How coherent is rainfall in northern tropical Africa in time and space – and why?

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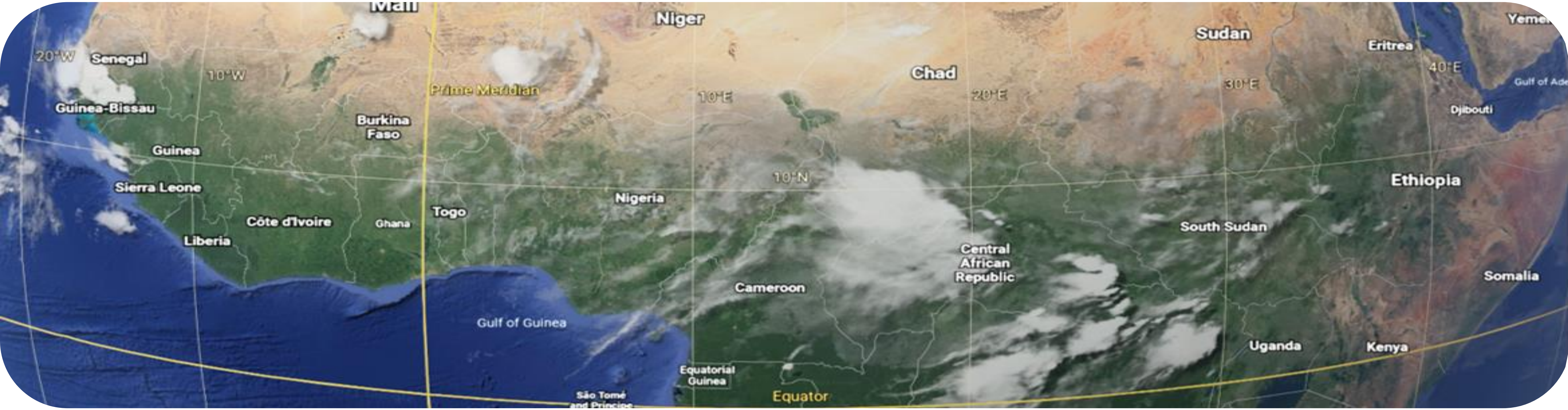

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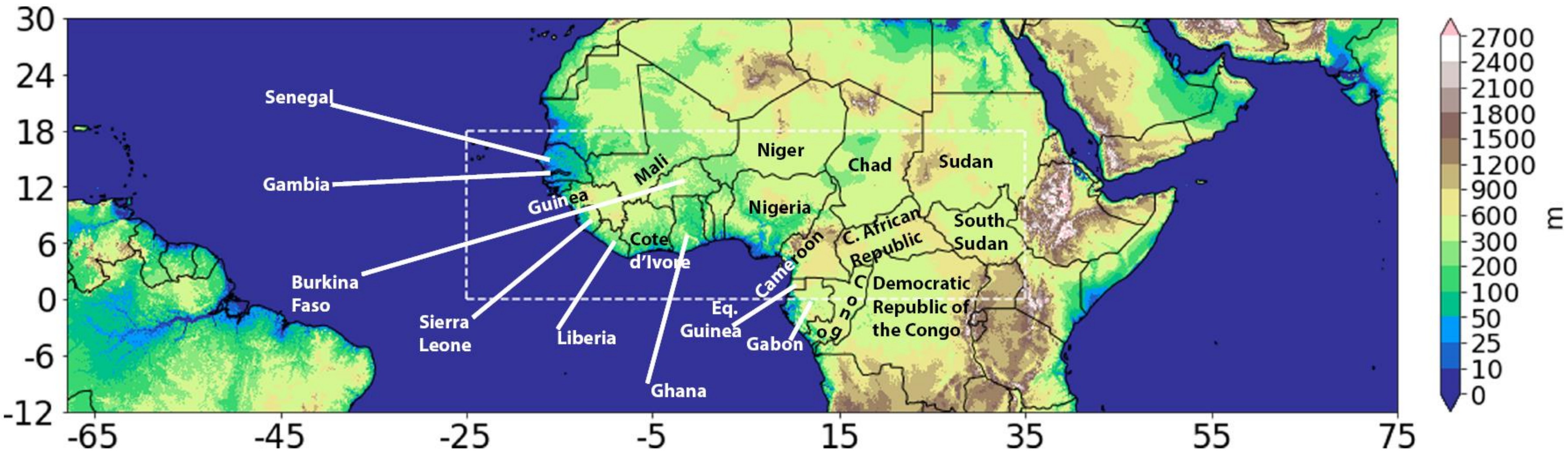
Orography of northern Africa



The dotted box in white shows the main region of analysis

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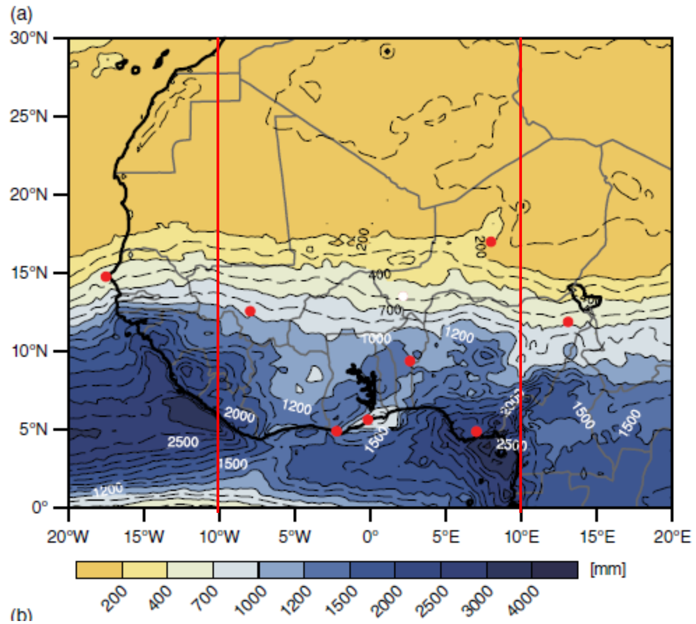
Quick introduction to north African Rainfall

Important features to note:

- Strong decrease in rainfall from Sahara to Sahel.

- Wet regions over the Guinea coast and the coastal regions near Cameroon.
  Mainly due to the lifting of moist monsoonal southwesterlies due to coastal orography.

- Relatively drier zone in between from Coast of Ghana to the north-western Nigeria.
  Caused by a combination of coastal upwelling of cold waters and frictional divergence along the SW-NE coastlines.



Mean annual precipitation
Source: **Meteorology of Tropical West Africa The Forecasters' Handbook, Fink et al. 2017**

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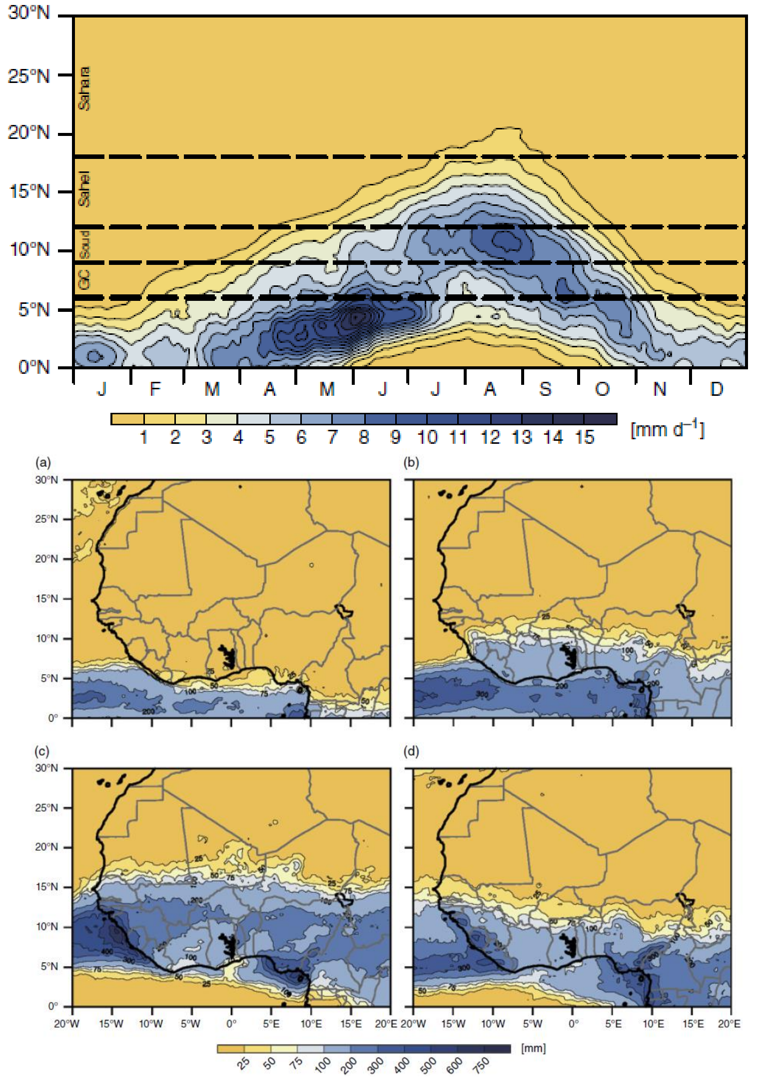
Quick introduction to north African Rainfall

Seasonality of rainfall:

- Sahara: Typically dry throughout the year.
- Sahel: Wet period from May- Sept of which highest rainfall occurs from Jul-Sept caused by WAM. This period is dominated by MCSs and organised convective systems coupled to synoptic features. Largely dry during winter (Dec-Feb).
- Gulf of Guinea: Wet period from Apr-June due to onset of WAM, dry season from Jul-Oct and lighter wet period from Oct- Nov. Hence the stations here show a bimodal distribution of annual rainfall.
- Tropical-extratropical interactions play important roles in causing major rainfall events (~2 per year) between 7.5°N- 15°N in the winter.
- Over the ocean: Wet period around Mar-May but relatively dry between Jun-Oct. Light wet period in the winter.



15-day running mean of daily precipitation (top), mean monthly rainfall Jan, Apr, Jul and Oct (middle and bottom)
Source: **Meteorology of Tropical West Africa The Forecasters' Handbook, Fink et al. 2017**

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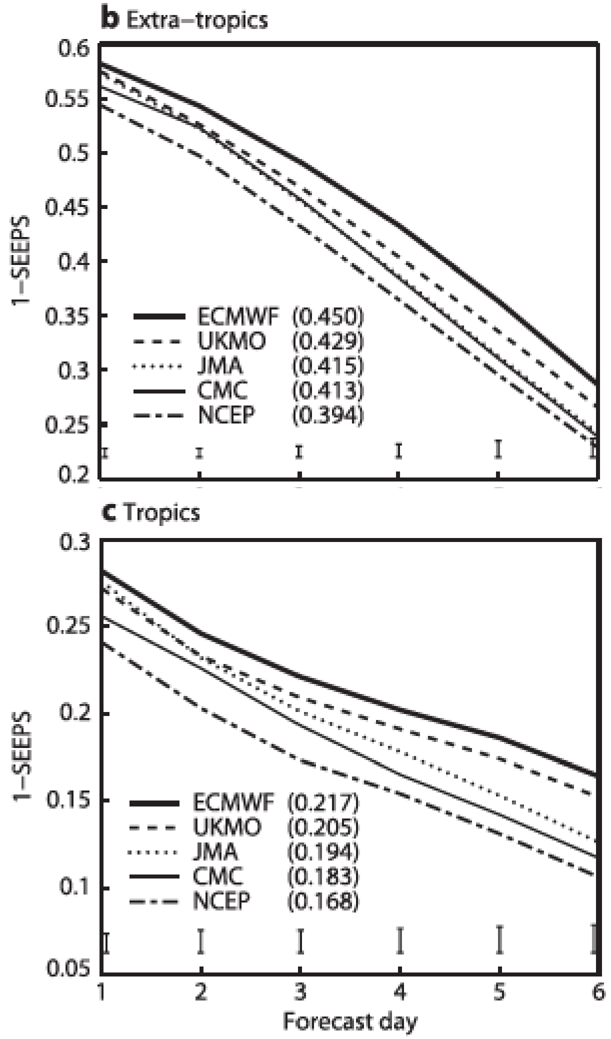
Why Africa?

- Rainfed agriculture is a main source of food and income in tropical Africa.

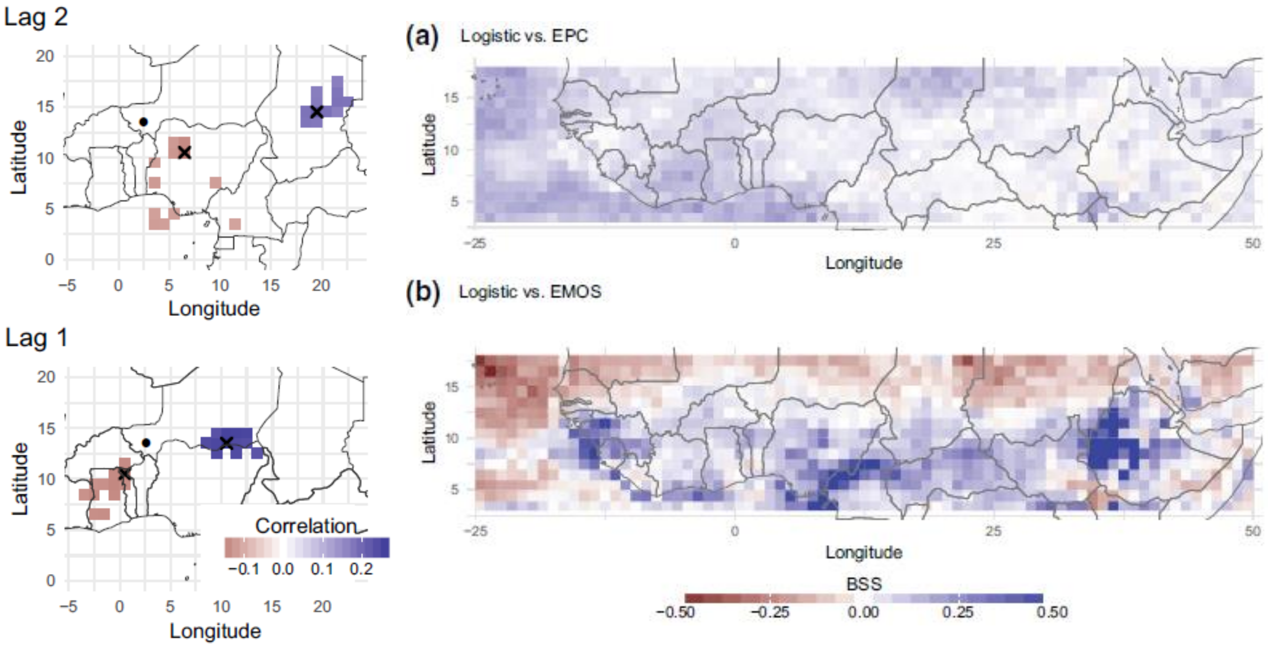
- While economies in the mid-latitudes have greatly benefited from the ‘quiet revolution’ numerical weather forecasting, the same is not true for the tropics due to the intrinsic uncertainties in the meso- and synoptic scales.
- For e.g., tropical rainfall forecast with a 1-day lead time is as skillful as a forecast in the extratropics for 6-day lead time (Haiden et al., 2020).



1-SEEPS for 5 models in the extratropics and tropics
Source: **Haiden et al., 2012**

Motivation

- Vogel et al. (2021) showed that a logistic regression model based on time lagged correlations of rainfall field outperforms all other forecasts.



Correlation field between time lagged daily accumulated TRMM precipitation fields (left), BSS of Logistic regression model vs. EPC (right top) and Logistic vs. EMOS (right bottom)
Source: **Vogel et al. 2021**

- This analysis was done over N. Tropical Africa in the summer when AEWs strongly modulate wind and precipitation fields at the synoptic time scale.
- Global ensemble prediction systems have low skill in the tropics and no skill over northern tropical Africa
- Statistical postprocessing can correct for biases and dispersion errors, but cannot outperform climatology- based forecasts over Africa.

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Methodology

Perform Spearman's rank correlation of daily accumulated (06-06UTC) precipitation fields lagged by -1, -2 and -3 days.

→

Identify points of max correlation and their distance and direction from the target gridpoints.

→

Compute coherence between the lagged correlation fields.

Seasons

- Monsoon (JAS)
- Boreal winter (DJF)
- Pre-monsoon (MJ)
- Transition seasons (MA and ON))

Modifications relative to Vogel et al. (2021)

- GPM-IMERG (2001-2019) instead of TRMM.
- Extend the correlation analysis to up to -3 days lag.
- Increase the area of analysis (0°-20°N, 68°W-50°E).
- Analyse all seasons.

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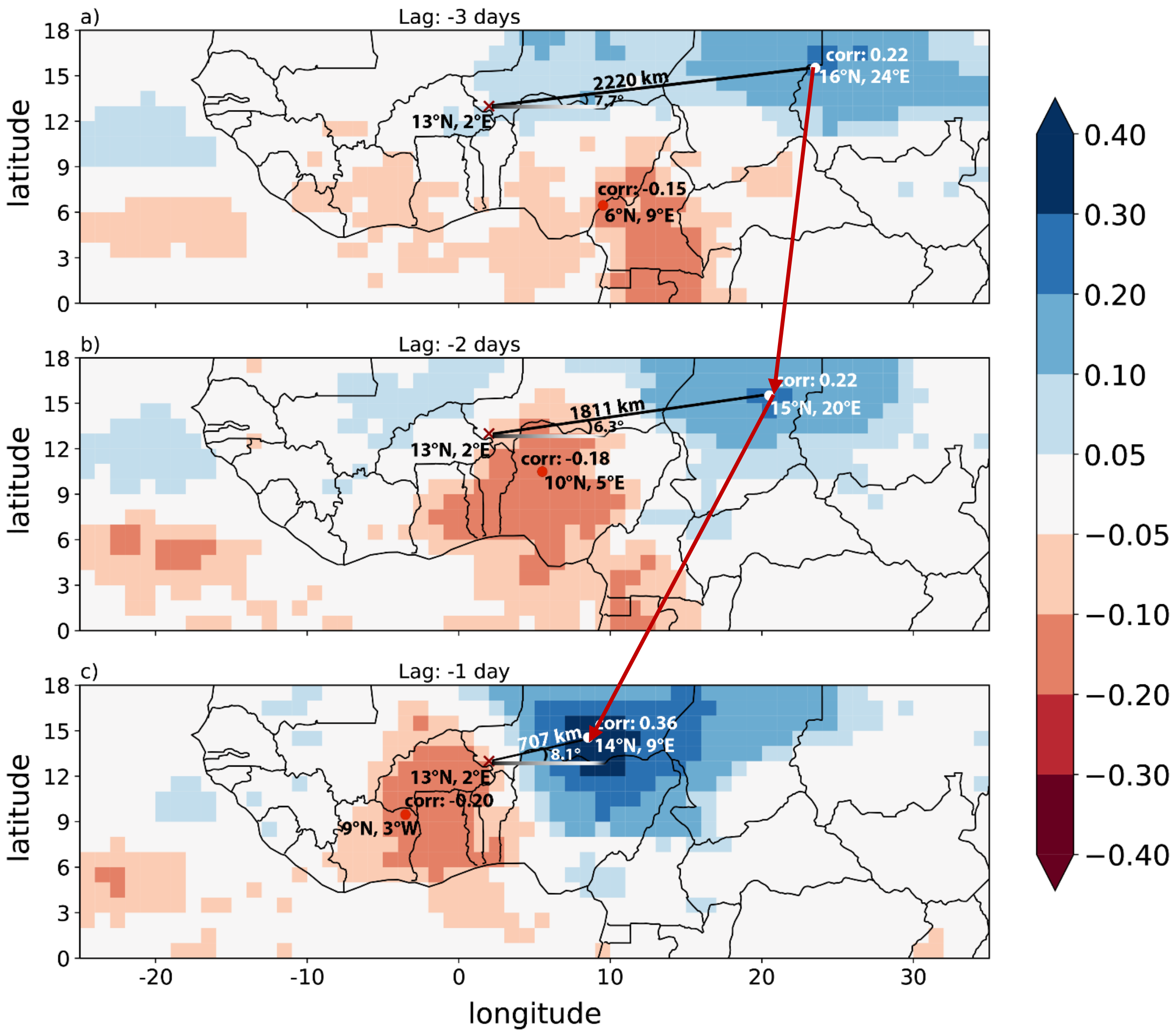
Lag- Correlation

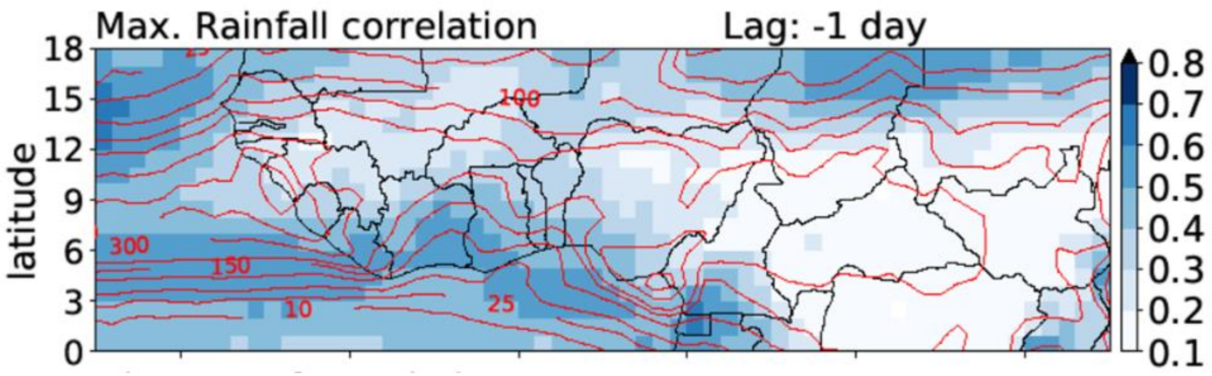
- E.g., Correlation field of daily accumulated IMERG rainfall at grid point near Niamey (13°N, 2°E) during July-Sept.
- Propagation of positively correlated field at ~8.5 m/s (About the speed of African easterly waves).
- Positive correlation extends even up to 3 days.



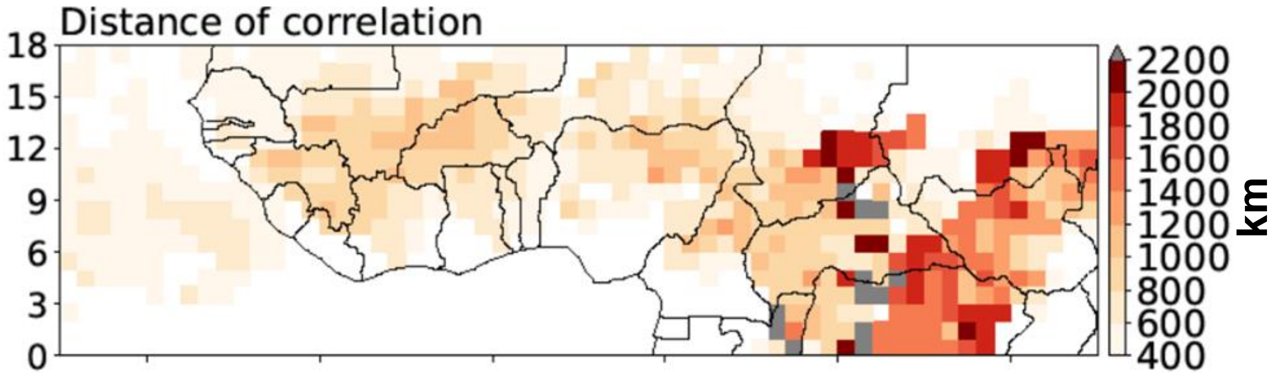
Rainfall correlation fields wrt. to Niamey (13°N. 2°E) modulated by AEWs, in Summer season (July- September)

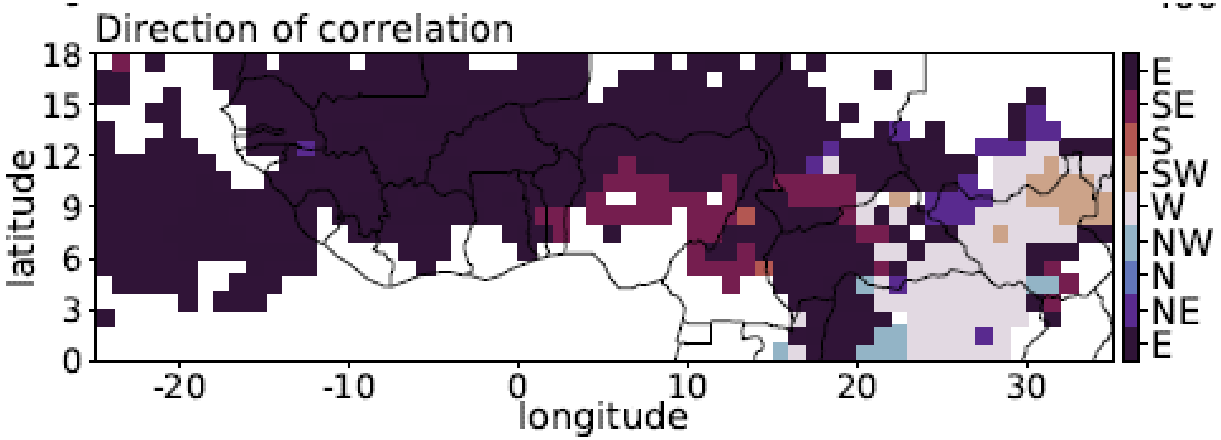
Max. Correlation, Distance and Direction

Max. correlation computed per grid point



Distance between target and the grid point of max correlation





Direction between target and the grid point of max correlation

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July- September (JAS)

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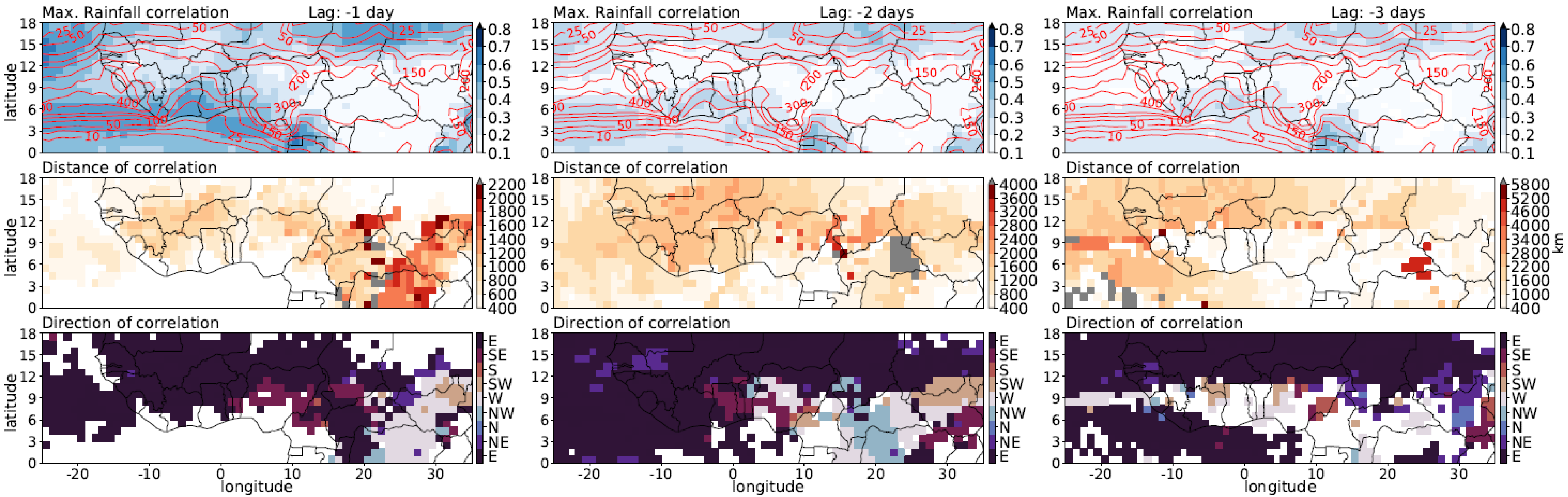
Max. Correlation, Distance and Direction (JAS)



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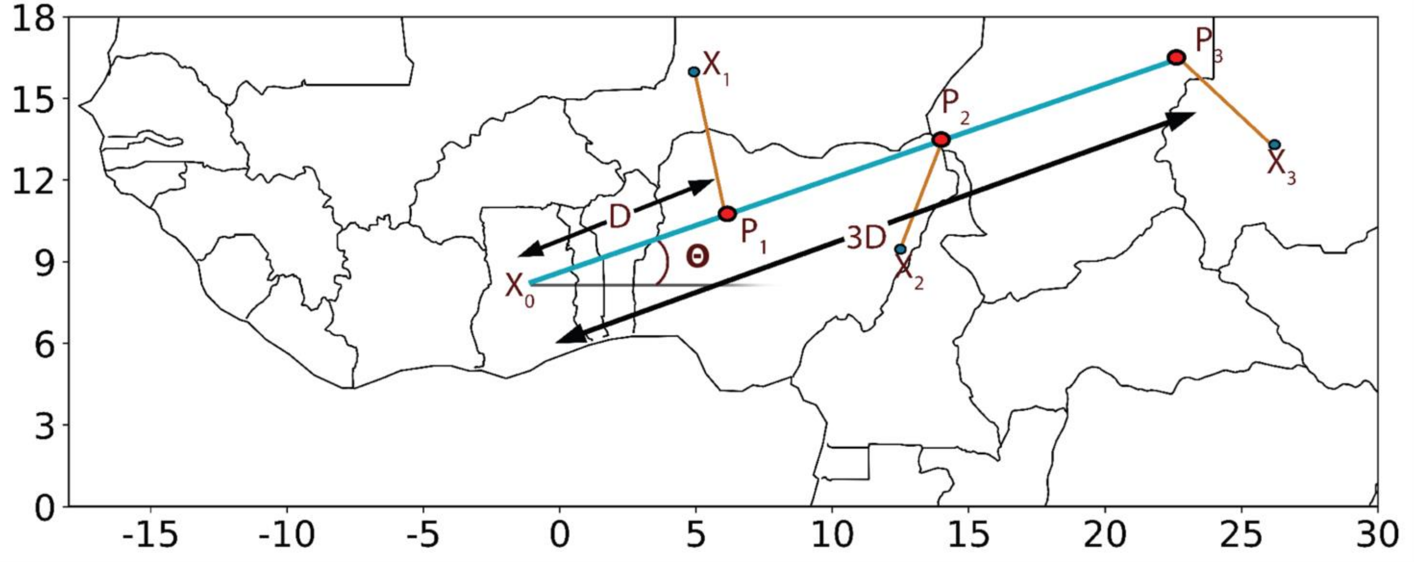
Coherence Factor

- Assumption: ideal propagation is linear and has a constant phase speed.

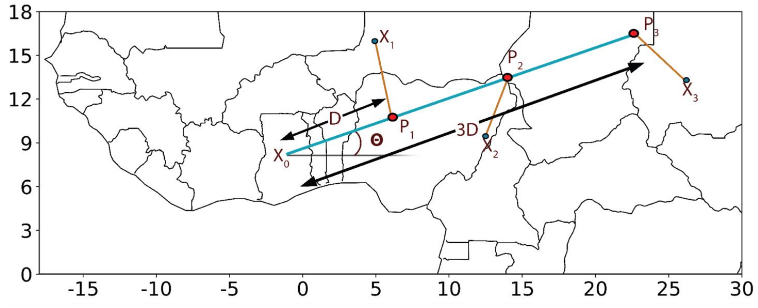
- Coherence factor = $\frac{3D}{3D+E}$

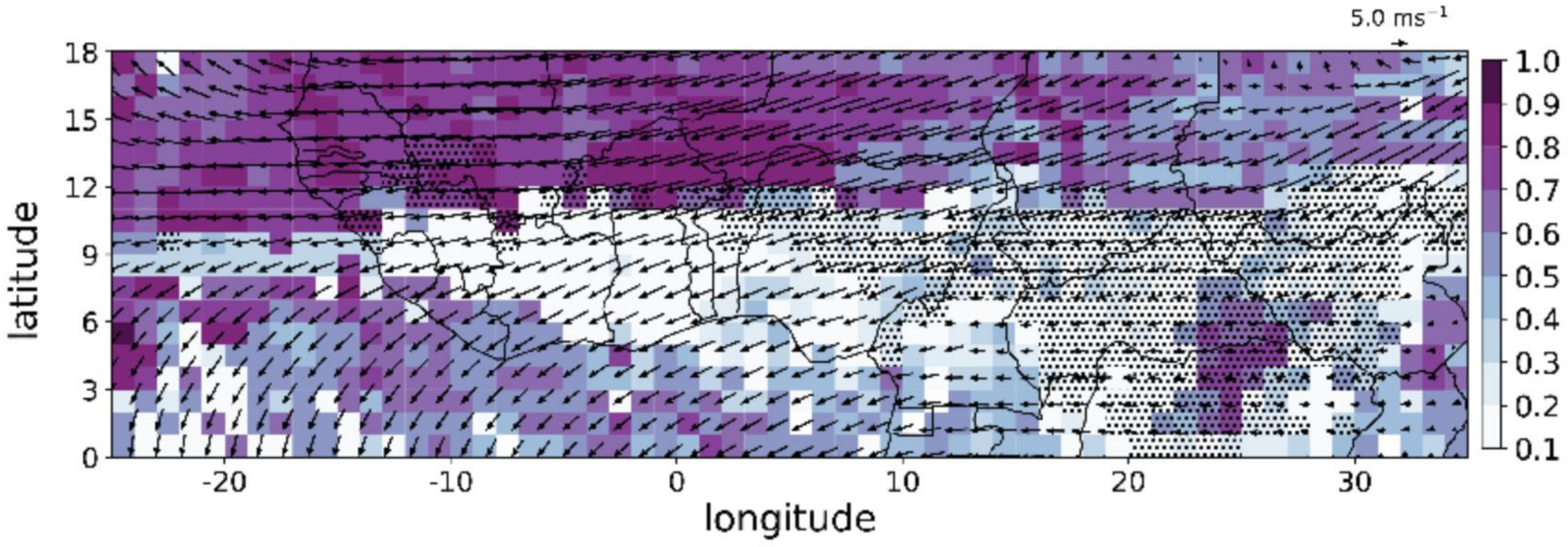


X_i: observed gridpoint
P_i: ideal gridpoint

$E = \sum_{i=1}^{3} X_i P_i$

Coherence Factor





Shading: coherence factor
Vectors: vertical shear (600 hPa – 925 hPa)
Stifled grids: correlation< 0.15

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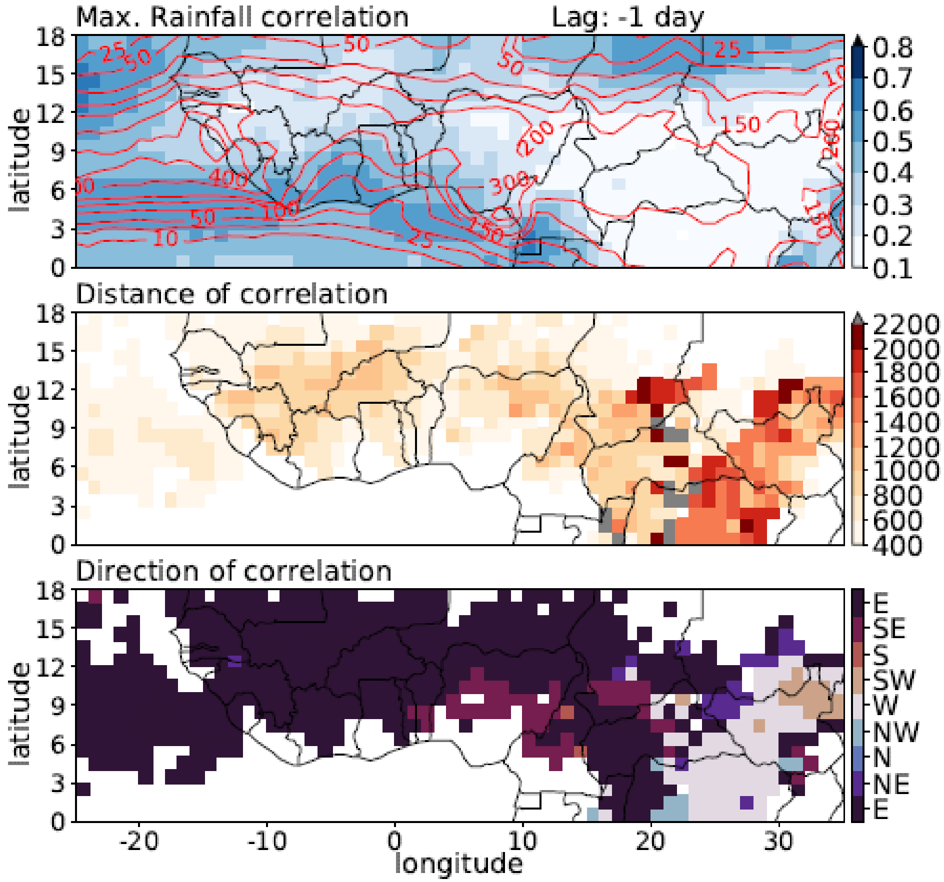
Possible explanations (JAS)

- 3 major zones can be identified:
  - High correlations in the North, and along the Guinea Coast
  - Low correlations over the rainbelt.
  - Moderate correlations over the ocean near the equator.

- High correlations coincide with high gradient in rainfall (fringes of the rainbelt) and conversely, low correlations coincide with low gradient in rainfall.
- Rainbelt is characterized by optimal conditions for rainfall which causes high stochasticity while, the fringes are more sensitive to coherent synoptic-scale features that trigger and sustain rainfall by modifying dynamical/ thermodynamical conditions.



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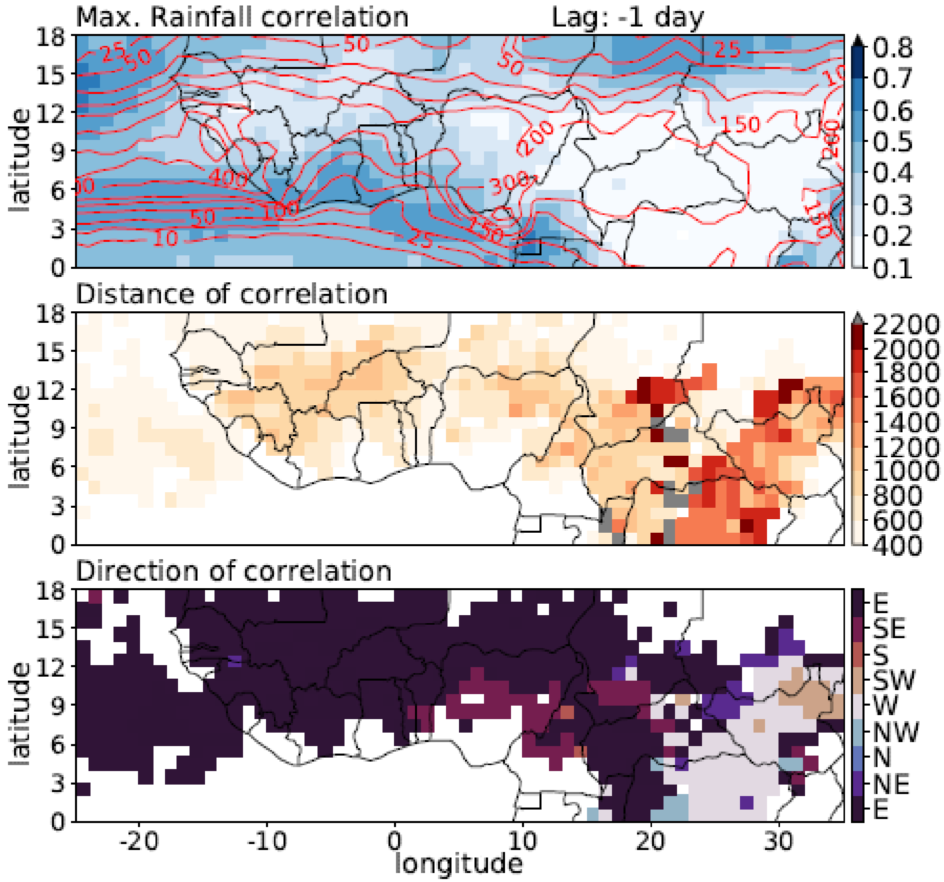
Possible explanations (JAS)

- Over the equatorial Atlantic correlations are almost constant at ~0.4.
- This may be due to the large number of dry timesteps (i.e., no rainfall).
- Low distances also indicate that the correlations occur with neighbouring grid points → very slow propagation if any.

- Largest distances (over 2000 km)are observed over central Africa (over South Sudan, Congo and Central African Republic).
- Closer to the coast the distances are ~1000 km and also show a very slow (< 5 ms^{-1}) westward propagation.
- However the correlations are the lowest → possibly artefacts due to coastal/ orographic features and not a coherent propagation.



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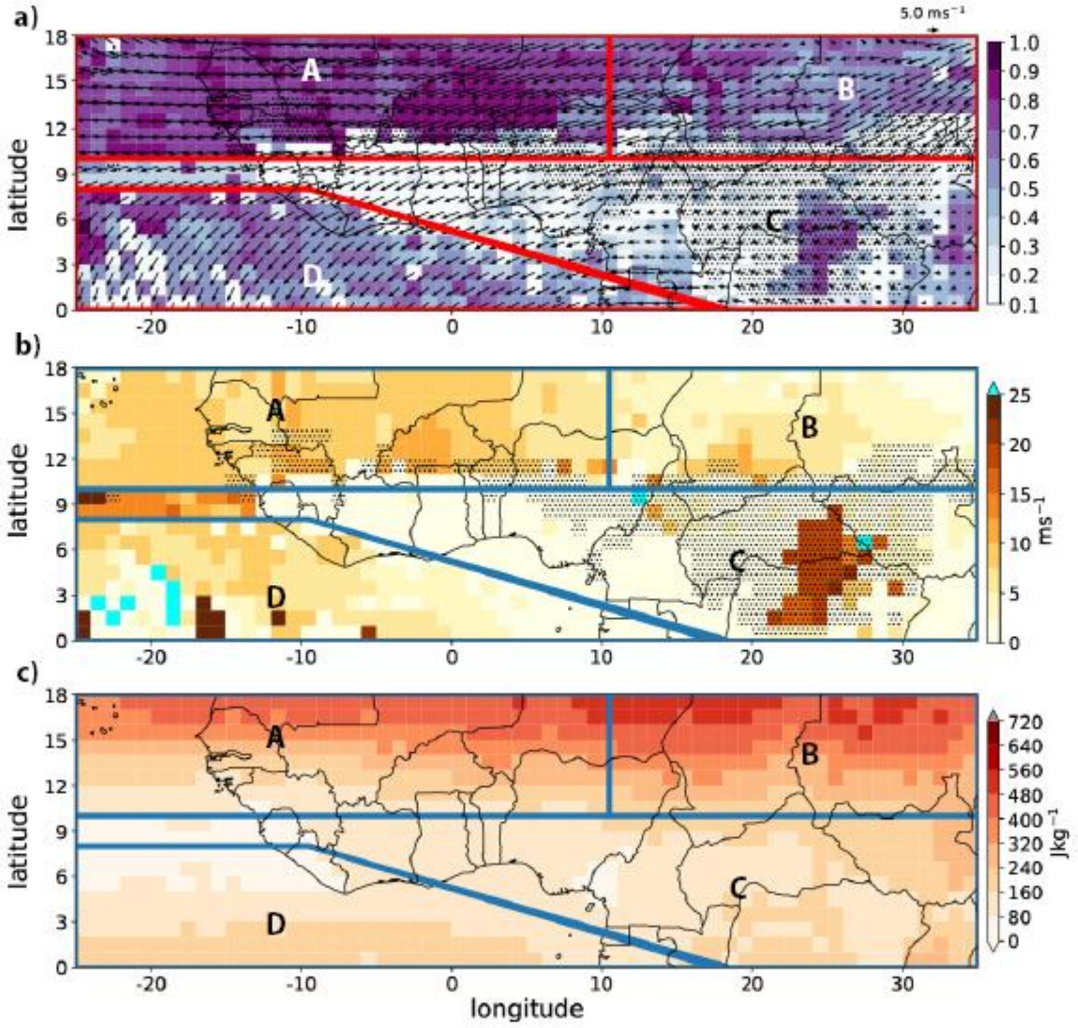
Possible explanations (JAS)

- Region A shows westward propagation at 7.5-10 ms^{-1}→ AEWs.
- High shear in A indicates MCS formation (driven by AEWs).
- Region B is similar to A, but shows less coherence and weaker shear→ weaker AEJ and hence weaker AEWs
- Region C exists in the centre of the rainbelt. Low values of convective inhibition indicates random convection → Could pose significant forecast challenges.
- Region D shows moderate values of correlations and coherence →Possibly due westward propagating synoptic-scale vortices, also observed during DACCIWA campaign (Knippertz et al. 2017).



Top: Coherence factor (boxes indicate regions showing similar coherences)
Middle: Phase speeds computed at every grid point
Bottom: Climatology of CIN in JAS

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December- February (DJF)

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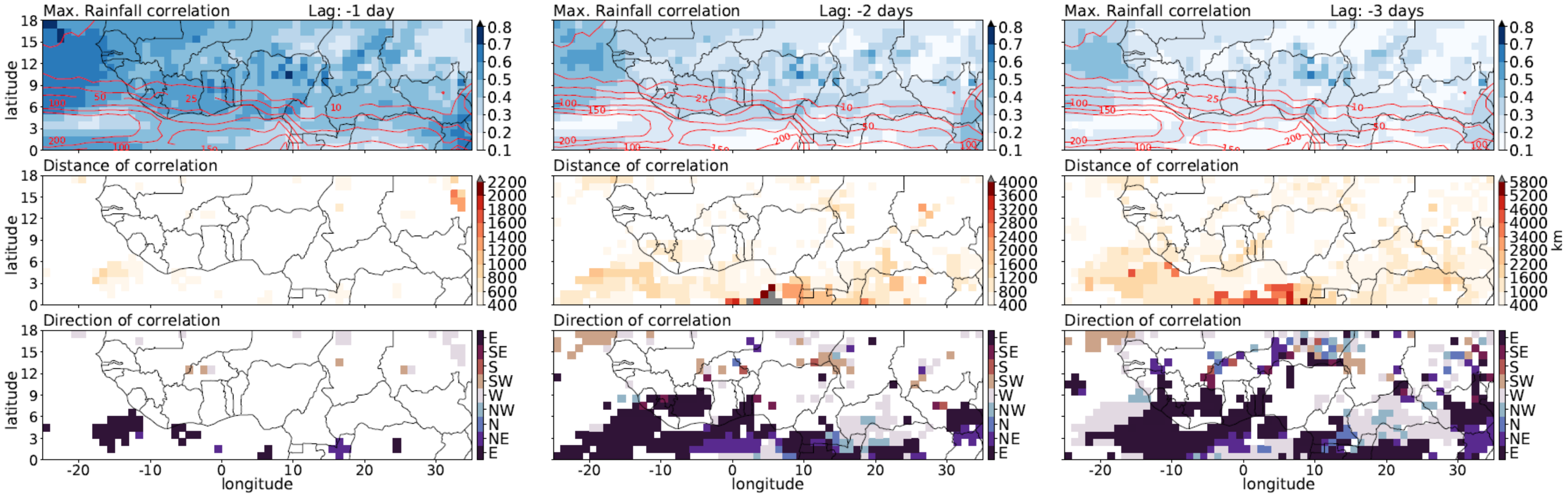
Max. Correlation, Distance and Direction (DJF)



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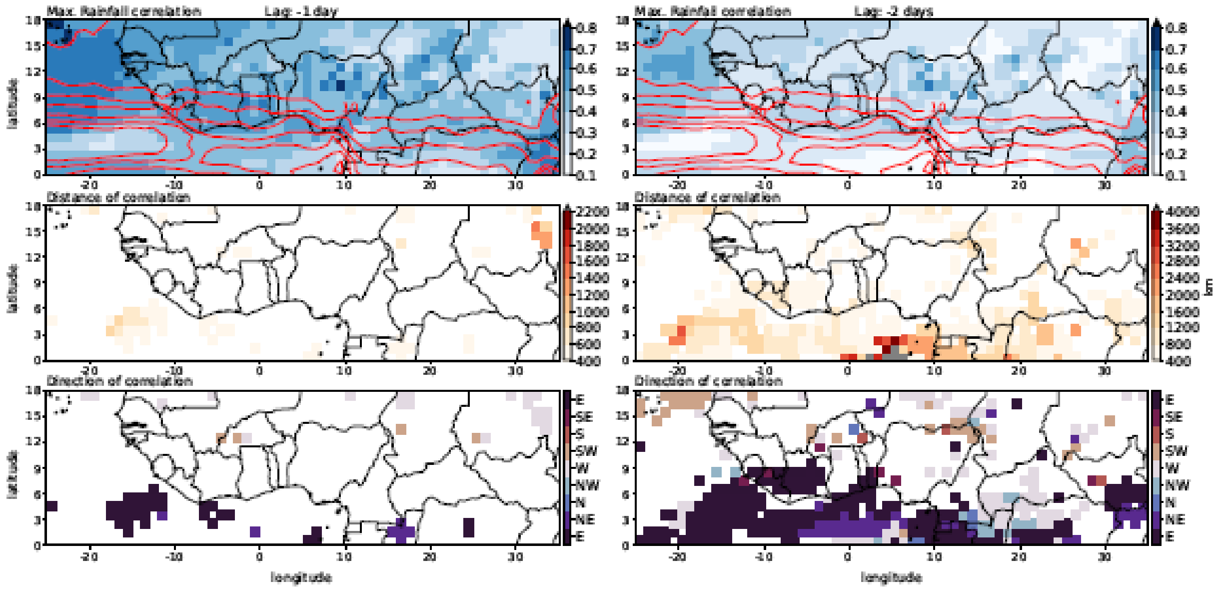
Possible explanations (DJF)

- 3 major zones can be identified:
  - High correlations all over the ocean and all over the land until ~25°E, northward of 6°N.
  - Moderate-high correlations over the equatorial ocean.
  - Low correlations over the equatorial land.



- High correlations coincide with low rainfall. Low distances indicate correlations between neighbouring gridpoints.

- Moderate-high correlations over the ocean coincides with monthly rainfall up to ~200 mm. Distances larger than 400 km are clearly seen until lag -2 days.
- One possible explanation is the presence of a uniform ocean surface.
- Very low CIN due to upwelling of warm water can also be a another factor.

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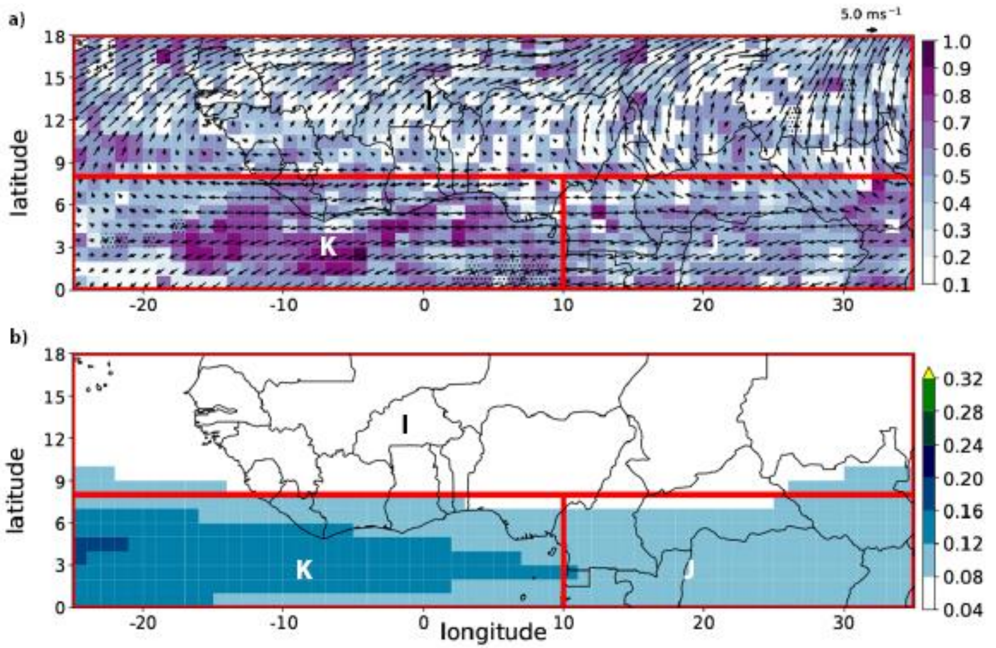
Possible explanations (DJF)

- Region I is largely dry and experiences rare rainfall events → no significant propagation over 3 days → low coherence factor.

- Region J is over the rainbelt and hence shows low correlations. Moderate coherence and weakly westward vertical shear indicates slow propagation.
- Ward et al. (2021) → eastward propagating convective envelops linked to extra-tropical troughs (~40°N).
- Westward propagation seen until lag -2 days → could have westward propagating convective plume like features generated inside.

- High coherence in K could be due to coherent westward propagation driven by equatorial Rossby waves.



Top: Coherence factor (boxes indicate regions showing similar coherences)
Bottom: Equatorial Rossby wave filtered IMERG rainfall field from 2001-2019

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Summary

- Operational forecasts of rainfall → poor skill over tropical Africa.
- Statistical models based on spatio-temporal rainfall correlations show promise.

- Coherence factor introduced in this analysis → effective metric in identifying regions dominated by synoptic-scale drivers causing coherent rainfall.
- Land regions located within the climatological rainbelt experiences very low correlations/ coherent forcing → high stochasticity and hence forecasting challenges.

- Sharpest gradient of coherence is seen in July-September season indicating:
  - Strengthening of AEWs in the Sahel.
  - High stochasticity over the region coinciding with the rainbelt lying to the south of Sahel.

- Very low rainfall with rare strong events over northern tropical Africa in winter results in high rank correlations but lack of coherent propagation causes low coherence.

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