On the Application of Moist Singular Vectors to African Easterly Waves

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Summary

Moist singular vectors (MSV) have been applied successfully to predicting mid-latitude storms growing in association with latent heat of condensation. Extending this approach to more general tropical weather systems here, MSVs are evaluated for understanding and predicting African easterly waves (AEW), given the importance of moist processes in their development (Cornforth et al., 2009, QJRMS 135, 894-913).

1. First results, without initial moisture perturbations, suggest MSVs may be used advantageously. Perturbations bear similar structural and energy profiles to previous idealised non-linear studies and observations. Can capture essence of AEWs.

2. Strong sensitivities prevail in the metrics and trajectories chosen, and benefits of initial moisture perturbations should be appraised.

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The Challenge

Predictions of rainfall in sub-Saharan Africa show high uncertainty. Short-range forecasts (up to 2 days) are needed for the public and aviation, and medium-range forecasts (10-30 days) are key for agriculture, hydrology and health information.

AEJ-AEW System is a crucially important component of West African monsoon (WAM) rainfall variability (see Laing et al, QJ, 2009).

(a) W3 - early WAM
(b) W20 - peak WAM

Fig.1: 10-day forecast tracks based on the 700 hPa 2-6 day filtered meridional wind for AEW3 and AEW20 that evolved in two contrasting (a) dry and (b) wet periods in the 2006 WAM (Fig. 2). Forecasts were made every 12 h (a) 9th-15th July; and (b) 1st-10th Sept, courtesy of Kevin Hodges, ESSC, UK. ECMWF.

But systematic errors plague forecast skill. AEWs decay far too quickly in forecasts (by 72 h, Agusti et al, 2008). Atmospheric processes are incorrectly represented. Need a theoretical framework to quantify NWP model error.

The Approach: ECMWF’s new MSV package

Fig. 2
Initial trajectories based on AEWs shown in Fig. 2. MSV package includes full moist physics - initial perturbations are dry, but the MSV structures can use moisture in their evolution. Total dry energy norms used at initial and final times here.

Set-up: Cycle 32R3 (used in AMMA), 62 levels in the vertical, a time-step of 30 minutes, horizontal resolution, T95 (cf.λaw=3000 Km), optimization times (OTI) of 24h (because of expected non-linearities) and a projection operator targeted on the main development region of AEWs (5-20°N, 20°W-30°E) constrains the final time amplitudes of the MSVs.

Questions

1. Can we use MSVs to build on our theoretical understanding from normal mode studies of the moist AEJ-AEW system (Cornforth et al, QJ, 2009).

2. Are MSVs targeted on W. Africa suitable as perturbations to the ECMWF ensemble system for improving AEW prediction and associated rainfall, given expected non-linearities?

1. Amplification Factors

Fig. 3 Amplification factors of the first 8 moist singular vectors for W3 (yellow) in the early drier WAM and W20 (turquoise) in the full monsoon. Sensitivity cases with extended target areas (5 to 25N, 35W to 35E) are shown for W3 (orange), W7 (violet), W9 (dark green) and W20 (blue), cf Fig. 2.

Amplification factors are generally reduced by factor of 5 of mid-latitudes: different growth mechanisms and new moist physics.

Trajectories initialised on more moist basic states (W7, 9, 20) exhibit reduced amplification of dry basic state (W3); greater non-linearities. Suggests MSVs are sensitive to something other than total dry energy metric used.

Sensitivity studies with different projection operators showed a need to: (i) confine the final time target area to 20°N in the meridional direction to avoid spurious amplification associated with mid-latitude troughs propagating into the region; (ii) maintain the longitudinal extent beyond 15°E so upstream perturbations triggered by meso-scale convective complexes are included (Thomcroft et al, JAS 2008).

Growth Mechanisms?

Mechanism for MSV growth is not clear. Barotropic, baroclinic and moist processes all contribute just as observed AEWs (cf. Haieh and Cook, 2007; Craig and Cho, 1988).

Difficulty lies in interpreting the MSV growth when moisture availability is associated with the cooler temperatures in the low-level southwest flow.

Important to review use of total dry energy norm since the metric or norm chosen should be related to the spatial distribution of expected errors in the analysis.

3. Energy Profiles

Fig. 4 Vertical distribution of total energy (solid line) for SV1 for (a) W3 and (b) W20

W3 profiles convey AEW-like nature of SV1: maximum at initial time is centred near the steering level but propagates downwards to 900 hPa at final time - consistent with observations of low-level amplitudes of AEWs (eg. Pytharoulis and Thorncroft, 1999) and modelling studies (eg. Cornforth et al., 2009).

W20 SV1 has peaks centred initially around the AEW steering level near 750 hPa, and 200 hPa, 750 hPa peak is AEW-like, but moister W20 SV1 fails to grow propagating downwards towards 900 hPa. Though 200 hPa peak is reminiscent of idealized mid-latitude MSV analyses (Badger and Hoskins, 2001) here, may reflect outflow of deep moist convection.

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