Using equatorial waves to forecast rainfall and evaluate models in the tropics

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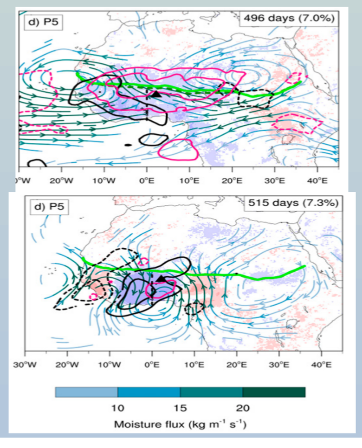
Background

Motivation : Rainfall forecast models struggle to capture daily rainfall events accurately in the tropics (Vogel et al. 2018). Convectively equatorial waves are influential to extreme precipitation events or Tropical Cyclone (Peyrillé et al. 2023, Latos et al. 2023).
⇒ How the drivers of convection can help forecast rainfall in several regions like West Africa, Reunion, Maritime Continent in a mixed research-operational exercice (MISVA) ?

The key drivers are identified at:
- interannual scale (ENSO, IOD),
- seasonal scale (monsoon onset)
- weather scale (Convectively Coupled Equatorial Waves – CCEW).

⇒ Here focus on CCEW. Forecast of CCEW is used to anticipate rainfall

Eq. Rossby (Top) and African Easterly Wave (bottom) composite moisture flux (streamlines) and precipitation percentile deviation (shading, Schluter et al. 2019)



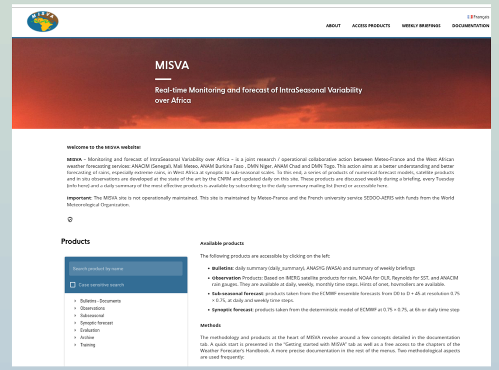
⇒ ECMWF forecast show a dry bias on the Sahel.

⇒ We use the knowledge of the composite rainfall pattern for each CCEW (here most examples are given for Africa Easterly Wave – AEW) et equatorial Rossby wave to derive the rainfall pattern

MISVA : Monitoring IntraSeasonal Variability : https://misva.aeris-data.fr

MISVA Strategy : Monitor and forecast for the last 10 years with archive on the website
- Intraseasonal anomaly + raw data are analysed at all scales by researcher and forecasters
- Precipitable water is used as proxy / predictor for deep convection
- Specific object / parameter/ is considered depending on the scale of interest

Large scale :
Global monsoon, Monsoon Onset, MJO
Velocity potential, PW, Streamfunction, SST, OLR



Regional scale:
Regional modes of variability :Heat Low, Convection
Equatorial waves : Easterly waves up to MJO

Seamless analysis across scales

Weather:
Convectively coupled equatorial wave
Specific diangostic: Monsoon eq. Depth
Layer-average vorticity and meridional wind

Data and methods

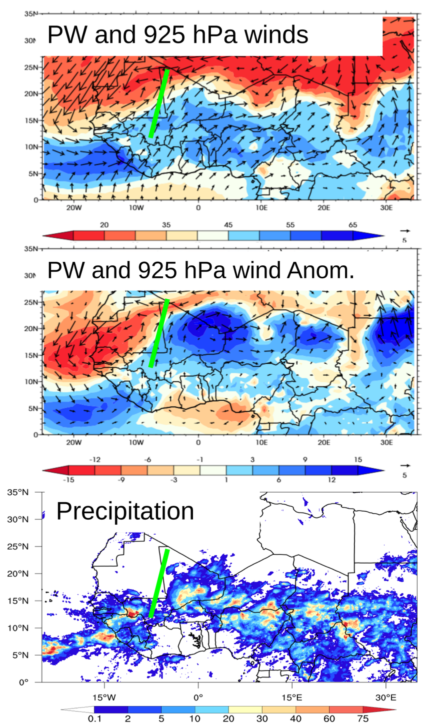
Data :
- ECMWF deterministic extended range forecast D1-D10 regridded at 0.,75x0.75°, 6 hourly
- ECMWF extended range ensemble forecast D+1-D+42, regridded at 0.,75x0.75°, 6 hourly

Methods :
Wave-number filtering based on Wheeler and Kiladis (1999) padded with zeros at the end of the forecast with 6 month data prior to the analysis

Key parameters linked to convection are also analysed as raw and anomaly fields :
- **Precipitable Water** (vertical integral of specific humidiy – **PW**), is related to precipitation (Holloway and Neelin 2009)
- **Velocity Potential** at 200 hPa (**VP200**)

⇒ The use of anomaly relative to the 6-hourly climatology emphasizes the disturbance at play driving rainfall occurrence

Snapshot of forecast Precipitable and 925 hPa wind for raw, and anomaly at +24h Leadtime against precipitation (mm/d IMERG)

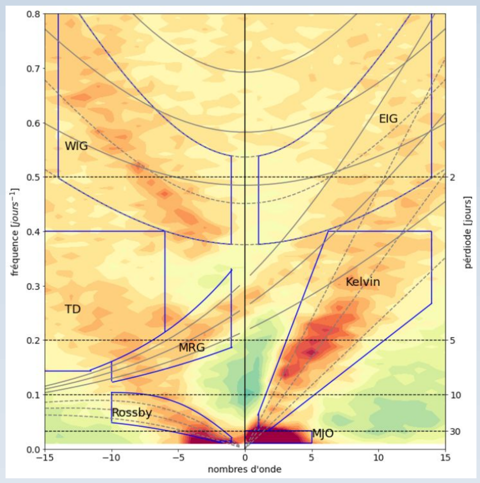


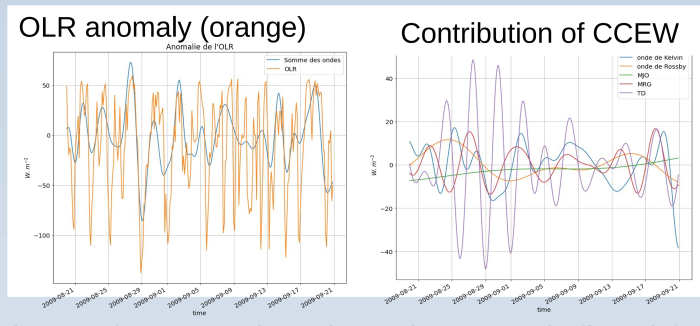
Global database for equatorial wave - CCEW-Database

A global database has been produced with IMERG precipitation, CERES OLR and ERA5 atmospheric parameters for the 2001-2021 period, 0.25°x0,25° , 3-hourly.

The different datasets are wavenumber filtered for each CCEW.
The anomaly of any parameter is decomposed into contributions of CCEWs. It is freely accessible (release soon , article in preparation). We use the database to evaluate the forecast of AEW against.

Normalized OLR spectrum (CERES)

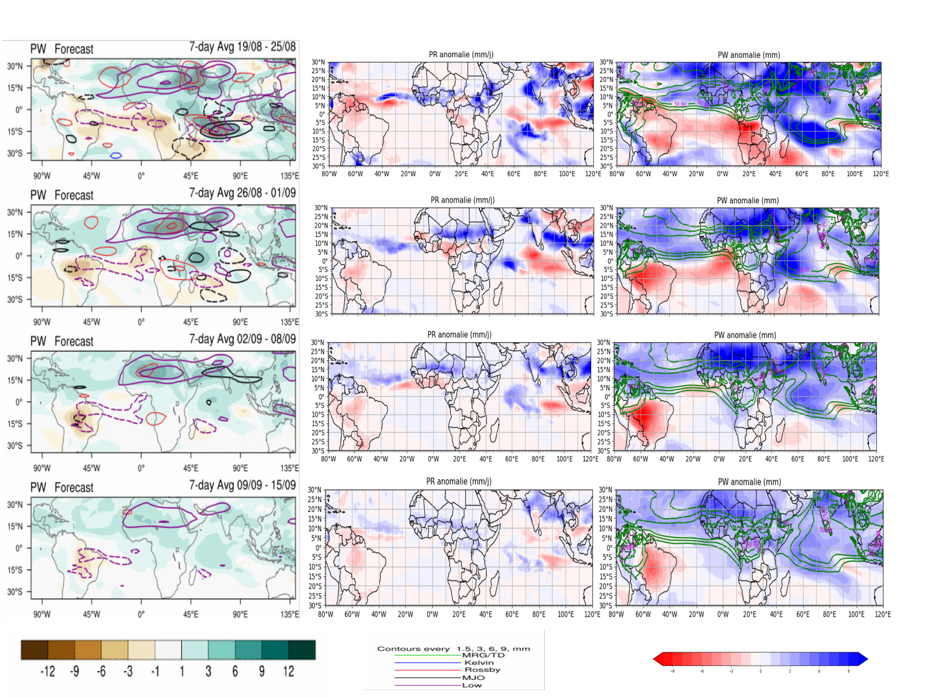




Left : Wavenumber – frequencies domains are defined for each CCEW : MJO , Eq. Rossby wave, Kelvin wave, Easterly wave etc for several parameters (OLR, precipitation, wind, PW). The anomaly of a given parameter is then decomposed into contribution from several CCEW (**right**)

CCEW decomposition at subseasonal scale

Weekly mean anomalies forecast (shading) and contributions from CCEW (contours) for PW (left). Rainfall (middle), and PW (right) weekly anomalie. Green contour on right are for raw PW > 45 mm



PW and VP200 are used to diagnose the large scale environment of convection for the coming weeks

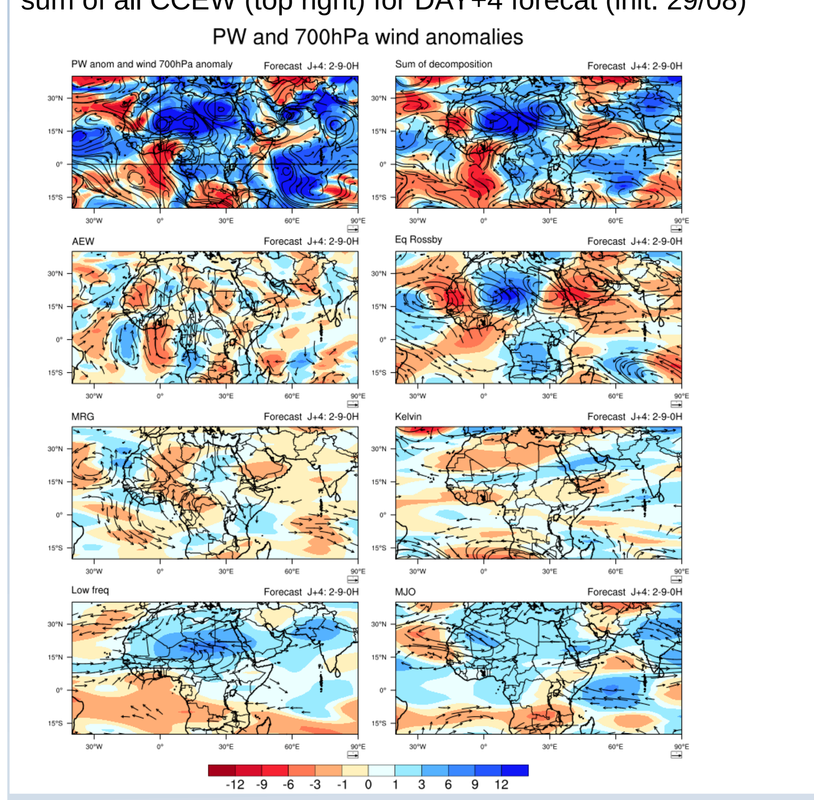
A low frequency moist and upper-level divergent anomaly prevails over West Africa, very specific of the 2024 season.

An equatorial Rossby wave circulate very north over Sahara from week 1 to week 3, which is a configuration found in Peyrillé et al. (2023) to promote extreme rainfall events.

The forecast rainfall is consistent giving confidence in the scenario.

Examples of wave and rainfall forecast

Deterministic forecast of PW (mm, shaded) and 700 hPa wind anomalies (top left), contributions from different CCEW and sum of all CCEW (top right) for DAY+4 forecast (init. 29/08)

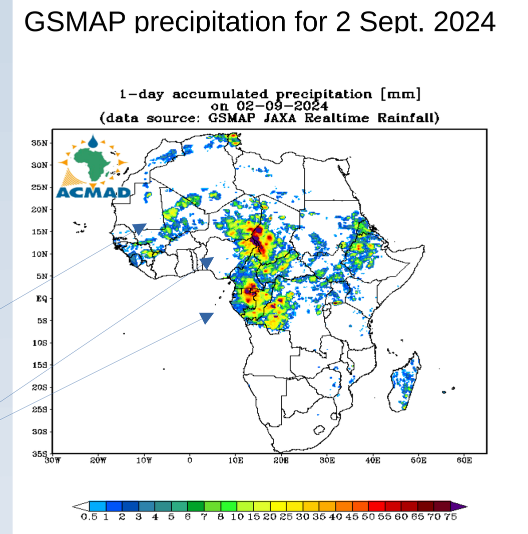


The sum of all CCEW contributions is compared to the forecast anomaly. If they compare well, the leading driver are followed in the forecast wavefiltered parameters.

⇒ The low frequency (periods > 100 days) and the MJO also play a role in the background

⇒ In that exemple, the African Easterly wave and Equtorial Rossby are key to northen Sahel and Central Africa moistening

GSMAP precipitation for 2 Sept. 2024

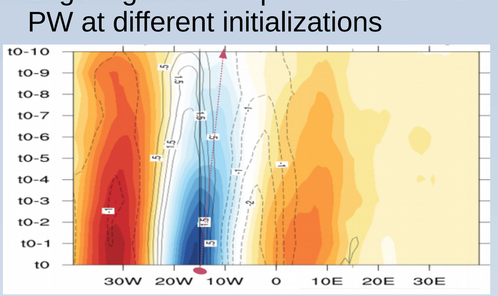


⇒ The precipitation pattern is composed of :
- the AEW pattern over central Sahel
- the ER pattern symmetric to the equator

CCEW Evaluation in global models : Easterly Waves

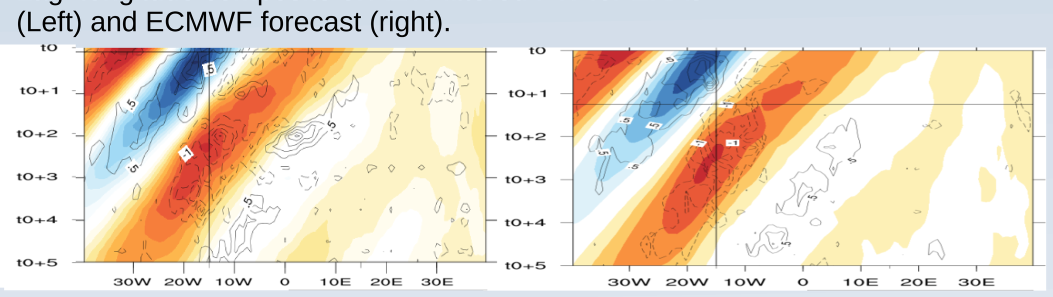
Methods :
The composite AEW is identified on PW wavefiltered anomaly in the Box centered on Senegal greater than 1 σ_{AEW}. The composite is applied for ERA5 and for the deterministic forecast from t0 (max anomaly) to t+10 days.

Lag-longitude composite of AEW filtered PW at different initializations



Results :
We first compared the t0 to forecast at previous initialisation in the composite framework for t-1 (forecast init at day-1) to t-10 (forecast init at day -10). ECMWF model is able to produce an AEW with a signature in PW almost 10 days in advance. There is phase / velocity bias since the peak PW is forecast at 10W at to-10 and occurs at 15W at t0. Naturally the forecast becomes better with closer initializations.

Lag- longitude composite of AEW filtered PW for ERA5 (Left) and ECMWF forecast (right).



Results :
Once initiated with and active Aew, the model propagates the AEW well although with a loss of intensity with growing leadtimes

Conclusions

- The analysis of raw parameter together with the anomalies from the daily 6-hourly climatology helps following disturbances in the tropics ⇒ reduce time to get expertise for a forecaster
- The monitoring of CCEW at different leadtime shows a great benefit to identify the driver of a given weather situation and helps anticipating the rainfall pattern with « conceptual composite scheme ». It brings a confidence range to the forecast scenario.
- A global databasae of CCEW filtered parameters has been produced. Using the CCEW analysis gives insight into the model behviour. For instance AEW are rather well forecast over Senegal ten days in advance pointing out the growth of AEW is well tackled. Not so sure for the genesis mechanism. The work is to be extended to other areas and CCEW.

References :

Latos, B., Peyrillé, P., Lefort, T. et al. The role of tropical waves in the genesis of Tropical Cyclone Seroja in the Maritime Continent. Nat Commun 14, 856 (2023). https://doi.org/10.1038/s41467-023-36498-w
Peyrillé, P., Roehrig, R., & Sanogo, S. (2023). Tropical waves are key drivers of extreme precipitation events in the Central Sahel. *Geophysical Research Letters*, 50, e2023GL103715. https://doi.org/10.1029/2023GL103715
Schlueter, A., A. H. Fink, and P. Knippertz, 2019: A Systematic Comparison of Tropical Waves over Northern Africa. Part II: Dynamics and Thermodynamics. J. Climate, 32, 2605–2625, https://doi.org/10.1175/JCLI-D-18-0651.1.

Vogel, P., P. Knippertz, A. H. Fink, A. Schlueter, and T. Gneiting, 2018: Skill of Global Raw and Postprocessed Ensemble Predictions of Rainfall over Northern Tropical Africa. Wea. Forecasting, 33, 369–388, https://doi.org/10.1175/WAF-D-17-0127.1.