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

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Outline

- Motivation & Background
  - SERVIR AST – Climate model downscaling
  - East African Rainfall variability

- Approach
  - Datasets
  - Hidden Markov Modeling & Compositing

- Results
  - Subseasonal variability
  - HMM States and Weather “regimes”
  - Connecting subseasonal to interannual variability

- Summary
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

Equatorial East Africa (5S-5N)

- 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.

Most studies of interannual variability have focused on seasonal mean variability.

- 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

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

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)
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.
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
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

Composites of 850mb winds, moisture convergence, and rainfall frequency

- 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.
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

Composites of seasonal anomalies for years with a high fraction of “wet” state

- 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

Reduced Walker cell over Indian sector → Increased moisture convergence and rainfall over equatorial East Africa
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**
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)).
• 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 gradients 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.