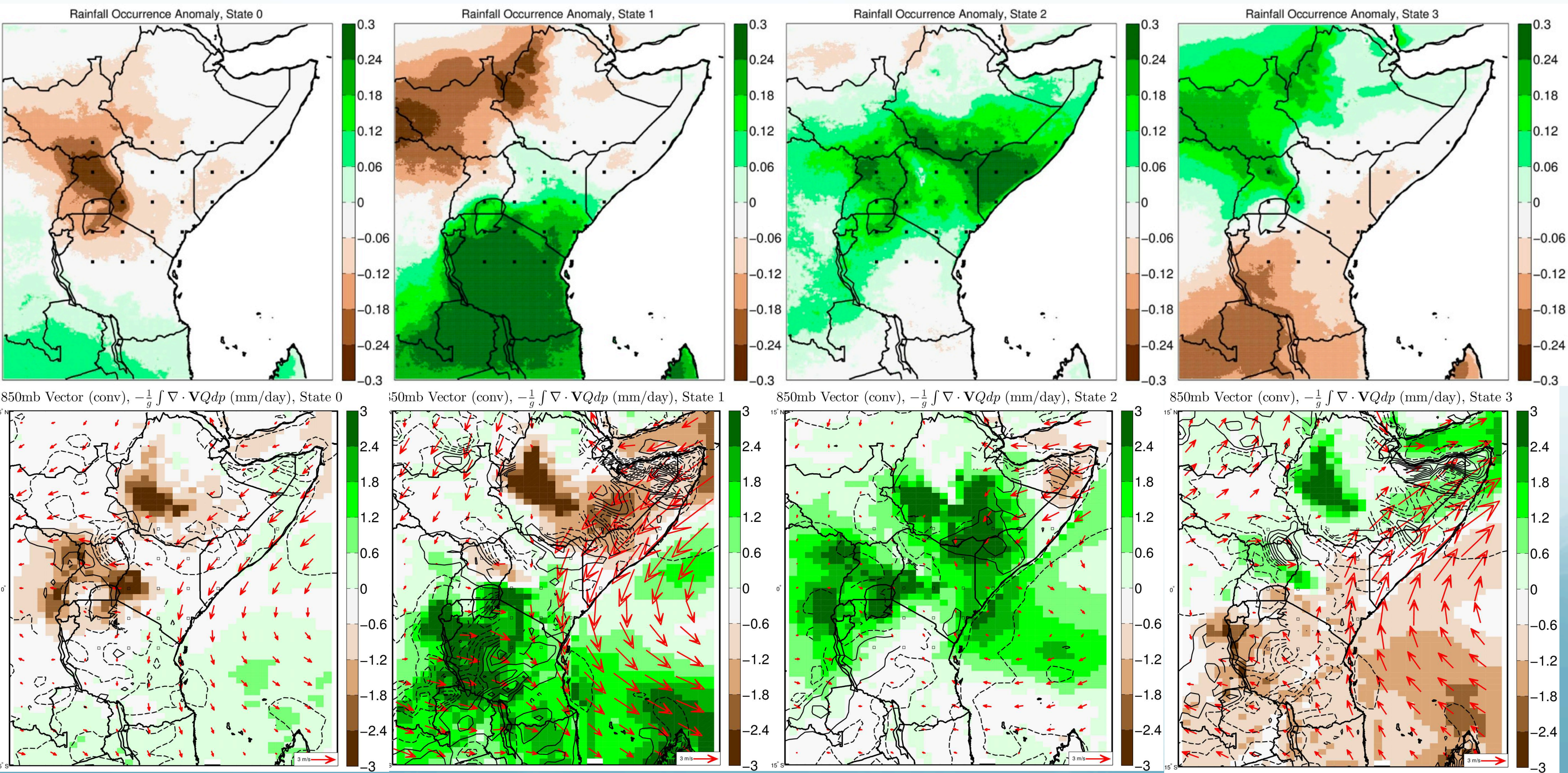
- Hidden capture an underlying evolution of rainfall variability within the short rains period.

3 → 2 → 1 → 0

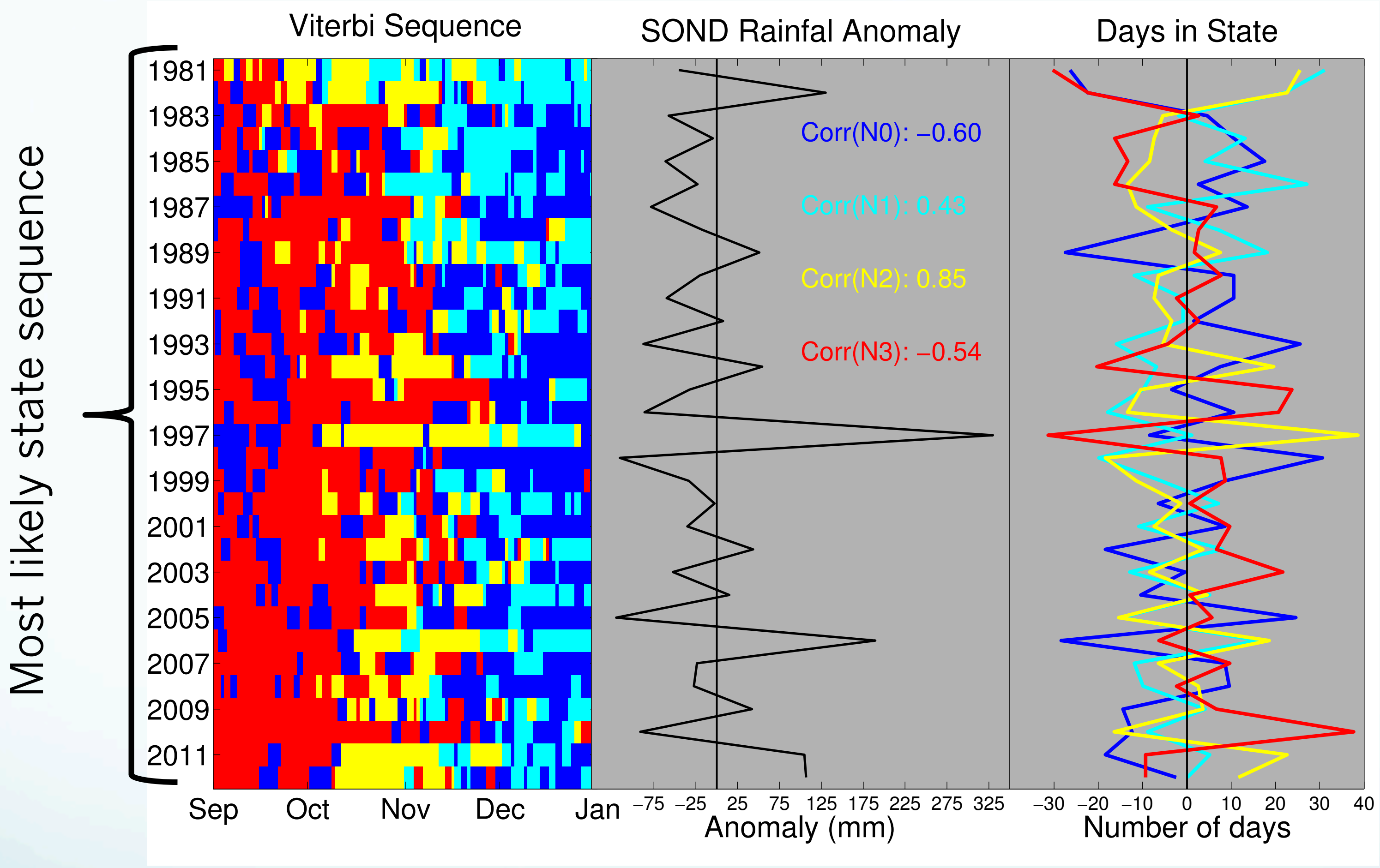
HMM States – Composite Meteorology

<u>Composites of 850mb winds, moisture convergence, and rainfall frequency</u>

- Progression from State 3 → 1 : Similar to ITCZ progression but State 2 (the "wet" mode) does not show in monthly averages.
- No analog for State 0 ("dry" mode) in monthly averages either.
- Rainfall anomalies correspond strongly with anomalous moisture convergence



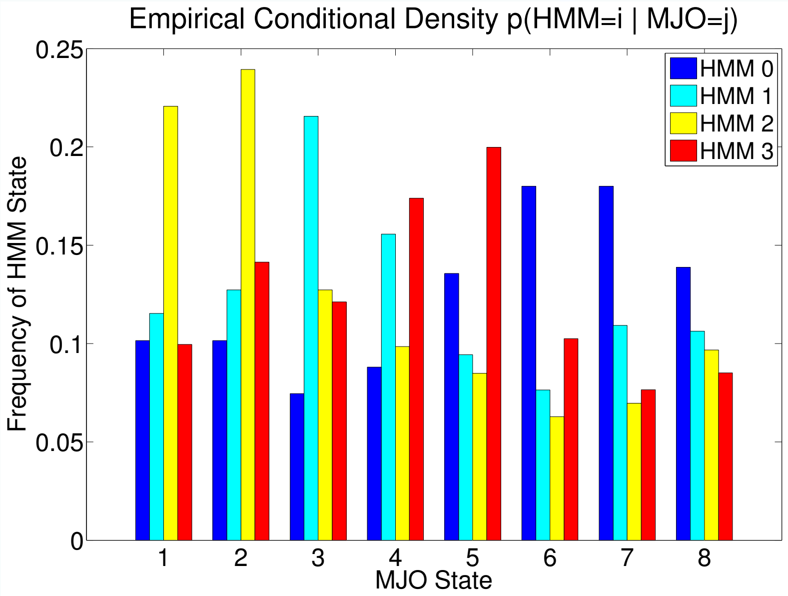
Subseasonal to Interannual variability

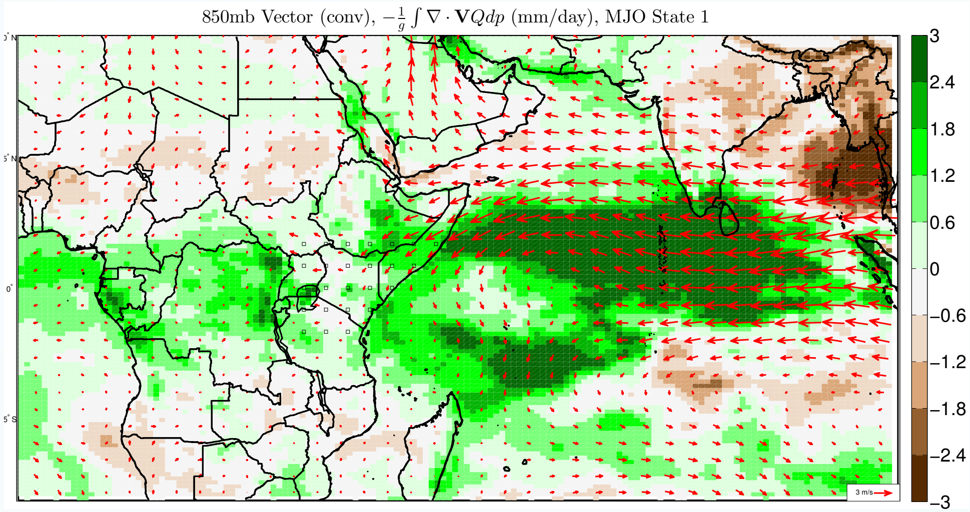


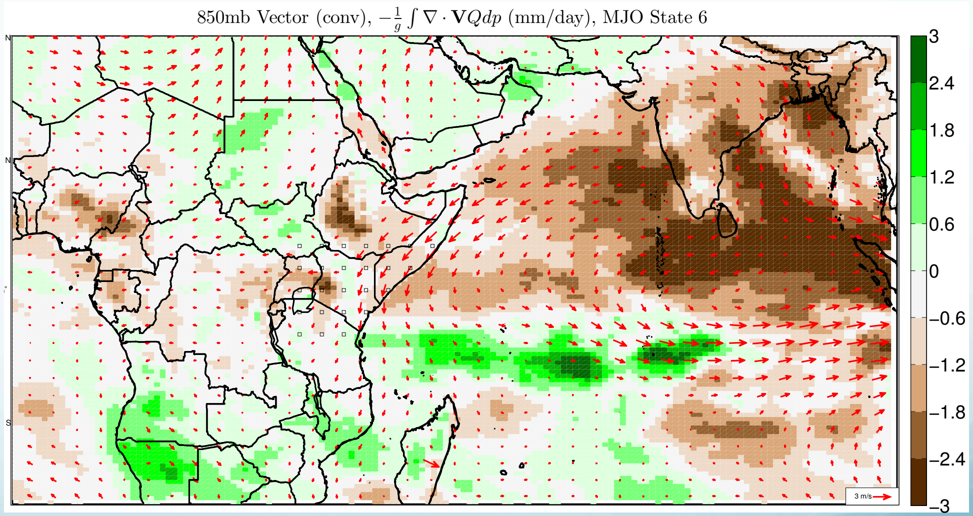
- Interannual seasonal rainfall anomalies are significantly correlated with interannual variations in the number of days in each HMM state.

- This is particularly strong (0.85) for the number of days in the “wet” state (2)

Connections to MJO Variability



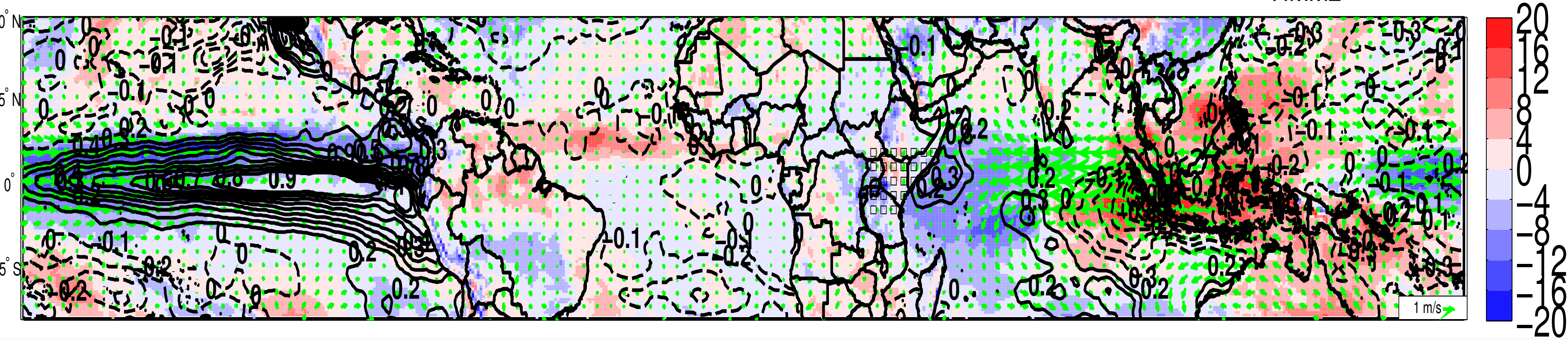




- “Wet” state (2) is most likely to be found occurs during MJO Phase 1 & 2
- “Dry” state (0) is most likely to be found occurs during MJO Phase 6 & 7
- MJO composites show very similar circulation anomalies to those found in compositing HMM states

Connections to ENSO & IOZM Variability

850mb Vector, Omega500 (shaded,hPa/day), SST (contour), Upper Quartile $\text{NDAYS}_{\text{HMM2}}$



<u>Composites of seasonal anomalies for years with a high fraction of "wet" state</u>

- Large-scale SST and circulation anomalies
  - El-Niño warming, east Indian cooling, west Indian warming
  - Anomalous subsidence over Maritime continent, ascent over west Indian
  - Anomalous westerlies over the Indian ocean

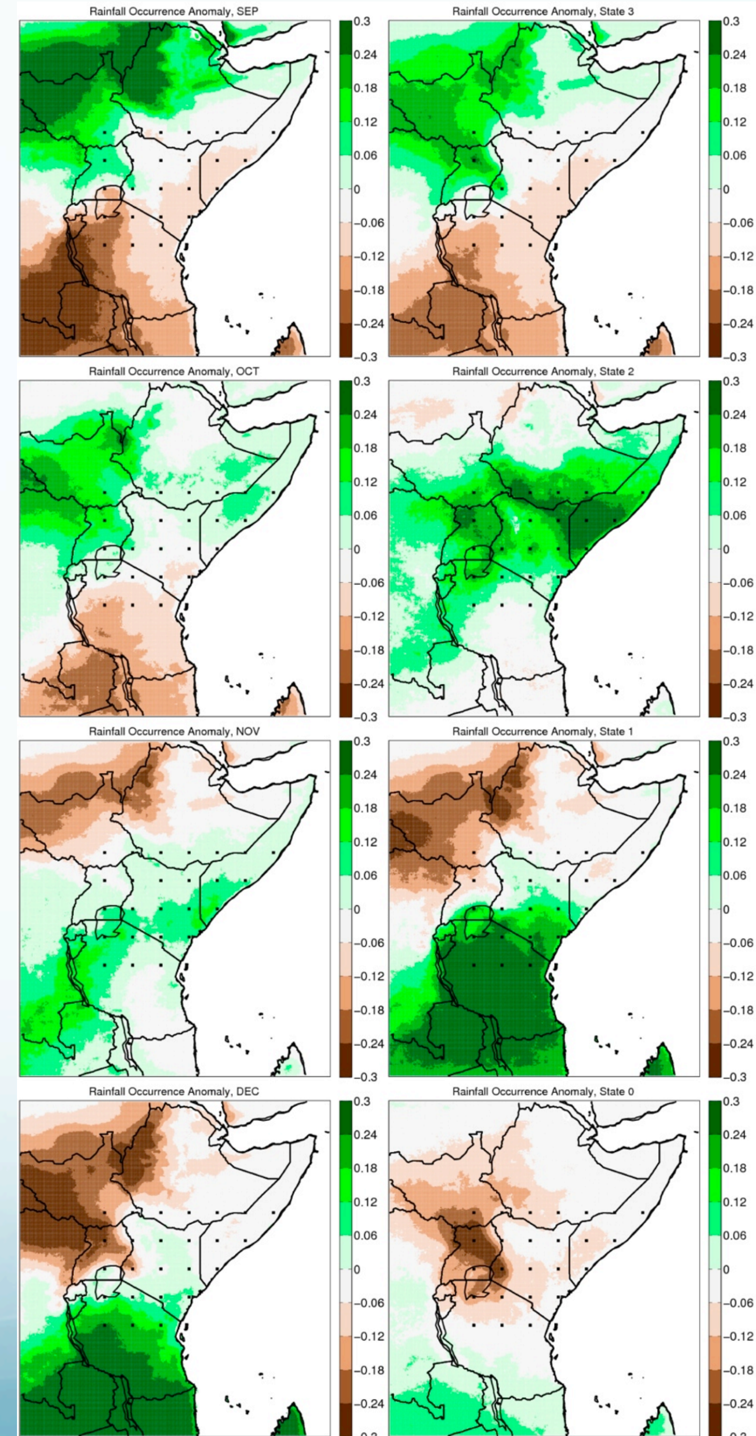
<u>Reduced Walker cell over Indian sector → Increased moisture convergence and rainfall over equatorial East Africa</u>

Summary

- **Hidden Markov models can be used to investigate structure of subseasonal variability.**
- **East African short rain variability has connections to large-scale tropical variability**
  - MJO – Intraseasonal variations connected with appearance of “wet” and “dry” states
  - ENSO/IOZM SST and circulation anomalies are apparent during years of anomalous residence time in the subseasonal “wet” state.
- Similar results found in previous studies, but
  - **We can interpret this with respect to variations of subseasonal wet and dry modes.**
  - **Reveal underlying connections between MJO/IOZM/ENSO with respect to East African rainfall**

Extras - 1

- Monthly averages (left) capture the large-scale seasonal progression of rainfall during the short rains season.
- However, there is no strong peak in anomalies over the equatorial East Africa regions at this monthly scale
- The HMM states appear to capture the two poles of the ITCZ progression (States 1 & 3)
- The HMM also captures two more regionally localized modes over EEA (a “wet” (2) mode and a “dry” mode(0))



Extras - 2

- Increases in in the frequency of MJO State 1 are correlated with increases in the number of days in the HMM wet state.
- During MJO State 1, the west Indian ocean is typically warm while the east Indian ocean is cold (w.r.t. to the SOND mean).
- This SST pattern is also prevalent with what is considered the IOZM and also has been shown to have some connections with remote forcing by ENSO.
- In response (?, perhaps "coexistence") to the anomalous SST gradient, anomalous pressure graidents are observed as is an anomalous low-level westerly circulation that weakens the Walker circulation and reduces the climatology export of moisture away from EEA.