The Dual Peaked Seasonal Cycle of Precipitation over Tropical East Africa

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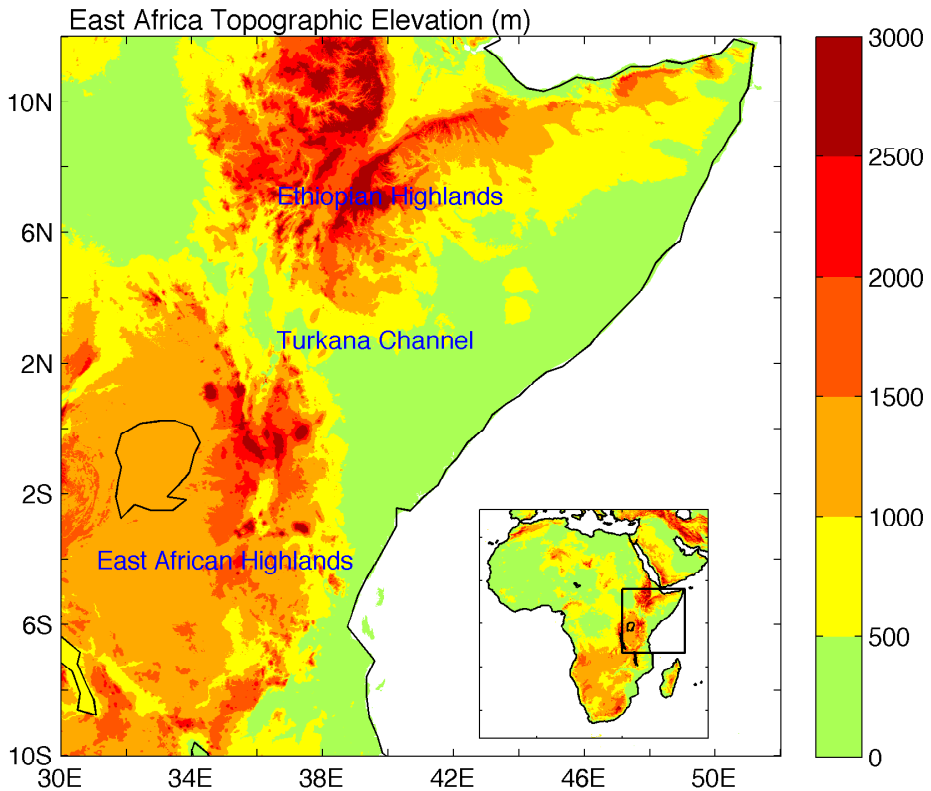
Outline

Outline

Background

East African (EA) topographic elevation:

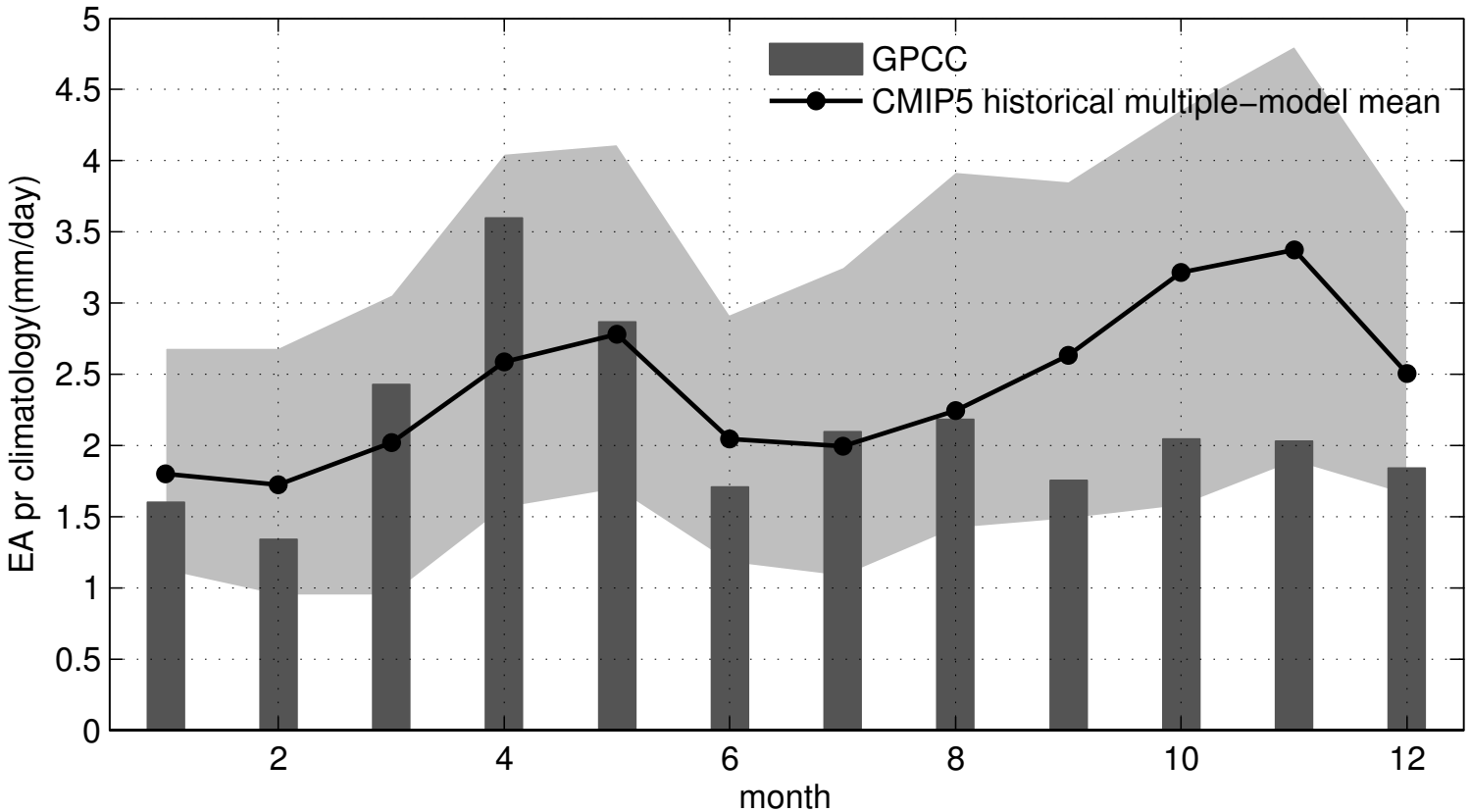


Two rainy season in EA:

- MAM: the long rains.
- OND: the short rains.
- Seasons of JF and JJAS are dry.

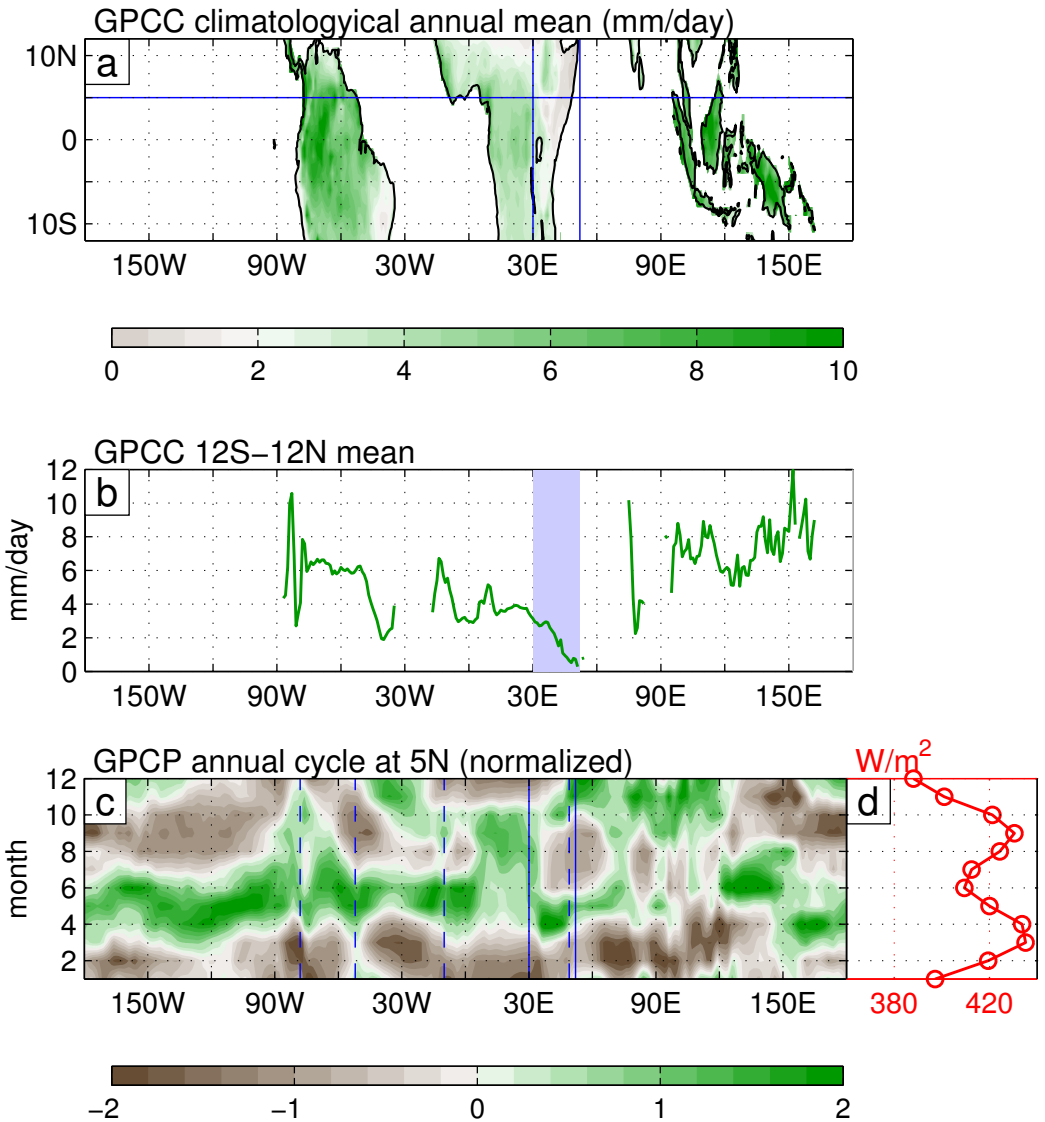
Motivation I

CMIP3/5 models overestimate the OND precipitation over EA.
Why is this?



Motivation II

- EA precipitation climatology is unique: dry annual mean climatology and bimodal seasonal cycle. –Why?
- Traditionally, the dryness of EA is explained by the land-ocean-friction-contrast-induced divergence. Is this correct?



Issues to be addressed

- Why does EA have a dry annual mean climatology?
- Why doe EA have two rainy seasons?
- What controls the EA precipitation annual cycle?
- Why are the long rains stronger than the short rains?

Outline

Data

Precipitation

- GPCC monthly prcp. v6: land-only, gauge-based, 0.5^0 lon $\times$ $0.5\ ^0$ lat.
- GPCP monthly prcp. v2.2: global, gauge + satellite, 2.5^0 lon $\times$ 2.5^0 lat.

SST

- NOAA NCDC ERSST v3b: monthly, 2^0 lon $\times$ 2^0 lat.

Thermodynamics, circulation and moisture budget

- ERA-Interim Re-Analysis.
- NCEP/NCAR Re-Analysis only for TOA downward solar radiation.

Methods

- All climatologies are computed based on the 1979-2009 period.
- Four seasons are defined as: JF (winter dry season), MAM (the long rains), JJAS (summer dry season), and OND (the short rains).
- The moist static energy (MSE) in this study is normalized by c_p and thus has the form:

$$h = T + Lq/c_p + gz/c_p$$

and has a unit of degree Kelvin.

Methods: moist budget equation

The seasonally climatological form of moist budget equation can be approximated by:

$$\begin{aligned}\overline{\overline{P}} - \overline{\overline{E}} &\approx -\frac{1}{g\rho_w}\nabla\cdot\int_0^{p_s}\overline{\vec{\bar{u}}\bar{q}}\,dp - \frac{1}{g\rho_w}\nabla\cdot\int_0^{p_s}\overline{\overline{\vec{u'}q'}}\,dp \\ &= -\mathrm{DVIqmum} - \mathrm{DVIqpup}\end{aligned}$$

where

$$\begin{aligned}\mathrm{DVIqmum} &= \frac{1}{g\rho_w}\nabla\cdot\int_0^{p_s}\overline{\vec{\bar{u}}\bar{q}}\,dp \\ \mathrm{DVIqpup} &= \frac{1}{g\rho_w}\nabla\cdot\int_0^{p_s}\overline{\overline{\vec{u'}q'}}\,dp\end{aligned}$$

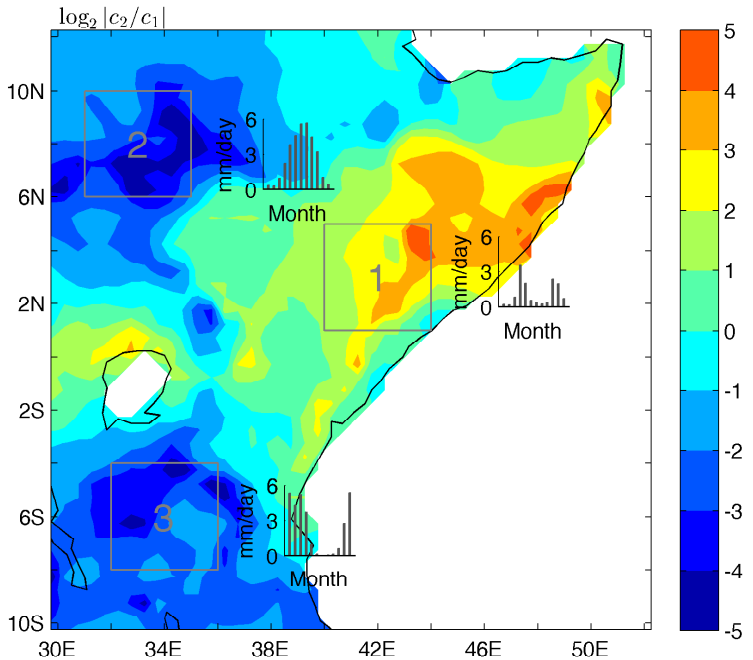
the top bar denotes seasonal climatology and the bar below denotes monthly mean.

Outline

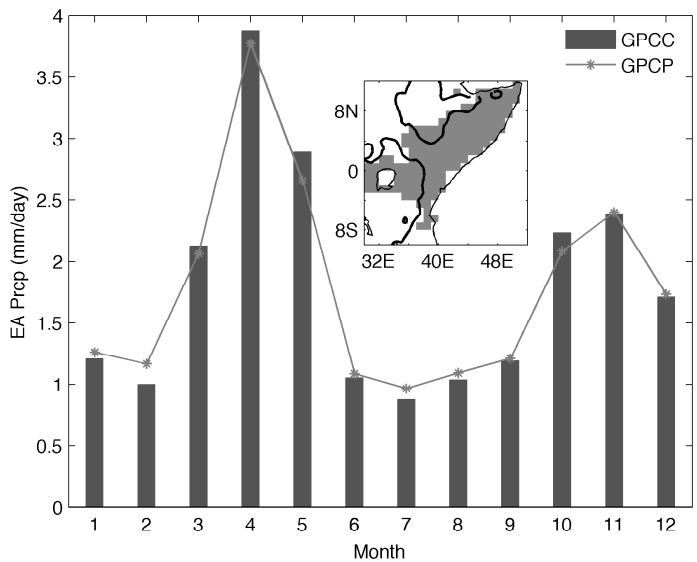
Bimodal annual cycle of precipitation

Map of log $|c2/c1|$:

- c_1 and c_2 are the first and second Fourier harmonics of local GPCC prcp. annual cycle.
- Positive values $\Rightarrow$ bimodal annual cycle dominates.

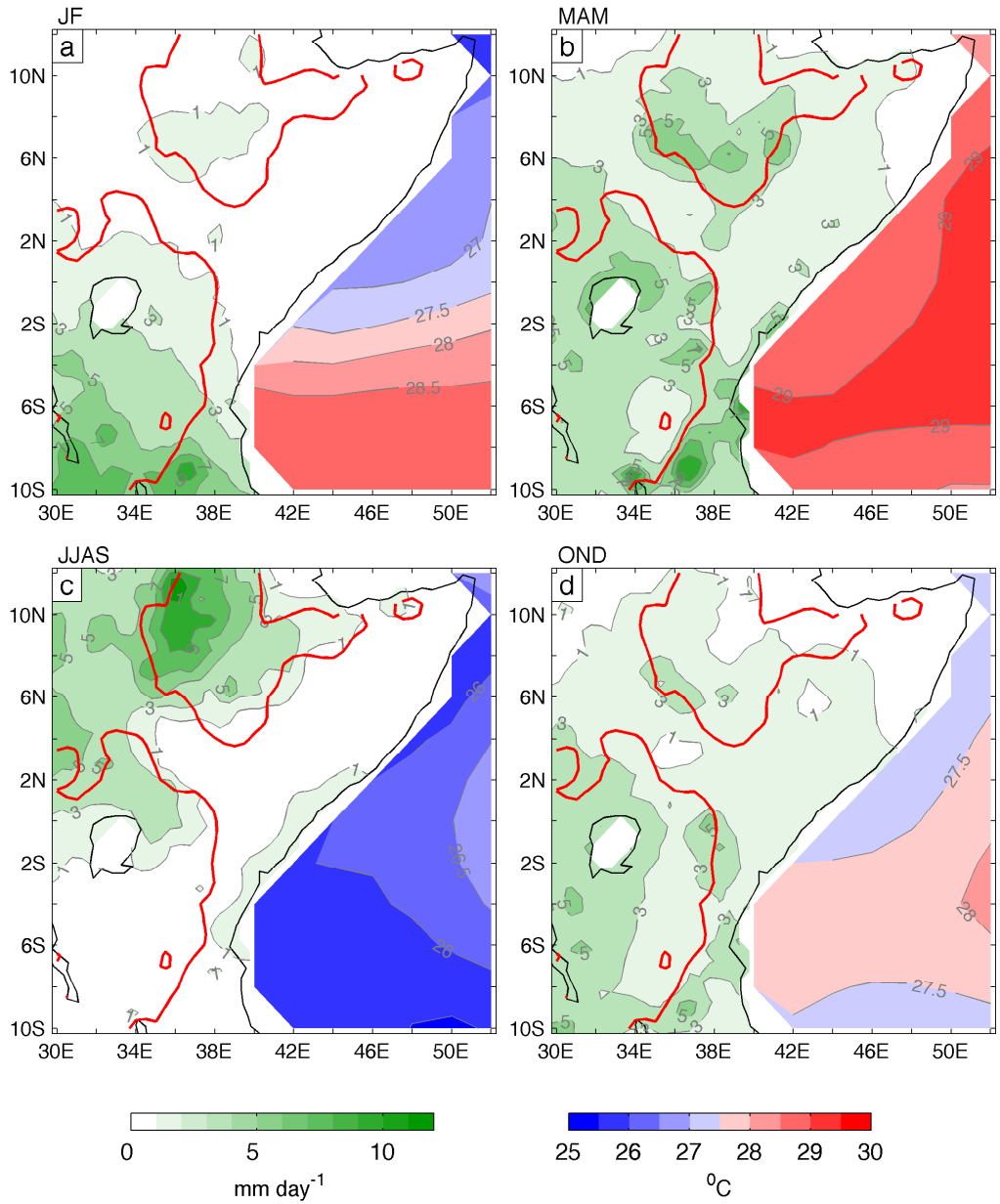


GPCC prop. annual cycle averaged over the shaded areas: where prcp(MAM)>prcp(JF) and prcp(MAM) > prcp(JJAS)



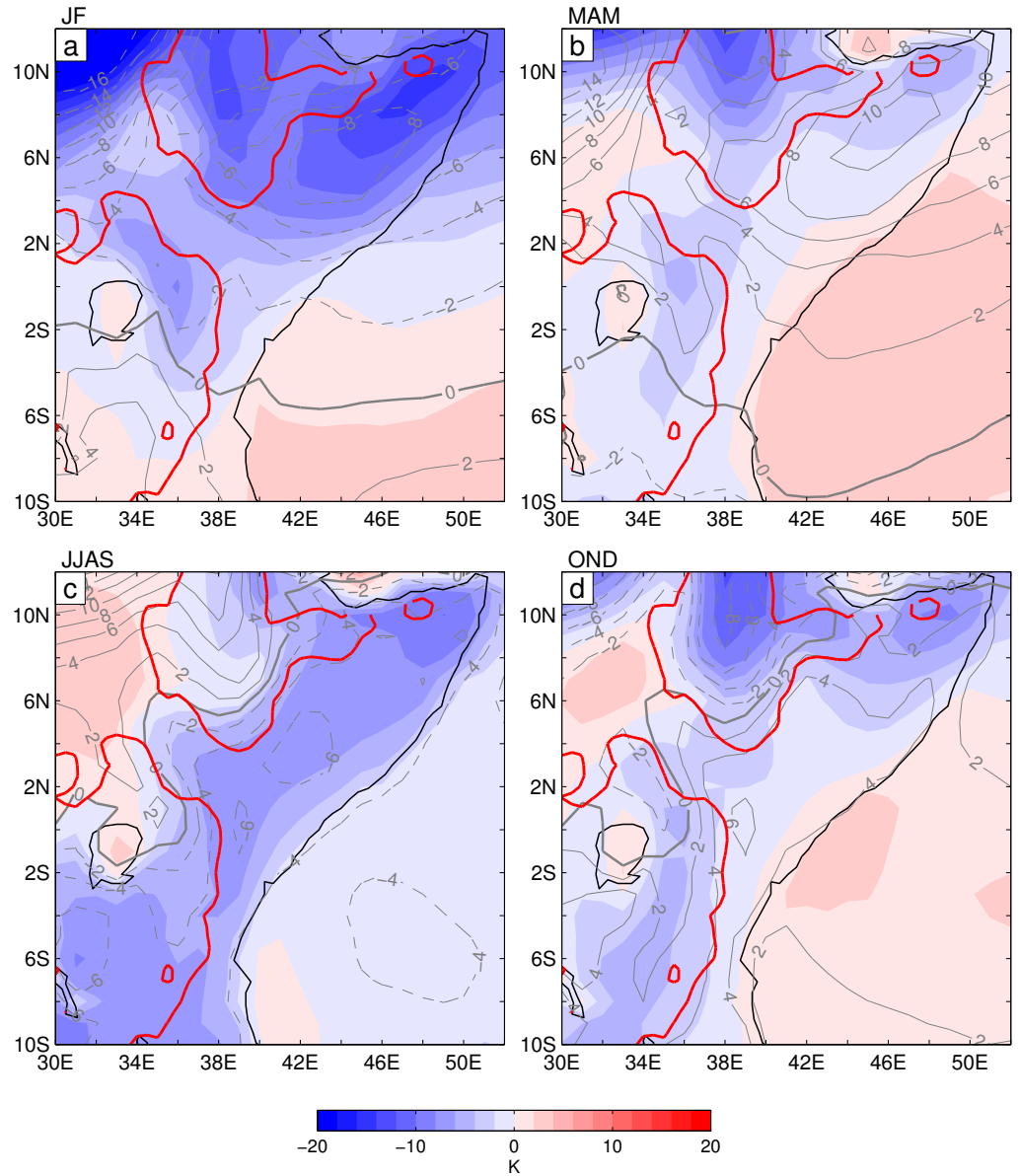
GPCC prcp. and off-coast SST

- Prcp. $>$ 1 mm/day in rainy seasons but $<$ 1 mm/day in dry seasons over much of the region to the east of the highlands.
- Off-coast SSTs are closely related to the seasonal variations of prcp. over the eastern land areas.



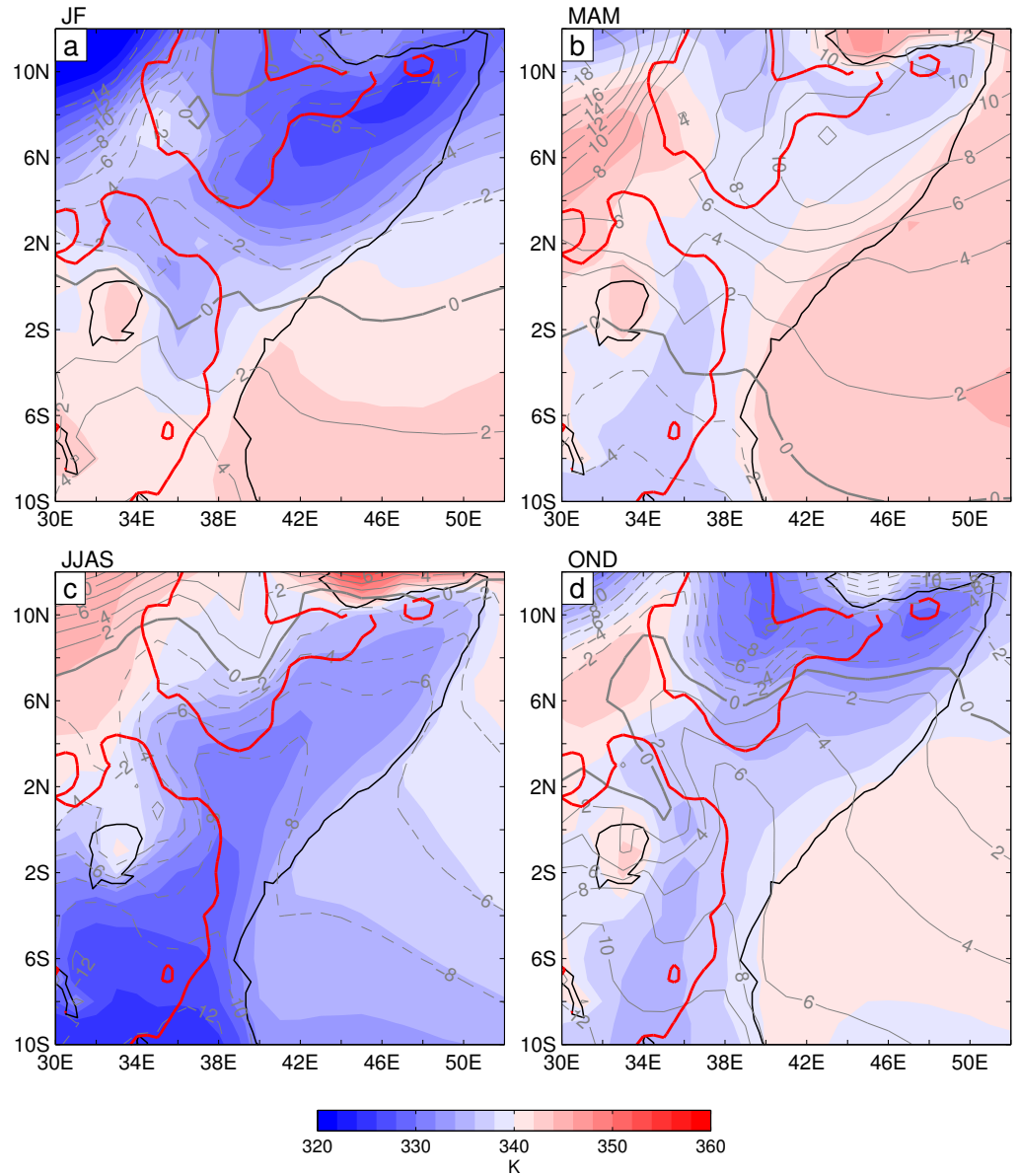
$h_s - h^*_{700hPa}$: convective instability

- EA atmosphere is generally stable across the year.
- Less stable in rainy seasons.



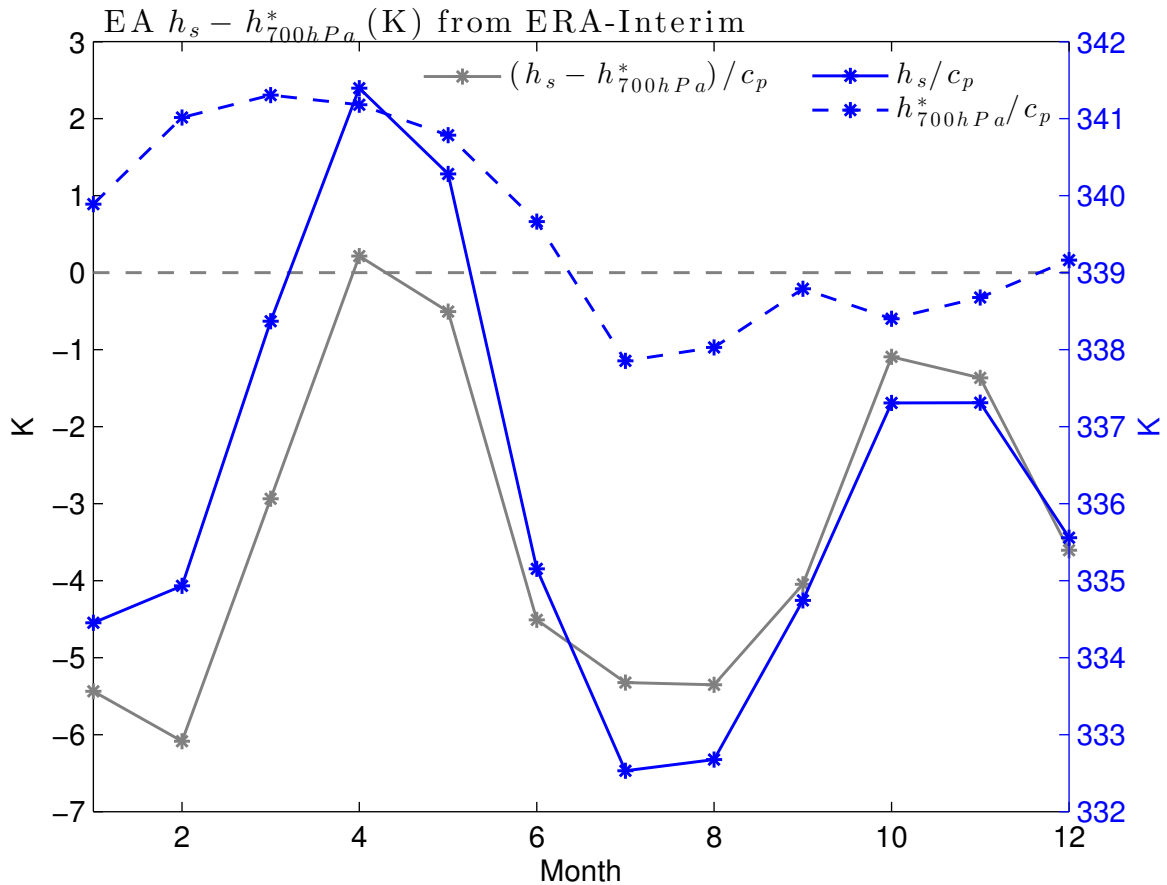
h_s: surface MSE

- $h_s - h^*_{700hPa}$ spatial and temporal variations are dominated by h_s.
- Higher h_s in rainy seasons.



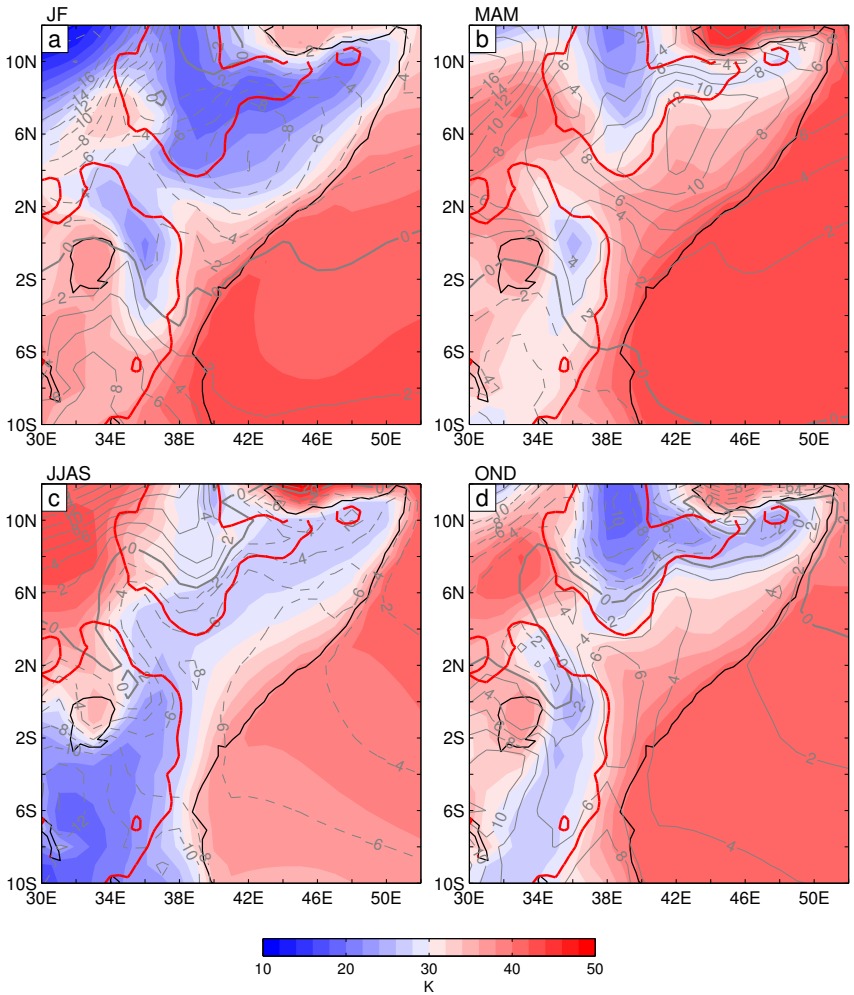
MSE seasonal cycle

- The amplitude of h_s seasonal cycle is around three times larger than that of h^*_{700hPa}.
- Both h_s and $h_s - h^*_{700hPa}$ follow the bimodal prcp. seasonal cycle.

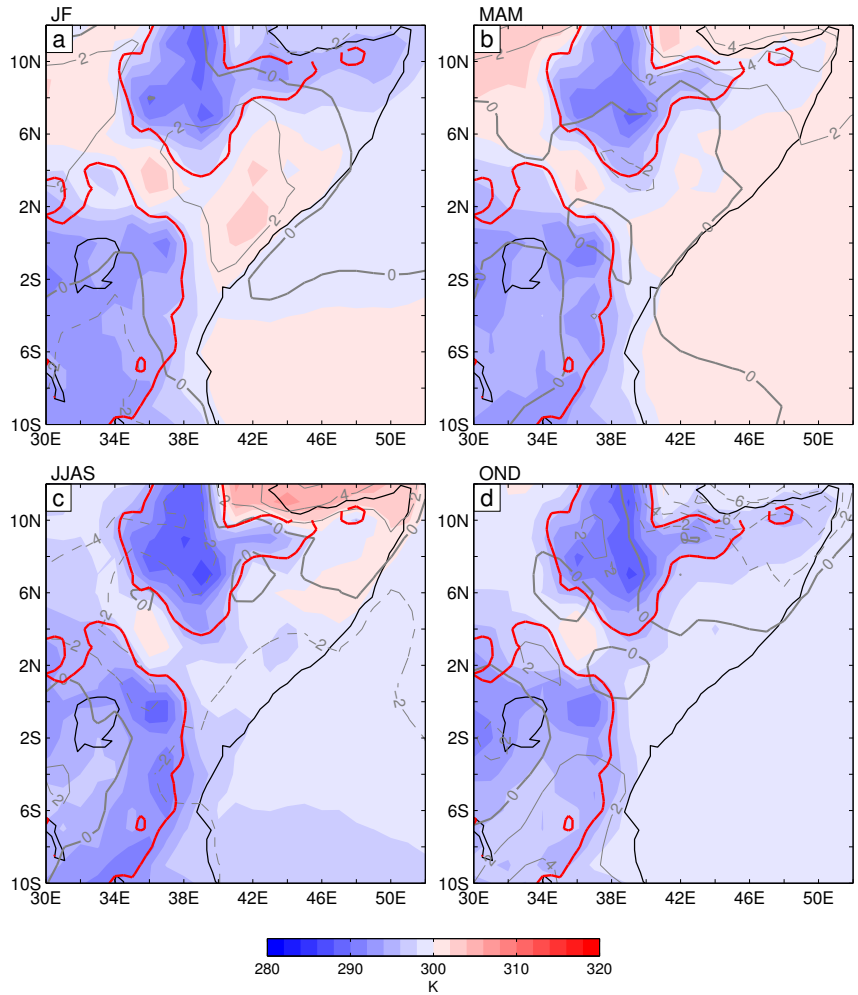


Surface MSE(h_s): moisture vs. temperature

Moisture component dominates the season-to-season change of h_s.



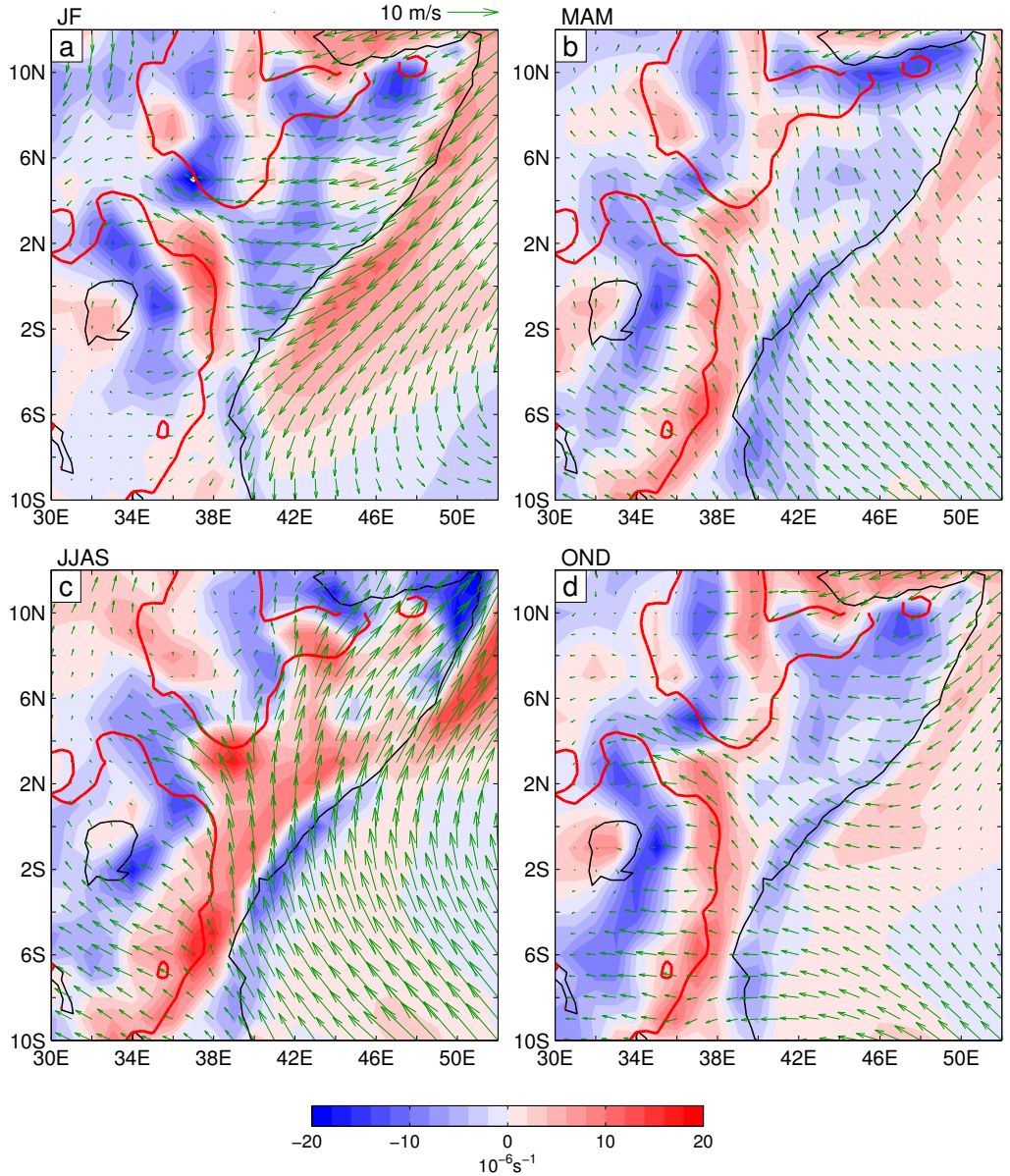
Moisture



Temperature

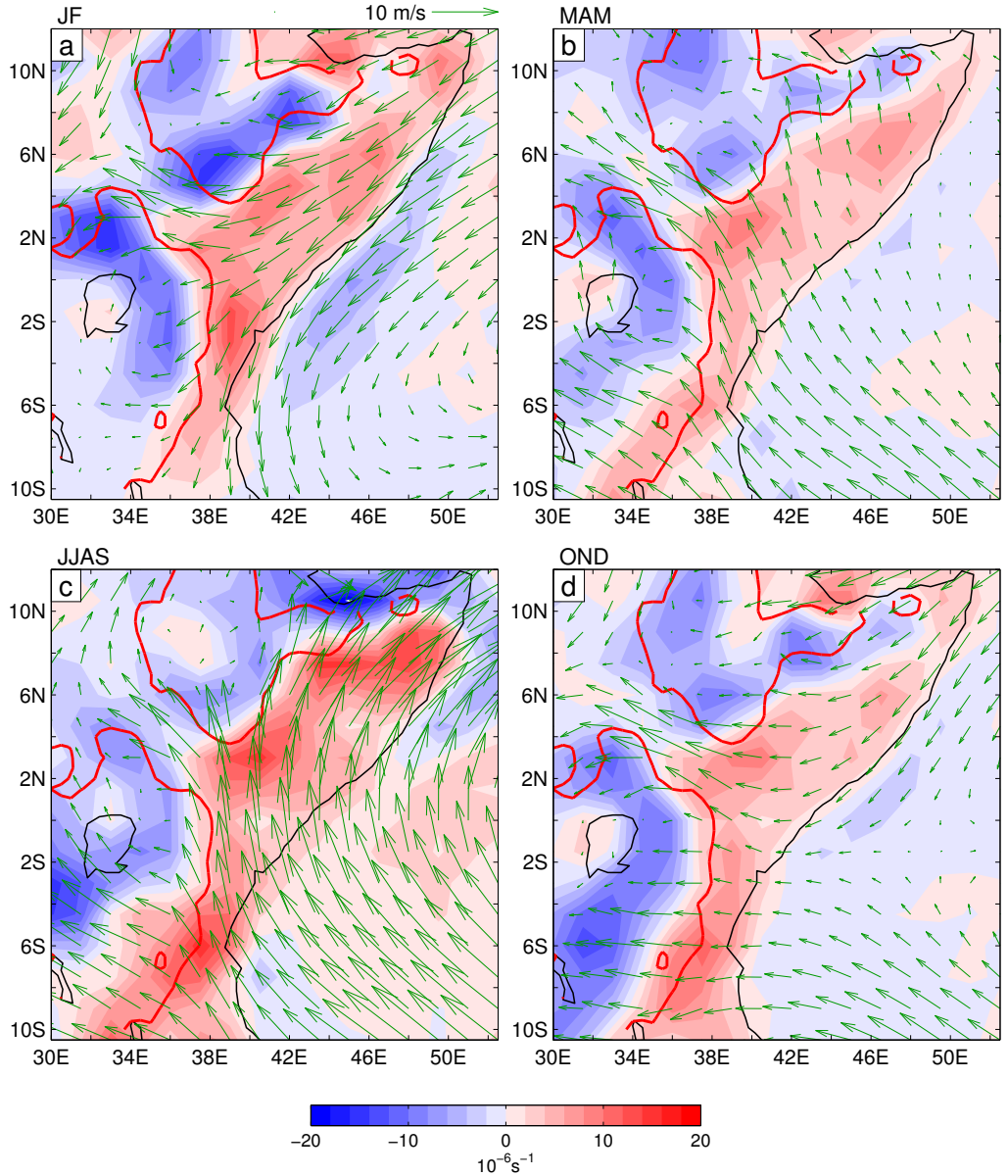
10m wind and divergence

- Wind speed is greater in dry seasons, when the Asian summer monsoon or winter monsoon is established.
- The surface flow is largely convergent to the east of the highlands except in JJAS.



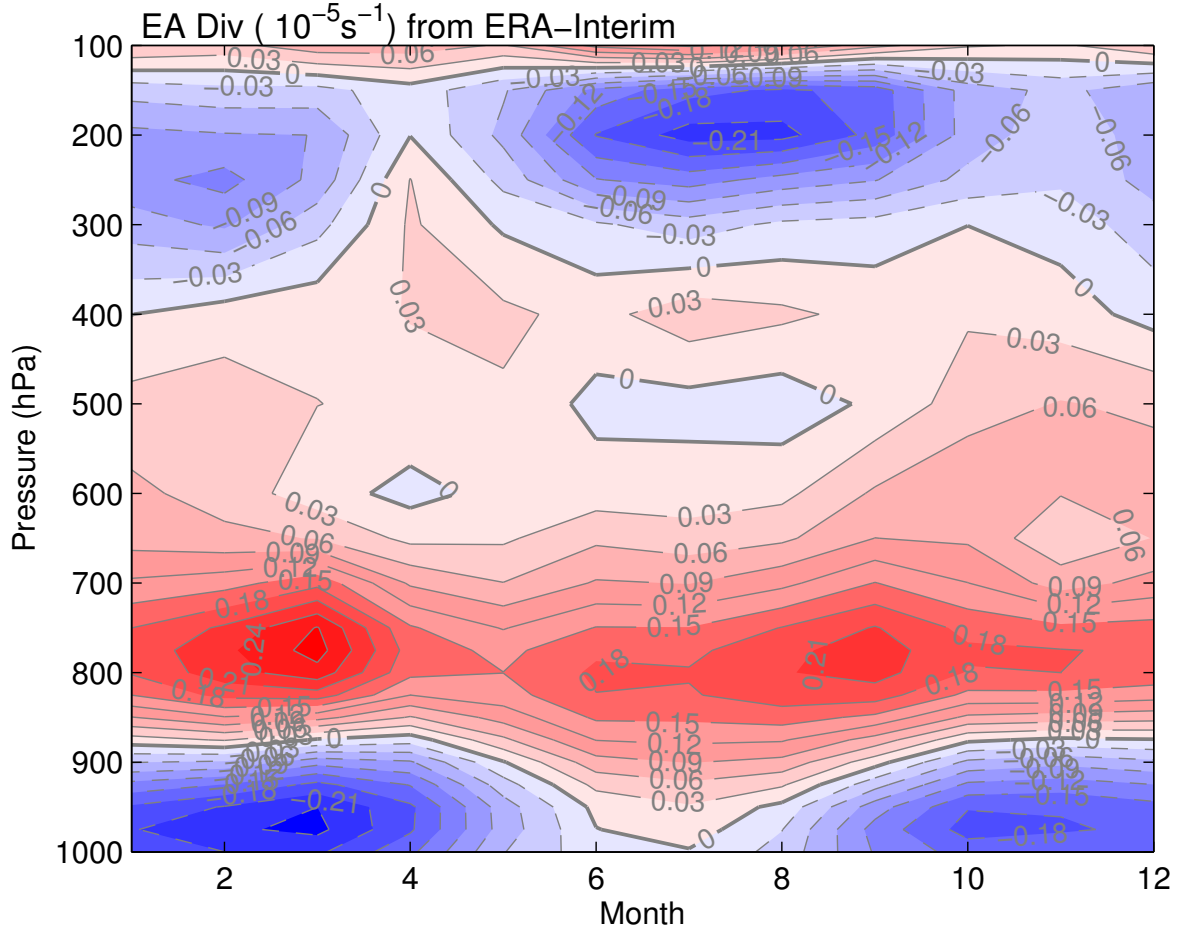
850hPa wind and divergence

- The circulation pattern is similar to that near the surface.
- However, the 850hPa flow is divergent year-round to the east of the highlands.
- The magnitude of divergence is greater in dry seasons.



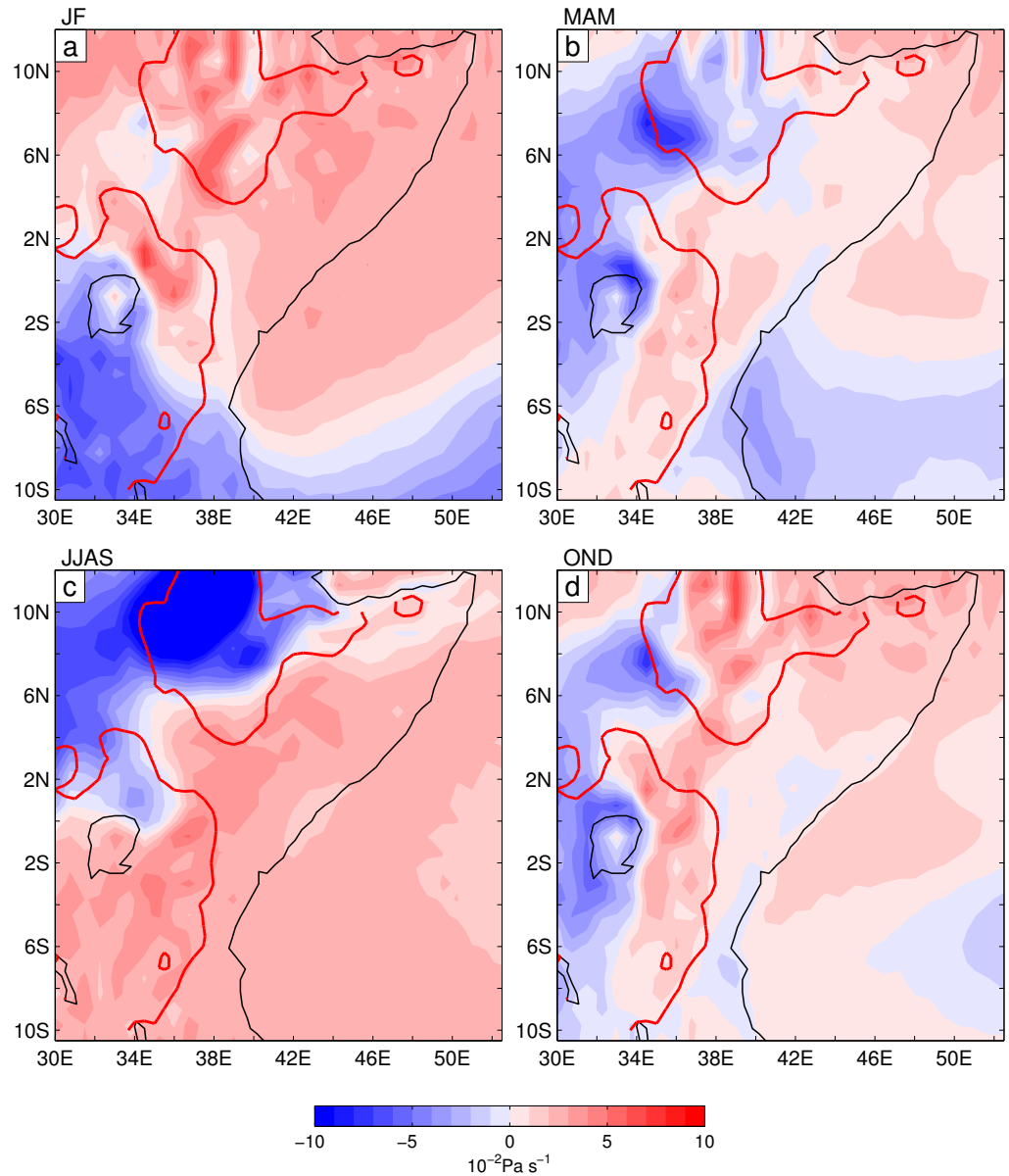
Divergence seasonal cycle

Convergent near surface, divergent in lower troposphere and divergent in upper troposphere.



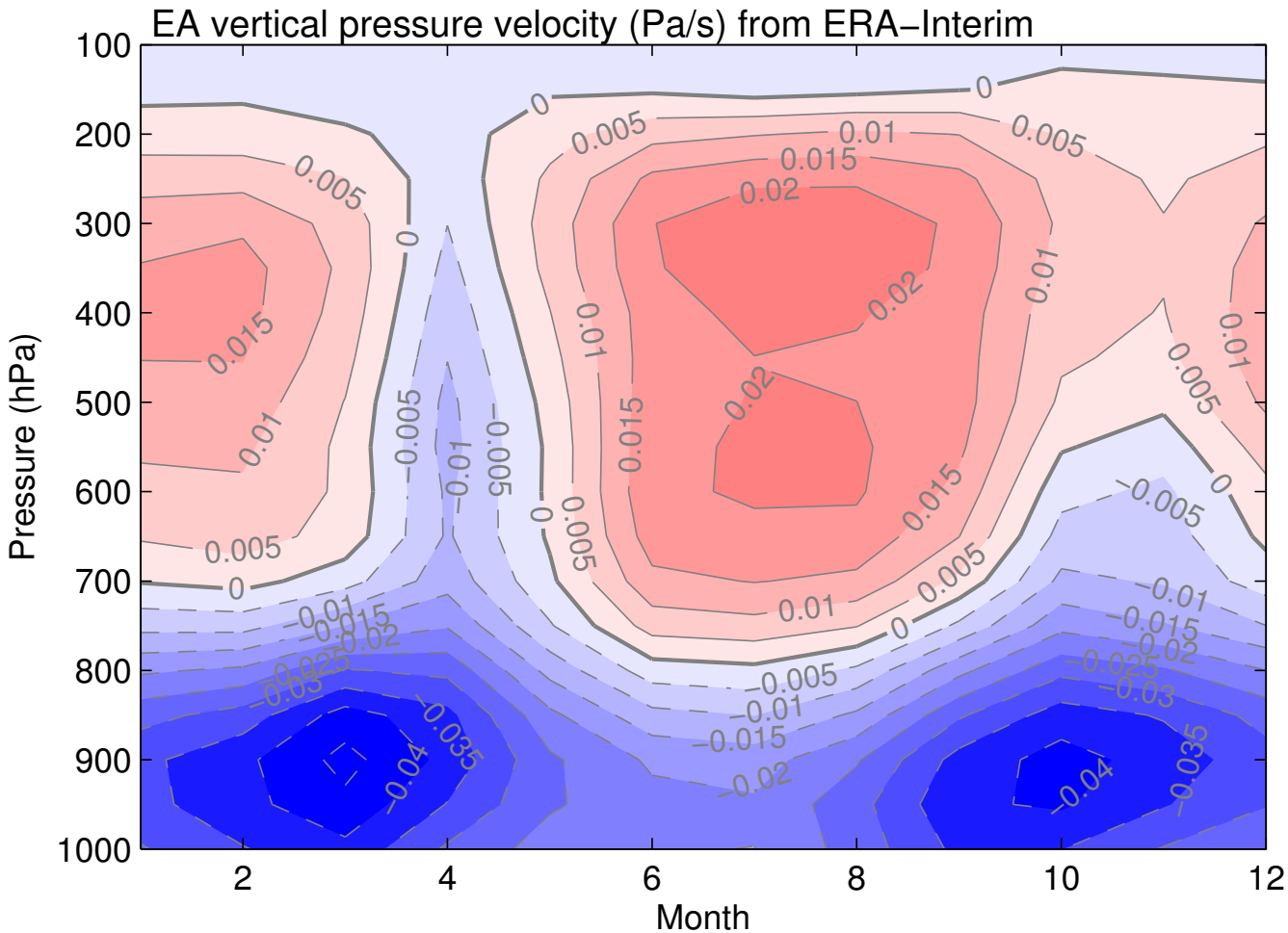
ω_{500hPa}: 500hPa vertical pressure velocity

- Consistent with the divergence field, downward motion dominates at 500hPa over EA.



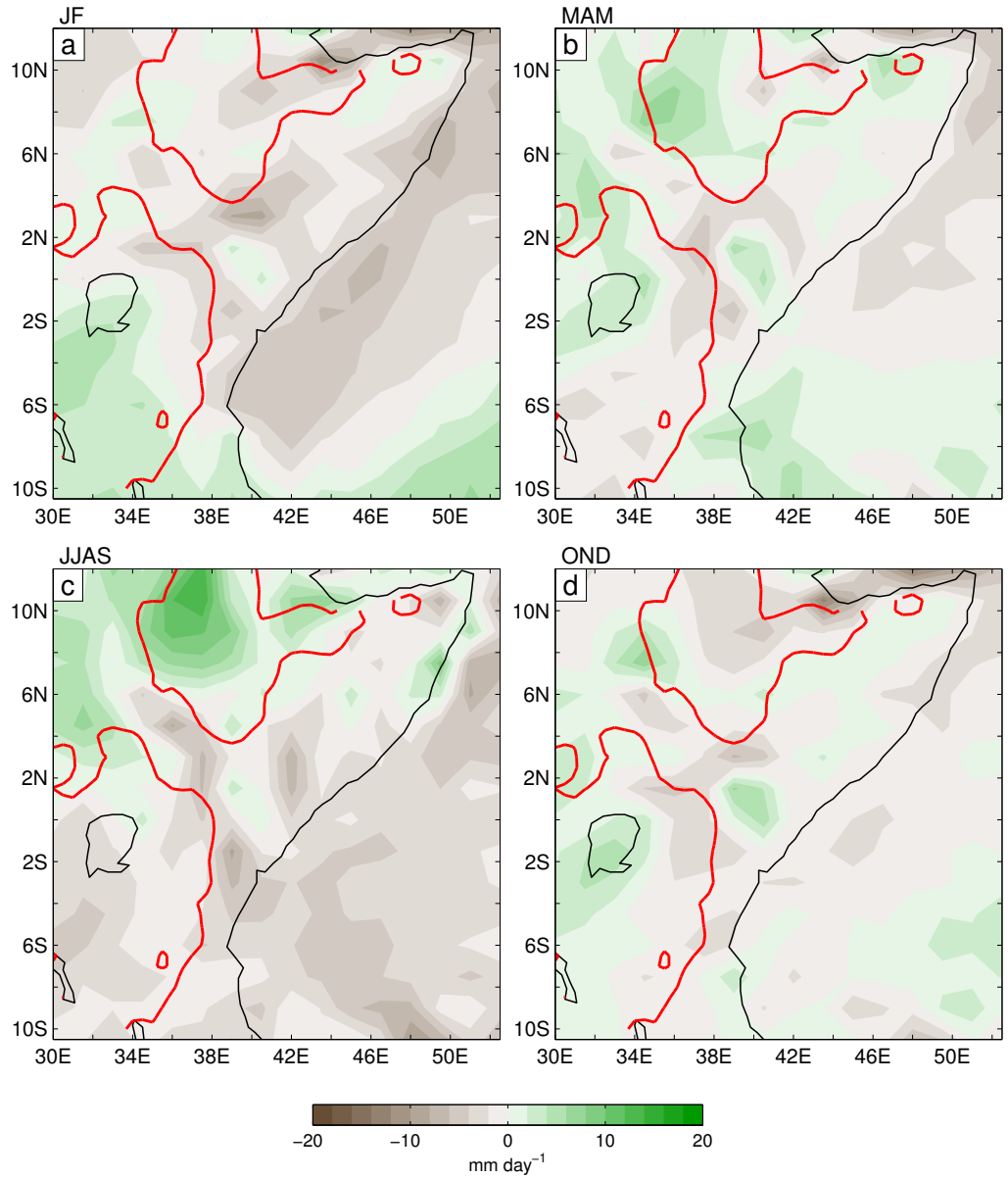
ω seasonal cycle

The lower troposphere is dominated by upward motion, but it is too shallow.



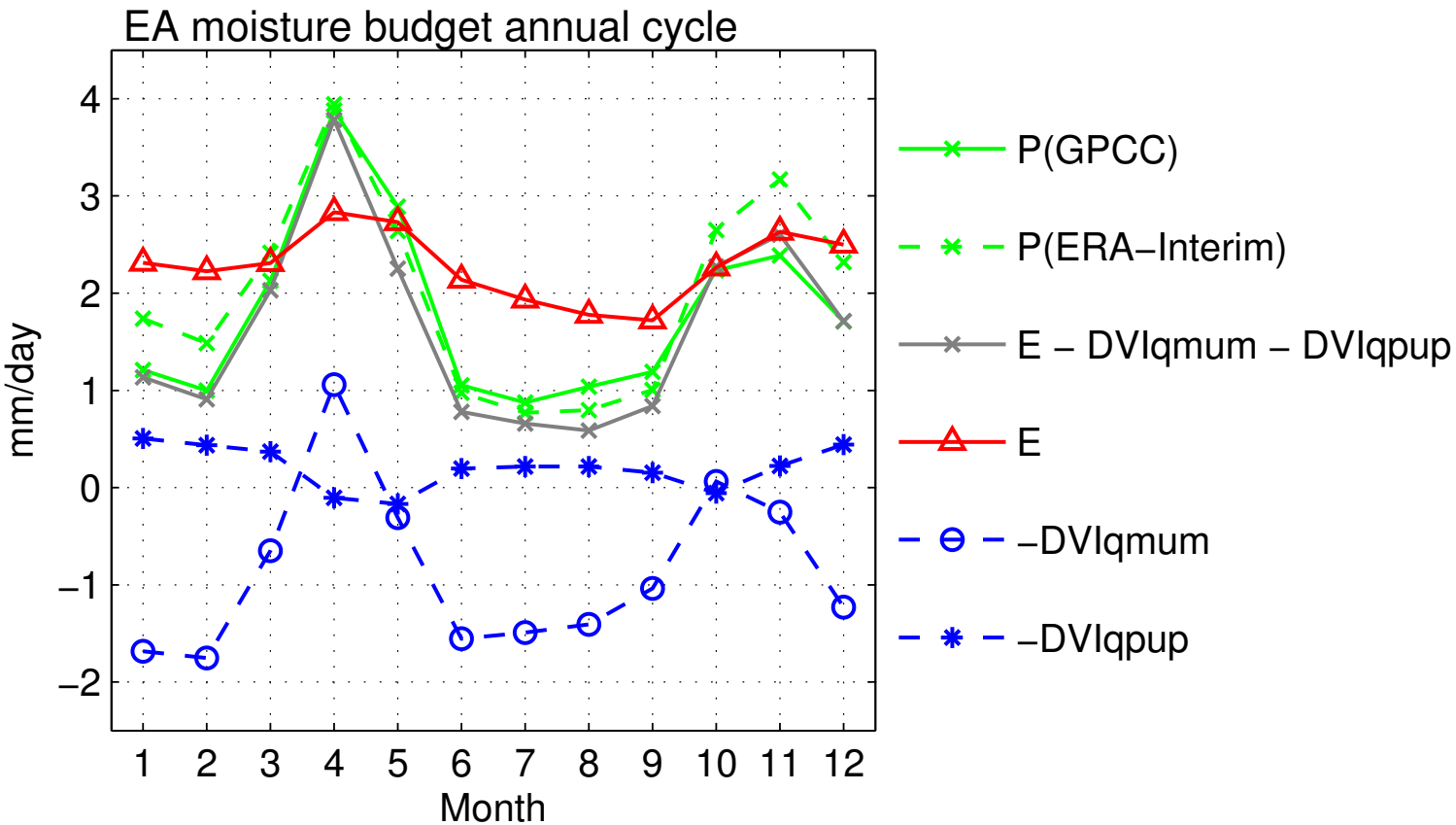
-DVIqmum: convergence of vertically integrated moisture flux

- Eddy component DVIqpup is much smaller than DVIqmum.
- Consistent with the divergence field, the moisture flux is generally divergent or slightly convergent in some areas during the rainy seasons.



Moisture budget seasonal cycle

- Area-averaged -DVIqmum follows the precipitation annual cycle.
- E - DVIqmum - DVIqpup approximates prcp. very well.



Outline

Conclusion

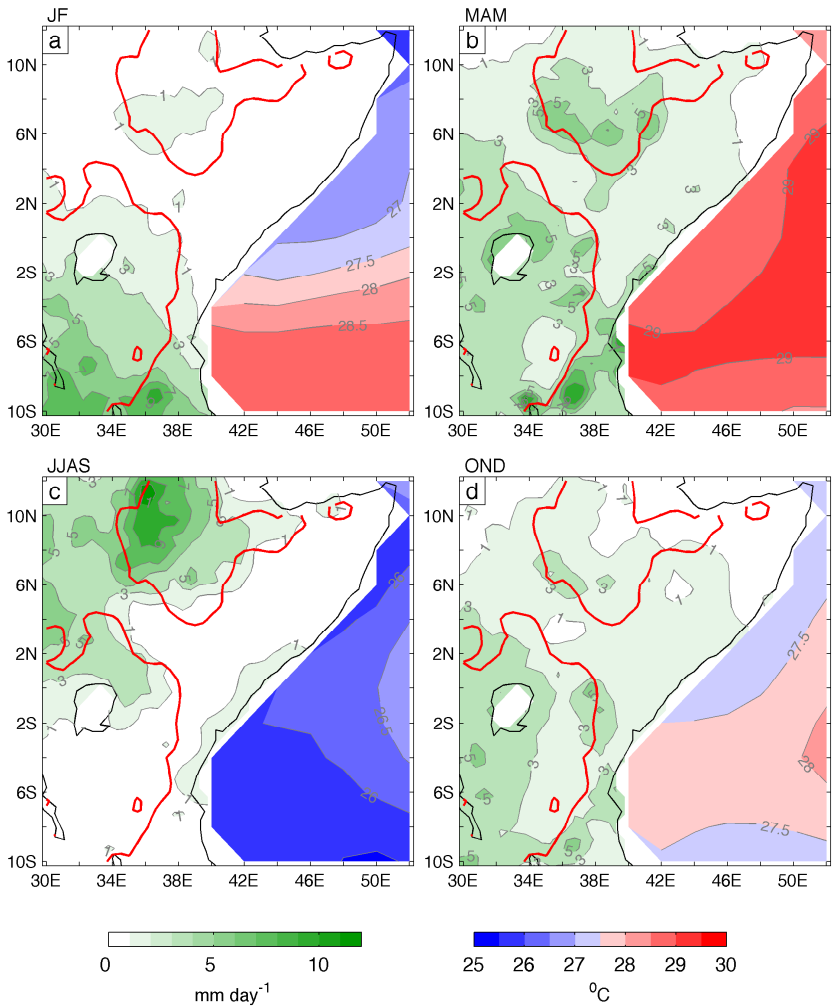
- The off-coast SSTs annual cycle is closely related to that for East African precipitation.
- The atmosphere is generally conditionally stable throughout the year but the instability follows the precipitation annual cycle.
- The annual cycle of the atmospheric stability is dominated by surface MSE.
- Although convergence prevails near the surface, divergence in the lower troposphere and convergence in the upper troposphere dominate year-round.

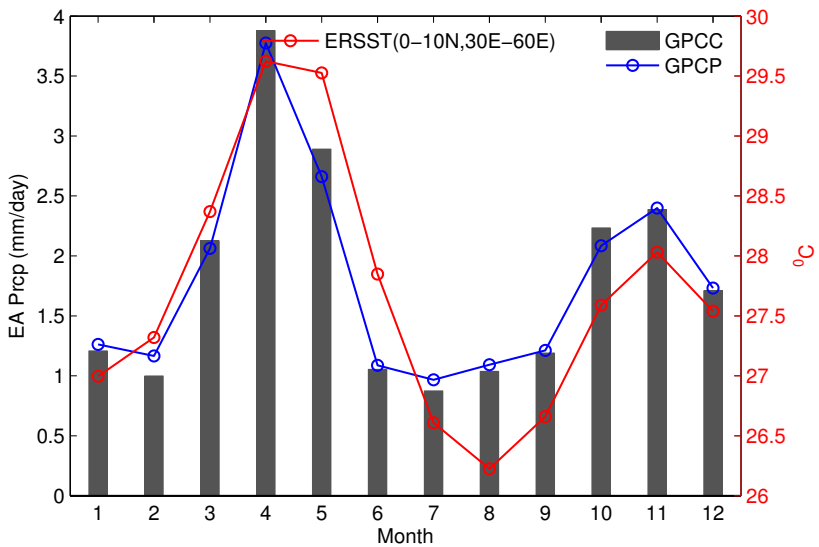
Conclusion (*cont.*)

- Consistent with the divergence field, the vertical velocity is predominantly downward in the middle troposphere and the magnitude is stronger in dry seasons than in rainy seasons.
- The vertically integrated moisture flux is dominated by the mean flow and the eddy component is generally weak but opposing. The mean flow moisture convergence follows the EA precipitation annual cycle and, when combined with the transient eddy convergence and evaporation (E), approximates the observed EA precipitation annual cycle very well.

Proposed explanation of EA precipitation annual cycle

Off-coast SSTs and the air above imported into EA control the EA surface MSE and thus the precipitation annual cycle.






Gulf of Aden
Djibouti
Ethiopian Highlands
Ethiopia
South Sudan
Somalia
Thank You!
East Africa
Lake Albert
Uganda
Eastern
Western Central
Kenya
Lake Victoria
Rwanda
Republic of the Congo
Burundi
Tanzania
Seychelles
Lake Tanganyika
Lake Rukwa
Lake Mwe
628 mi
Image Landsat
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
Imagery Date: 4/9/2013 1°52'30.36" N 40°39'30.70" E elev 1060 ft eye alt 2018.87 mi