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Extratropical-Tropical Interactions over Ethiopia

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1. Introduction

The Belg rainfall contributes significantly to economic activities in Ethiopia, but is also characterized by high temporal and spatial variability. This study identified synoptic and subseasonal features that lead to rainfall deficits and surpluses during Ethiopian Belg season (February – May; Bekele-Biratu *et al.* 2018). In particular, the theory of tropical plume formation (Knippertz 2007) seems to hold true for Belg as tropical-extratropical interactions play a major role in modulating rainfall during this time of the year. This work also complements earlier studies on seasonal variability of Ethiopian rainfall by Habtemichael and Pedgley (1974), Camberlin and Philippon (2002), and Diro *et al.* (2011).

2. Data and methods

Daily rainfall data from 117 stations of the National Meteorological Service of Ethiopia is used to define dry (lower tercile) and wet Belg (upper tercile) in 1980-2010 period. The NCEP/CDAS data is used to construct composites of circulation anomalies.

3. Results and summary

A tripole structure in a trough/ridge pattern in the region between the Northeast Atlantic Ocean and Red Sea regions is a dominant feature that is associated with Belg rainfall variability in Ethiopia. We have identified two modes of this tripole structure. In general, rainfall deficits (surpluses) in the Belg season are associated with the anticyclone-cyclone-anticyclone (cyclone-anticyclone-cyclone) modes. The ingredients summarized below contribute to rainfall deficits over Ethiopia during the Belg season due to reduced tropical-extratropical interactions: (1) the presence of an anomalous mid- to upper-level warm anticyclone over the Red Sea; (2) the absence of a poleward moisture flux and moisture convergence across the Horn of Africa; (3) the limitation of the southward extension of the mid-to-upper-level extratropical cyclonic trough; (4) upper-level

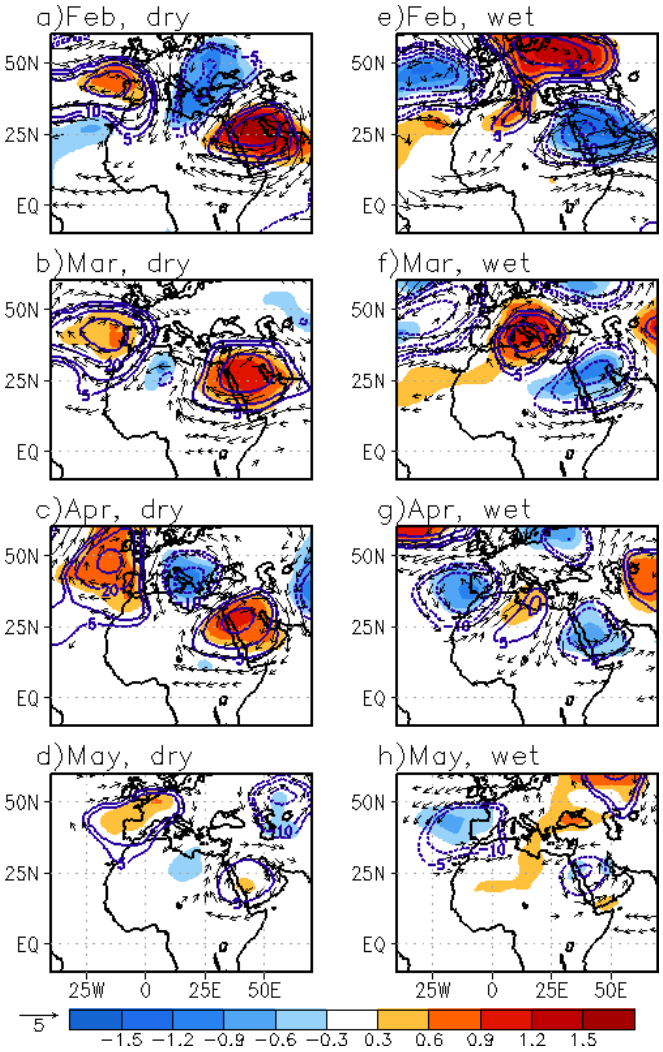

Fig. 1 (a) - (d) Composites of daily average 500-hPa circulation anomalies for dry events: shaded temperature anomalies (k); contours are geopotential height anomalies (gpm) and vectors are wind anomalies (m s^{-1}), significant at the 95% confidence level (student's *t*-test). (e) - (h), same as (a) - (d) except for wet events.

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negative PV anomaly north of Ethiopia; and (5) the prevalence of upper-level convergence across the Horn of Africa. Moreover, the presence of an anticyclonic anomaly across the Red Sea region and the neighboring areas of the Arabian Peninsula keeps the ITCZ south of its normal position during dry Belg events (Fig. 1a-1d).

In contrast, factors that contribute to the enhancement of tropical-extratropical interactions and moisture surpluses during the Belg season include: (1) the presence of anomalous mid-to upper-level cold cyclonic trough over the Red Sea; (2) the presence of a northward moisture flux that extends deep into the Horn of Africa and the prevalence of horizontal moisture convergence over Ethiopia; (3) a southward penetration of mid- to upper-level extratropical cyclonic trough in the Red Sea region; (4) the presence of an area of anomalous upper-level positive PV anomaly cut-off north of Ethiopia; and (5) an elongated area of anomalous upper-level divergence across the Horn of Africa (Fig. 1e - 1h)).

Correlation and composite analyses suggest a possible link between phases of the NAO and rainfall surpluses or deficits during the Belg season. Belg rainfall tends to be below (above) average over many parts of Eastern and southern Ethiopia during the positive (negative) phase of NAO events (Fig. 2).

The tripole pattern also plays a role in connecting NAO with circulation anomalies in the Red Sea region such that NAO induces an amplified (suppressed) Azores High in Northeast Atlantic (Diro *et al.* 2011) resulting in enhanced (weakened) Arabian High via the tripole modes. However, the regional circulation patterns and NAO belong to different scales of motion, and may not always interact with each other constructively.

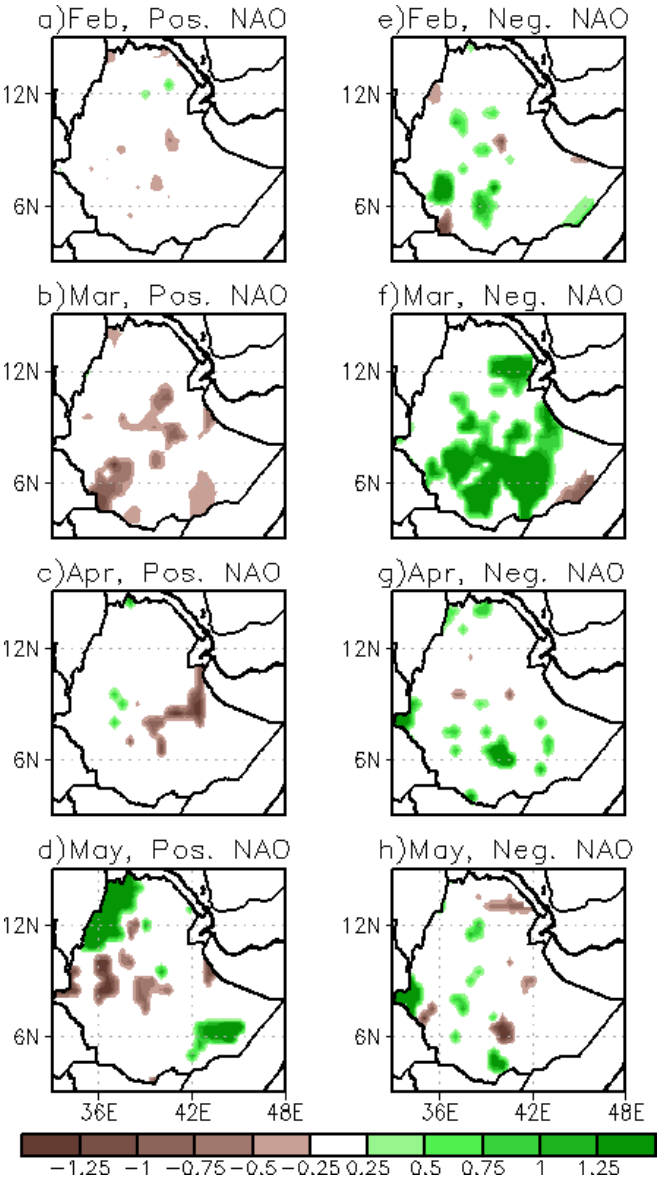

Fig. 2 (a) - (d), Composites of daily average rainfall anomaly (mm day^{-1}) for NAO positive events, significant at the 95% confidence level (student's *t*-test). (e) - (h), same as (a) - (d) except for NAO negative events.

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