Energetics of African Easterly Waves using the Canadian Regional Climate Model (CRCM): A first approach.

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The Lorenz energy cycle of African Easterly Waves (AEWs) as simulated by the Canadian Regional Climate Model (CRCM), has been calculated.

The CRCM uses a semi-implicit, semi-Lagrangian numerical scheme to solve the fully elastic non-hydrostatic Euler equations (Laprise *et al.* 1997) and the subgrid-scale physical parameterization package of the second-generation Canadian Centre for Climate modelling and analysis atmospheric General Circulation Model (CCCma AGCM 2) (McFarlane *et al.*, 1992). A complete description of the numerical formulation of the model and the principal characteristics of the physical package can be found in Caya and Laprise (1999). In the present work, we use the version 3.5 of the CRCM in which moist convection is parameterized using the Kain and Fritsch (1990) scheme. The model is driven by National Centers for Environmental Prediction (NCEP) atmospheric re-analyses and the Sea Surface Temperatures (SST) are from the Atmospheric Model Intercomparison Project (AMIP II) data.

A first simulation (simulation # 1) over a 171 by 75 gridpoint domain with 100-km grid spacing in the horizontal and 10 Gal-Chen (GC) levels in the vertical, was made for the period from May to September 1995. The data generated by this simulation were used to drive a second run of the model (simulation # 2) at higher resolution over a 151 by 81 gridpoint domain with 50-km grid spacing and 19 GC levels, for August 1995 (Fig. 1).

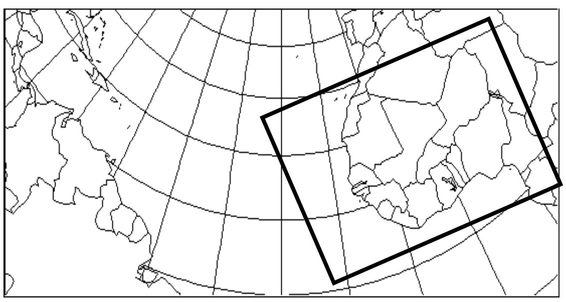

Figure 1. Computational domains. The largest domain corresponds to the simulation #1 with a 100-km grid increment and the smallest domain to the simulation #2 with a grid increment of 50 km.

Figure 2(a) displays a cross section between 5° and 25° N of the August 1995 mean zonal wind at 0° longitude (simulation #1). The main features of the wind structure in west Africa as simulated by the model are: a 600-700 hPa African easterly jet (AEJ) located between 15° and 20° N with a maximum wind speed of 8 - 10 m s^{-1}, an upper level tropical easterly jet (TEJ) at about 200 hPa equatorward of the AEJ, a low-level westerly flow to the south, and a westerly jet to the north. This is in agreement with the observational study of Reed *et al.* (1977) using Global Atlantic Tropical Experiment (GATE) data (23 August to 19 September 1974) averaged between 10°E and 31°W (Fig. 2b). A difference is that the simulated jet for 1995 is a little weaker than the analysed one in 1974 (10.0 m s^{-1} *vs* 12.5 m s^{-1}, respectively).

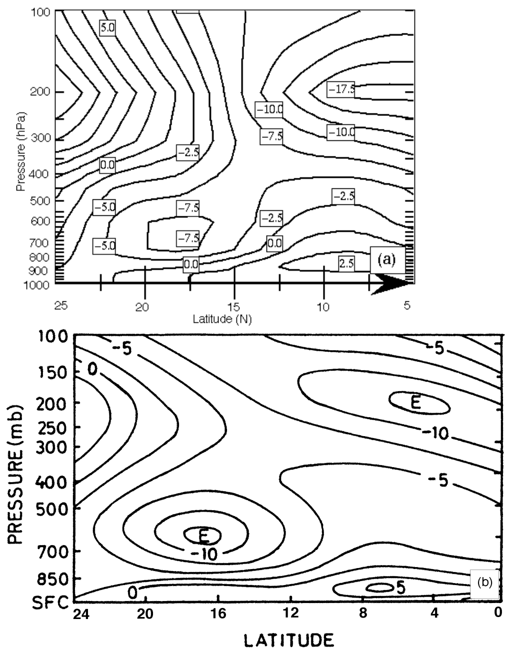

Figure 2. Mean zonal wind distribution over west Africa : (a) as simulated by the CRCM for August 1995 and (b) as obtained from GATE for the period 23 August to 19 September 1974 (after Reed et al., 1977). The contour interval is 2.5 m s^{-1}.

AEWs can be identified in the fields of relative vorticity, winds, precipitation and sea level pressure. Figure 3 shows the CRCM-simulated relative vorticity at 700 hPa from August 11 to 14 (00Z) 1995, superimposed with the wind vectors at the same level.

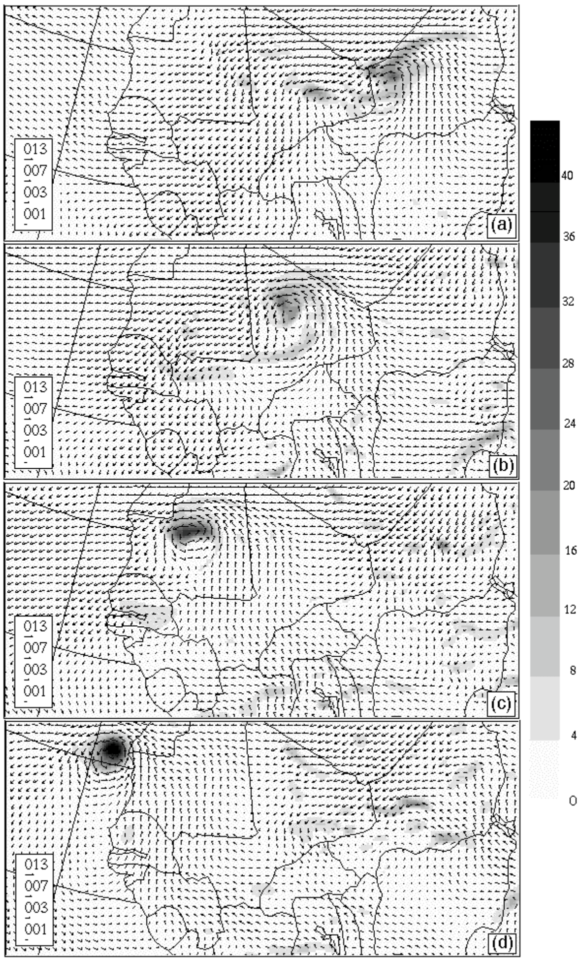

Figure 3. Relative vorticity in gray shade (x10^{-5} s^{-1}) and winds vectors (m s^{-1}) at 700 hPa for the (a) 11th, (b) 12th, (c) 13th and (d) 14th August 1995 as simulated by the 50-km CRCM.

The Lorenz cycle is calculated using the equations for the time evolution of eddy energy in a limited-area domain as in Norquist *et al.* (1977), who followed the formalism developped by Muench (1965) for an open system, based on the seminal work of Lorenz (1955). The energy, conversion and generation terms are calculated over the entire CRCM computational domain (except the sponge zone) for the month of August 1995 (simulation #2). These are time-averaged to obtain the Lorenz cycle presented in Fig. 4. The vertical integrations have been made between 1000 and 350 hPa in order to concentrate on the interactions between the mid tropospheric jet (AEJ) and its effect over the AEWs. As it can be seen in Fig. 2, this allows to isolate the AEJ from the strong TEJ which could contaminate the computations.

On a monthly average basis, the eddy kinetic energy K_E is maintained by the barotropic energy conversion C_K and the baroclinic energy conversion C_E, the later being the more intense.

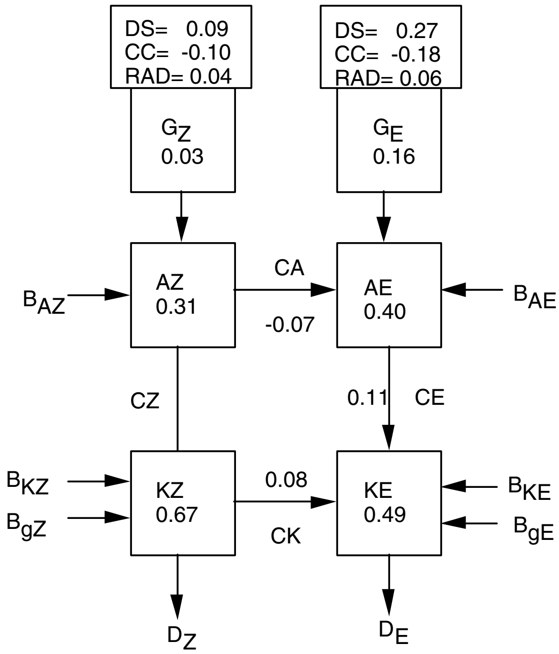

Figure 4. Lorenz diagram of the AEWs using the CRCM simulation for August 1995. Energies in J m^{-2}, conversions and generations in W m^{-2}.

The ratio of K_E / (C_K+C_E) gives a doubling time of 2.6 days for the eddy kinetic energy which agrees well with the value of 2.9 days obtained by Norquist *et al.* (1977) for another year (23 August - 19 September, 1974). The generation ($G_E > 0$) of eddy available potential energy by diabatic processes is roughly of the same magnitude as the conversion terms. The largest contribution to G_E comes from the combined contribution of vertical diffusion and surface flux term, G_E(DS) = 0.27 W m^{-2}. The combined contribution of the condensational heating and convective heat flux term, G_E(CC) = -0.18 W m^{-2}, is negative in sign but has magnitude greater than the combined contribution of solar and terrestrial radiation term, G_E(RAD) = 0.06 W m^{-2} (which is the smaller). In our version of CRCM, the individual contributing components of Q_{DS} and Q_{CC} can not be obtained separately, so we can not say anything more about their relative strength. This is the reason why the contribution of the condensational heating, which is thought to be an important source of energy for the perturbations, can not be evaluated separately. The generation ($G_Z > 0$) of zonal available potential energy is very weak in the domain, as expected for a tropical atmosphere (Newell *et al.*, 1972), but its sign is such as to maintain the meridional temperature gradient that is associated with the AEJ.

A « composite » of the energy and conversion terms for the three most intense perturbations of the month has been constructed and is shown in Figs. 5 and 6. The compositioning technique consisted in aligning the central time of the three most intense perturbations, and averaging them, taking five days on each side of the maximum. The remaining energy and conversion terms are similarly composited. It can be seen in Figs. 5 and 6 that the maxima in the conversion terms lead that of the eddy kinetic energy, and that the most important conversion terms are those of the CK and CE. This conforms with the idea that the perturbations feed from the barotropic and baroclinic energy conversions Burpee, 1972; Thorncroft, 1995). In the three composited systems, the baroclinic conversion seems to initiate the growth, followed 1 day later by barotropic conversion. The diabatic generation of eddy available potential energy, G_E, also contributes substantially in the period preceeding the maximum intensity.

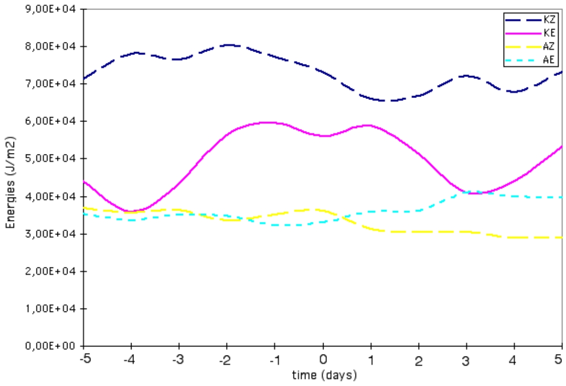

Figure 5. Composite of AZ, AE, KZ and KE (in J m^2). Day 0 corresponds to the time of maximum AEW amplitude in the relative vorticity field.

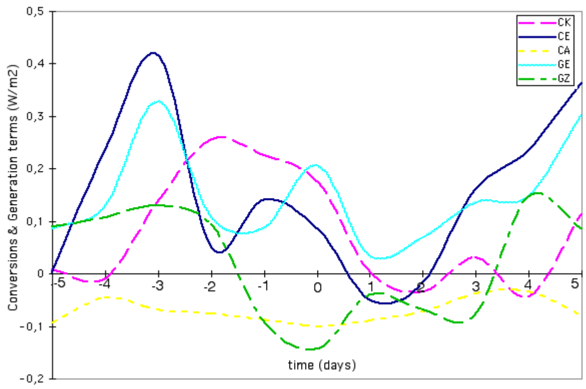

Figure 6. Composite of the conversion (CK, CE, CA) and generation (GE, and GZ) terms (in W m^{-2}).

References.

Burpee, R. W., 1972: The origin and structure of easterly waves in the lower troposphere of North Africa. *J. Atmos. Sci*., **29**, 77 - 90.

Caya, D. and R. Laprise, 1999: A Semi-Implicit Semi-Lagrangian Regional Climate Model: The Canadian RCM. *Mon. Wea. Rev*., **127**, 341 - 362.

Kain, J. S. and J. M. Fritsch, 1990: A One-dimensional Entraining/Detraining Plume Model and Its Application in Convective Parameterization. *J. Atmos. Sci*., **47** (23), 2784 - 2802.

Laprise, R., D. Caya, G. Bergeron and M. Giguère, 1997: The formulation of André Robert MC2 (Mesoscale Compressible Community) model. The André J. Robert Memorial Volume (C. Lin, R. Laprise and H. Ritchie, Eds.), companion volume to Atmos.-Ocean, **35** (1), 195 - 220.

Lorenz, E. N., 1955: Available potential energy and the maintenance of the general circulation. *Tellus*, **7**, 157 - 167.

McFarlane, N. A., G. J. Boer, J.-P. Blanchet and M. Lazare, 1992: The Canadian Climate Centre Second-Generation General Circulation Model and Its Equilibrium Climate. *J. Climate*, **5**, 1013 - 1044.

Muench, H. S., 1965: On the Dynamics of the Wintertime Stratosphere Circulation. *J. Atmos. Sci*., **22**, 349 - 360.

Newell, R. E., J. W. Kidson, D. G. Vincent and G. J. Boer, 1972: The General Circulation of the Tropical Atmosphere and Interactions with Extratropical Latitudes. The Massachusets Institute of Technology, 370 pp.

Norquist, D. C., E. E. Recker and R. J. Reed, 1977: The energetics of African Wave Disturbances as Observed During Phase III of GATE. *Mon. Wea. Rev*., **105**, 334 - 342.

Reed, R. J., D. C. Norquist and E. E. Recker, 1977: The structure and properties of African wave disturbances as observed during Phase III of GATE. *Mon. Wea. Rev*., **105**, 317 - 333.

Thorncroft, C. D., 1995: An idealized study of African easterly waves. III: More realistic basis states. *Q. J. R. Meteorol. Soc.,* **121**, 1589 - 1614.

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