

# INTER-HEMISPHERIC COMPARISON OF THE DYNAMICS OF RAIN-PRODUCING SYSTEMS IN TROPICAL AFRICA: IMPACTS ON CLIMATE CHANGE IN THE SAHEL

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## INTRODUCTION

More than three-quarters of the total annual rainfall in Sahelian Africa are attributable to squall lines (Eldridge, 1957; Omotosho, 1985, 1990). Adedoyin(1989b, 1989c) has shown that the process of initiation of these tropical disturbances is linked with the instability of waves generated along the surface of discontinuity between the two tropospheric air masses (i.e. the moist south-westerlies and the dry north-easterlies) in the sub-region. These squall-inducing vertical transverse waves are likely initiated by the passage of the trough of the dominant horizontal transverse wave in tropical north Africa namely, the African Easterly Waves(AEW). It may therefore seem that the more the number of AEW in any year, the more the number of squally activities and the better the rainfall regime in Sahelian Africa.

In pursuance of this hypothesis, Reed(1988), Druyan(1989) and Landsea and Gray(1992) have suggested that AEW are less numerous in Sahelian dry years but Pasch and Avila(1994) have shown that the number of waves per year is relatively constant (around 60) no matter if the Sahel is wet or dry. Therefore, the reduction in the number of squall lines in the Sahel in dry years, as found by Adedoyin(1989a), cannot be conclusively ascribed to a reduction in the number of AEW.

However, one synoptic feature which seems to distinguish Sahelian dry years from the wet is the strength of the African Easterly Jet(AEJ). AEJ is stronger in dry years (Newell and Kidson, 1984; Janicot, 1992). There is therefore a need to investigate whether or not there is any relationship between enhanced horizontal shear (caused by stronger AEJ) in the lower troposphere of West Africa and the evolution of wave-like perturbations along the surface of discontinuity between the two tropospheric air masses in the sub-region since, the amplification of these perturbations has been shown to be fundamental to the development of squall lines (Adedoyin, 1989b, 1989c). This paper examines the effects of an increase in the strength of the AEJ on amplifying waves along the surface of discontinuity between the moist south-westerlies(SW) and the dry north-easterlies(NE) in tropical north Africa. The strength of the AEJ is then linked with global sea-surface temperature(SST) anomalies and the persistence of drought in the sub-region since the late 60's.

To appreciate changes in tropical south Africa rainfall pattern, in relation to global climate variability, knowledge of the air masses that bring moisture to different parts of the tropical Africa sub-continent is necessary. Adedoyin(1989c) has described the scenario for tropical north Africa but the case for tropical south Africa, especially Botswana, should be mentioned.

## BASIC AND FREQUENCY EQUATIONS

Atmospheric disturbances can be assumed to be wave-like perturbations superimposed on the basic state of the atmosphere. If these perturbations are expressed in the form

$$u' = u(p) e^{i(\sigma_0 t + \alpha x + \beta y)}$$

$$v' = v(p) e^{i(\sigma_0 t + \alpha x + \beta y)}$$

etc. and the basic five basic equations of hydrostatics (Eqs. 1-5) are transformed into their equivalents in pressure co-ordinates with the Coriolis term neglected because it is of a second order of smallness for the area of study; and if  $\mu_1$ ,  $\mu_2$  and  $\mu_3$  are tracer elements attached to the horizontal advection, Coriolis and latent heat terms respectively, we obtain

$$\frac{\partial^2 \omega}{\partial p^2} + \frac{g\Gamma}{p_s^2} \left( \frac{\alpha^2 + \beta^2}{\sigma^2} \right) \left( 1 - \mu_1 \cdot \frac{\alpha u_s}{\sigma} \right) \omega = - \mu_2 \frac{f}{\sigma} \frac{\partial}{\partial p} (\beta u_s) \quad (6)$$

where the atmospheric static stability is expressed in units of length as:

$$\Gamma = \frac{R^2 T_s}{g^2} \left[ \frac{g}{C_p} \left( 1 - \frac{\mu_3 L P_s \partial r}{R \theta_s \partial p} \right) - \gamma \right]$$

The solution to Eq.(6) is of the form

$$\omega = A(P) P_2^{\frac{1}{2} + \lambda} + B(P) P_2^{\frac{1}{2} - \lambda} - \frac{4 C P^2}{9 - 4 \lambda^2} \quad (7)$$

where  $A$  and  $B$  are constants and

$$\lambda = \left\{ \left( \frac{1}{4} - \frac{g\Gamma(\alpha^2 + \beta^2)}{\sigma^2} \right) \left( 1 - \mu_1 \cdot \frac{\alpha u_s}{\sigma} \right) \right\}^{\frac{1}{2}}$$

Applying some boundary conditions (Adedoyin, 1997) to Eq.(6) results in:

$$\begin{aligned} & \{ [Q_1 \left( \frac{1}{2} + \lambda_1 \right) - H_B] + [Q_1 \left( \frac{1}{2} - \lambda_1 \right) - H_B] \cdot R_1 \} \cdot \frac{P_B^{\lambda_1}}{\sigma_1} \cdot A_1 \\ & + \{ [Q_2 \left( \frac{1}{2} - \lambda_2 \right) - H_B] \cdot R_2 - [Q_2 \left( \frac{1}{2} + \lambda_2 \right) - H_B] \} \cdot \frac{P_B^{\lambda_2}}{\sigma_2} \cdot A_2 = \\ & \{ [Q_1 \left( \frac{1}{2} - \lambda_1 \right) - H_B] \cdot R_3 + [2Q_1 - H_B] \} \cdot \frac{P_B^{\frac{1}{2}}}{\sigma_1} \cdot N_1 \\ & + \{ [Q_2 \left( \frac{1}{2} - \lambda_2 \right) - H_B] \cdot R_4 - [2Q_2 - H_B] \} \cdot \frac{P_B^{\frac{1}{2}}}{\sigma_2} \cdot N_2 \quad (8) \end{aligned}$$

$$\begin{aligned} & \{ 1 + R_1 \} \cdot \frac{P_B^{\lambda_1}}{\sigma_1} \cdot A_1 - \{ 1 - R_2 \} \cdot \frac{P_B^{\lambda_2}}{\sigma_2} \cdot A_2 = \\ & \{ 1 + R_3 \} \cdot \frac{P_B^{\frac{1}{2}}}{\sigma_1} \cdot N_1 - \{ 1 - R_4 \} \cdot \frac{P_B^{\frac{1}{2}}}{\sigma_2} \cdot N_2 \quad (9) \end{aligned}$$

where subscripts 'O', 'B' and 'T' respectively indicate values at the base, boundary and top of the two-layer model. Subscripts '1' and '2' indicate values within the model's lower(i.e. SW) and upper(i.e. NE) air masses, respectively, in the case of tropical north Africa.

Eqs. (8) and (9) are simultaneous in  $A_1, A_2$  and they can be written in matrix form. The method of solution of the matrix equation is contained in Appendix B. If Appendix B is applied to Eqs. (8) and (9) the result is:

$$\begin{aligned} & \sigma_0^2 \left\{ \left[ 2\lambda_1 \left( \frac{I+R_1}{I-R_1} \right) + I + D_1 \right] - \left[ 2\lambda_2 \left( \frac{I+R_2}{I-R_2} \right) + I + D_2 \right] \right\} \\ & + \sigma_0 \left\{ 2\alpha u_1 \left[ 2\lambda_1 \left( \frac{I+R_1}{I-R_1} \right) + I + D_1 \right] - 2\alpha u_2 \left[ 2\lambda_2 \left( \frac{I+R_2}{I-R_2} \right) + I + D_2 \right] \right\} \\ & + \left\{ \alpha^2 u_1^2 \left[ 2\lambda_1 \left( \frac{I+R_1}{I-R_1} \right) + I + D_1 \right] - \alpha^2 u_2^2 \left[ 2\lambda_2 \left( \frac{I+R_2}{I-R_2} \right) + I + D_2 \right] \right\} = 0 \quad (10) \end{aligned}$$

where

$$\begin{aligned} D_1 &= N_2 \sigma_2 (I - R_4) \left[ \lambda_1 (I - R_1) + \frac{1}{2} (I + R_1) \right] \\ D_2 &= N_2 \sigma_2 (I + R_1) \left( \frac{R_4}{2} - 2 \right) - N_2 \sigma_2 \lambda_2 R_4 (I + R_1) \\ &\quad - N_1 \sigma_1 \lambda_1 (I - R_1 + 2 R_3) + \frac{3}{2} N_1 \sigma_1 (I + R_1) \end{aligned}$$

## RESULTS AND DISCUSSION

Results show that some modes of the wave-like disturbances generated along the surface of discontinuity between the air masses propagate and amplify with time. In the case of West and Central Africa, this instability is found to be most-pronounced when the surface of discontinuity between the South-westerlies and the North-easterlies is at 700 hpa level. Further, it is shown that in Sahelian dry years, the zone of these unstable waves shifts slightly southwards. This shift causes a deficit in rainfall in West African isohyet bands north of latitude  $12^0$ . The persistence of this deficit is linked with the continuous warming, in July, August and September of the 18-year period 1969-1986, of the three oceans (Indian, Pacific and South Atlantic) whose sea-surface temperature(SST) anomalies influence rainfall in tropical north Africa. It is shown that anytime these oceans warm up anomalously, the strength of the AEJ is enhanced leading to the climate-change process of: SST anomaly, increased AEJ strength, southward shift of the zone of squall-inducing waves and consequent reduction in total annual rainfall north of latitude  $12^0$  in tropical North Africa. In the case of East and Southern Africa, a solution was obtained for a wave-like disturbance which has a phase speed of  $6.0 \text{ ms}^{-1}$  in the East-West direction, a wavelength of 2000 km, a period of 3.49 hours and growth rate of 3.6 per hour, when the surface of discontinuity between the North East monsoon and the South East Trade winds is at 500 hpa. It is shown that the axis of this wave is greatly influenced by the Indian ocean SST. A look at the ECMWF analyses for MSL and vertical velocity

at 400 hpa during a period of active convective activities over Botswana (15-21 February, 1995) confirmed the existence of this wave pattern. These results have applications, and implications, in the health and tourism sectors of some countries in Africa. Although the scheme developed has been applied to atmospheric dynamics, it can be used to study any wavelike disturbance at the interface between any two fluids of different densities.

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