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An objective identification technique for 2D African Easterly Wave troughs and associated 3D potential vorticity structures and its application to ECMWF data

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WAVES TO WEATHER

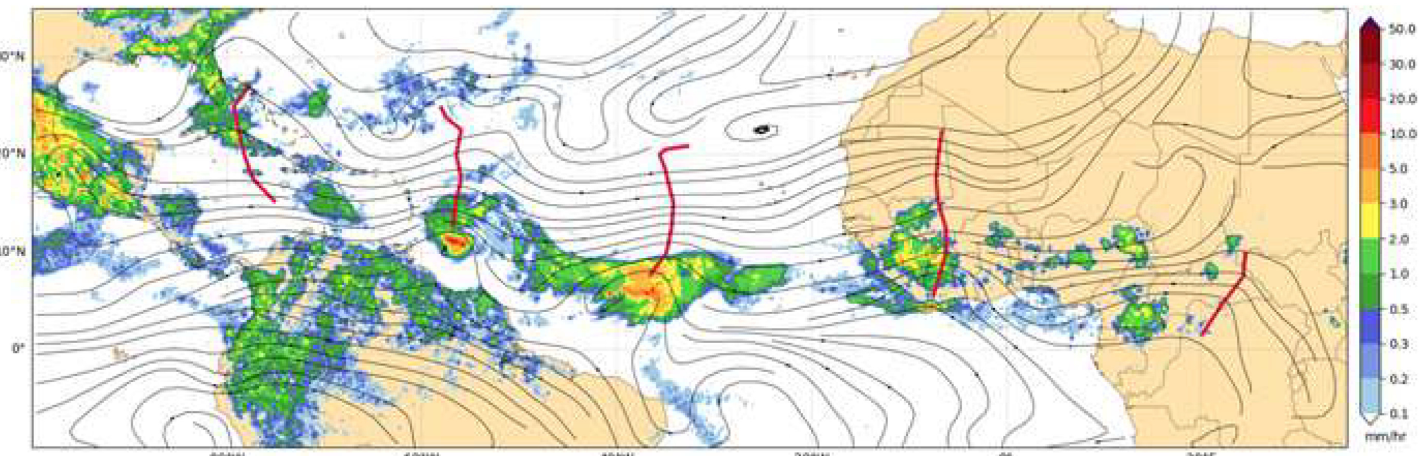
I. MOTIVATION

- African Easterly Waves (AEWs) are synoptic-scale perturbations propagating along the midlevel African Easterly Jet in summer.
- Through coupling with convection, they significantly impact the precipitation distribution in West Africa and even tropical cyclogenesis over the downstream North Atlantic.
- Objectively identifying them is an important first step towards better understanding AEW dynamics and improving their representation and coupling with convection in forecasts.

II. METHODS

2D AEW trough identification and tracking

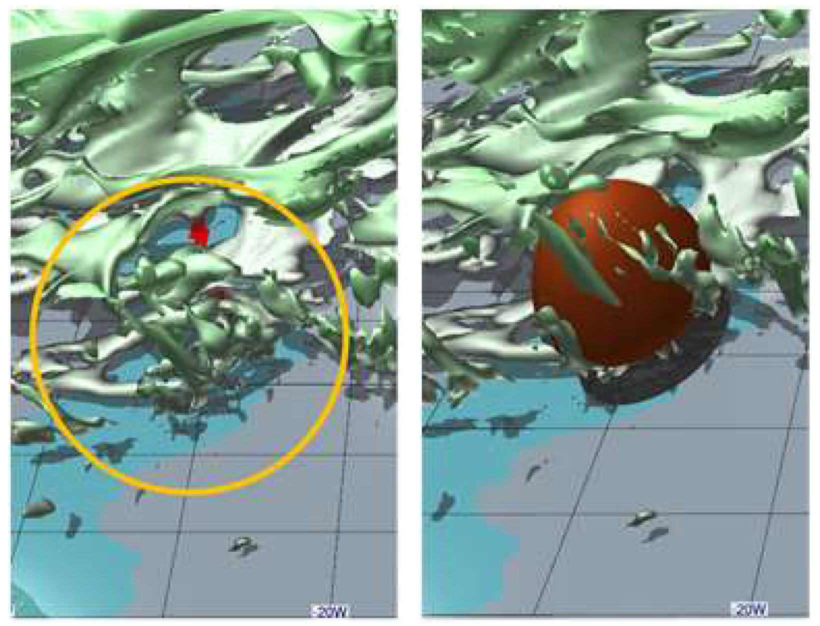
- Identify AEW troughs by analyzing the **advection of curvature vorticity anomalies** (CVA).
- Local minima are candidates for wave troughs.
- An overlap approach is employed for tracking AEWs by **predicting future trough positions** based on propagation speed.



⮝ Near-Real-Time display of AEW troughs detected at 1 July 2024 at 00 UTC in the ECMWF HRES analysis. Display available at www.kit-weather.de (see VI. for more details).

3D PV structure identification

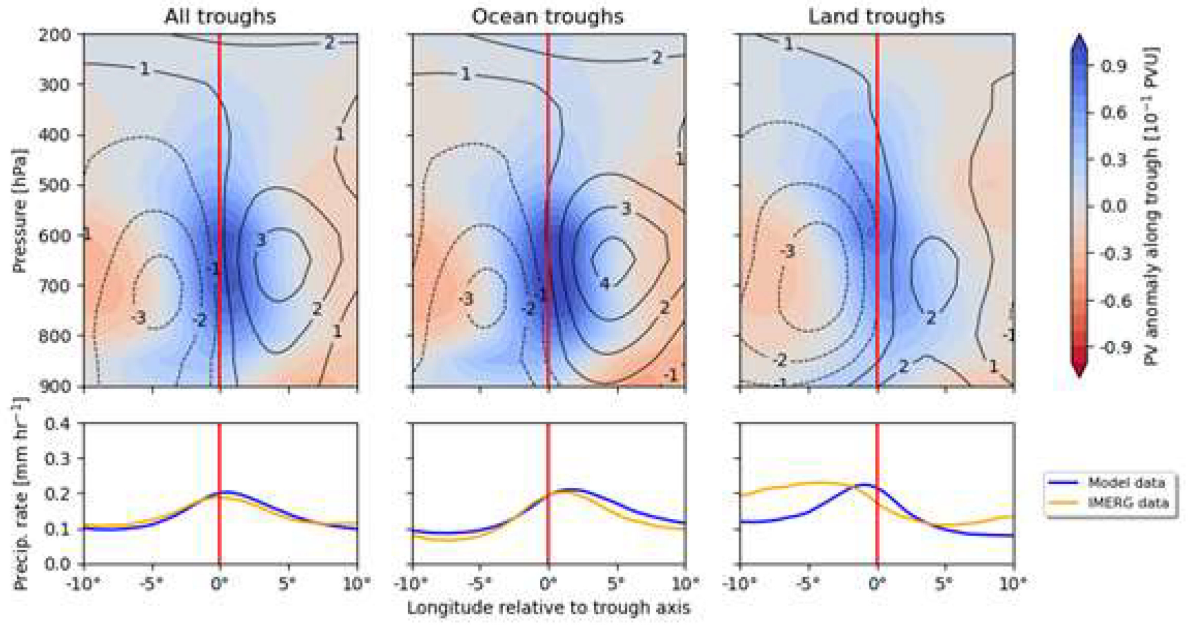
- Collect potential vorticity (PV) areas near an AEW trough (based on wave phase) and with a significant anomaly (≥0.7 PVU).
  → Define **PV features** from contiguous areas
- Apply morphological filters to refine PV features
- Compute **best-fit ellipsoids** for PV features using image moments to describe their spatial and geometric properties



➤ A segment of a 3D visualization of PV anomalies (green isocontour at 0.7 PVU). The right panel shows the computed best-fit ellipsoid for the anomaly in the left panel. For more details, see Fischer et al. (2024).

III. RESULTS

- Identified and tracked AEW troughs and PV structures for June–Oct. 2002–2022 from ERA5 data.
- Statistical evaluation confirms robustness and relevance of the method.



⮝ Upper panels: Composite of PV anomalies (shading) and meridional wind in m/s (contours) relative to identified AEW troughs (red lines) along a longitude-pressure cross-section for June-October 2002-2022 based on the ERA5 reanalysis, split by land vs. ocean. Lower panels: 6-hourly centered satellite-estimated (GPM-IMERG) and model-predicted (ERA-5 short-range forecasts) rainfall.

Cross-section through AEW composites

Over Land:
- Downshear tilt of PV column with height
- Deep penetration of PV anomaly slightly ahead of trough axis indicative of convective generation
- Dipole of meridional wind with strong northerlies ahead of trough
- ERA5 places rainfall too close to trough

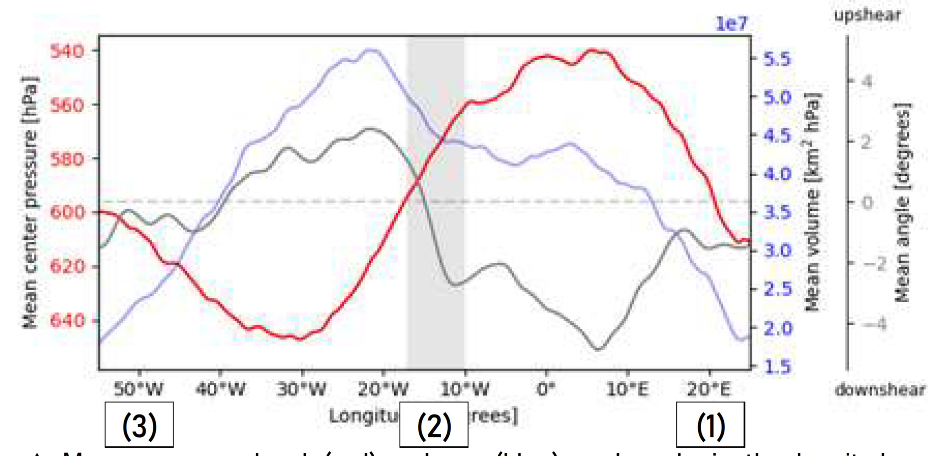
Over Ocean:
- PV signal shallower (lower CAPE) and aligned with trough
- Southerlies behind trough dominate
- Modelled and observed rainfall match

Characteristics of AEW-related PV anomalies

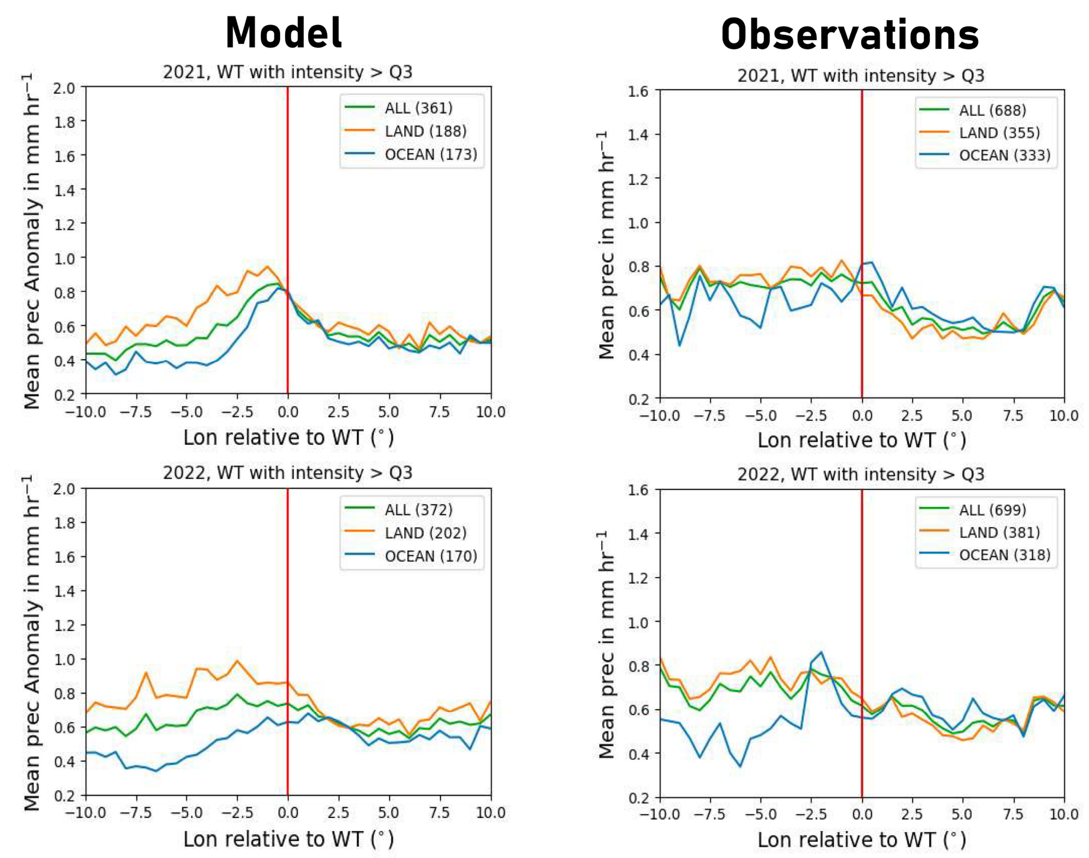
(1) Over land (10°W–25°E):
- Elevated PV features ⟵ deep convection
- Intermediate volume, downshear tilt

(2) Transition phase (17–10°W):
- Fast lowering of feature center
- Anomaly becomes more upright

(3) Over ocean (55–17°W):
- Low center ⟵ shallower convection
- Large volume ⟶ mature phase



⮝ Mean pressure level (red), volume (blue), and angle in the longitude - pressure plane relative to the vertical (grey) for all identified PV features for June-October 2002-2022, plotted against longitude. The horizontal dashed line marks a perfectly vertical orientation. The grey area highlights the region where features transition from land to ocean within our study domain.



⮝ Composites of 2021 and 2022 (before and after moist physics upgrade in ECMWF IFS Cycle47r3, respectively) AEW troughs (red lines) and associated precipitation rate from (left) model prediction at initial condition t=0 and (right) satellite-estimate GPM-IMERG.

Phase relationship between 2D wave trough axis and precipitation

(1) 2021 (before moist physics upgrade)
- Model: Precipitation peak ahead of (closer to) trough axis over land (ocean)
- Observations: Though noisy, more rainfall in broad area ahead of trough over land

(2) 2022 (after moist physics upgrade)
- Model: Broader maximum ahead of trough over land than in 2021
- Observations: Overall better agreement with the model

IV. CONCLUSIONS

- A useful **objective tool** was developed to investigate the life cycles and characteristics of AEWs in 2D and 3D using gridded meteorological fields and satellite-based rainfall.
- Data and code are made **available for public use** (Fischer et al., 2024); a near-real time display is available (see details under VI. below).
- There are distinct differences between **land and ocean** with the former characterized by deeper and tilted PV structures related to intense convection, which supports the AEW propagation.
- The ECMWF model tends to **underestimate** the rainfall peak ahead of the AEW trough over land. This pertains to both ERA5 and the operational model.
- The substantial **upgrade to ECMWF's moist physics** package appears to have led to some improvements but the one year investigated is too short for a robust assessment.

V. FURTHER RESEARCH QUESTIONS

- How do the 2D/3D characteristics of AEWs and PV features correlate with **tropical cyclogenesis**, and can these findings be utilized to improve tropical cyclone forecasts?
- Is the impact of the **moist physics upgrade** robust and can the involved mechanism be understood?
- How good does the model forecast the marked **structural transition** of individual AEWs when crossing the West African west coast?

VI. REFERENCES/ACKNOWLEDGMENTS

Parts of this work was published in Geoscientific Model Development (GMD). Please also refer to the literature therein.

Fischer, C., Fink, A. H., Schömer, E., Rautenhaus, M., and Riemer, M.: An objective identification technique for potential vorticity structures associated with African easterly waves, Geosci. Model Dev., 17, 4213–4228, 10.5194/gmd-17-4213-2024, 2024.

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The impact of the 2022 moist physics upgrade was analyzed as part of Nicolas Lo's MSc thesis "Representation of African Easterly Waves and associated rainfall in two versions of ECMWF Integrated Forecasting System" (KIT, 2024)

Near-real-time displays of analyzed and forecast AEW trough axes based on ECMWF data can be found at kit-weather.de