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BAROTROPIC ENERGY CONVERSION AS A PREDICTOR OF DEVELOPMENT FOR NAMMA AFRICAN EASTERLY WAVES

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1. INTRODUCTION

This paper examines African easterly waves (AEWs) occurring during the NASA African Meteorology Multidisciplinary Analysis project (NAMMA) in the context of analysis and simple diagnostics using NCEP FNL analyses. A major goal of the 2006 NAMMA field experiment was to better understand why some AEWs develop into depressions and storms, and why some do not develop beyond the wave stage. Seven AEWs were studied during NAMMA with wave #2 developing into Tropical Storm Debby and wave #7 developing into Tropical Storm Helene (ultimately Hurricane Helene) both within the NAMMA domain. Two other waves developed into hurricanes beyond the NAMMA domain but they remained waves within the NAMMA region and were, thus, non-developers as far as their examination within the domain of the field experiment: wave #1 ultimately developed into Hurricane Ernesto, and wave #5 eventually developed into Hurricane Gordon. The remaining waves, wave #3, #4, and #6, were non-developers both within the NAMMA domain and beyond.

This research shows that the barotropic energy conversion at 700 hPa was a robust and definitive predictor of wave development. The waves that developed into Tropical Storms Debby and Helene within the NAMMA domain both had strong and unambiguous positive barotropic energy conversions, while all the remaining waves that were non-developers within the study region of NAMMA either had neutral or negative barotropic energy conversions.

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2. BAROTROPIC ENERGY CONVERSION

The barotropic energy conversion for zonal flow to eddies carries the following terms:

$$-u'v'\frac{\partial \bar{u}}{\partial y} \quad -v'^2\frac{\partial \bar{v}}{\partial y} \quad -u'\omega'\frac{\partial \bar{u}}{\partial p} \quad -v'\omega'\frac{\partial \bar{v}}{\partial p}$$

The prime terms are departures of the respective variable at a point from the zonal mean of that variable. The over bar indicates the zonal mean of the variable. The first term was found to be one or more orders of magnitude larger than the remaining terms and only that term will be utilized in the calculations presented here. We shall illustrate the importance of this barotropic conversion term for developing and non-developing NAMMA AEWs.

3. RESULTS

Non-developing wave #4 moved across the NAMMA domain from near the prime meridian on August 29, 2006 to near 45W by September 3, 2006. The axis of the wave trough was tilted northwest to southeast throughout, and the wind maximum was located *behind* the trough axis.

Fig. 1 presents a diagnosis of the barotropic energy conversion for wave #4 on August 31, 2006. Note the northwest to southeast tilt to the trough axis in Fig. 1a. With strong southeasterlies behind the wave trough axis and weaker northeasterlies ahead of this axis, uprime (Fig. 1b) is negative (positive) behind (ahead) of the trough axis, and vprime (Fig. 1c) is positive (negative) behind (ahead) of the trough axis. This produces a negative product of uprime*vprime both ahead of and behind the trough axis (Fig. 1e). Inspection of the meridional profile of ubar in Fig. 1d indicates that the African easterly jet (AEJ) is a maximum near 18N, so that the patterns just described are occurring to the south of this jet. This makes the meridional profile of ubar negative in our region of examination. All of this yields a negative result for the barotropic conversion term in Fig. 1f on both sides of the trough axis, but especially behind the trough axis for this particular wave. This means that eddy kinetic energy of the wave is being converted into zonal kinetic energy of the jet in a situation where the wave may be considered barotropically stable.

Developing wave #7 moved across the NAMMA domain from near 5E on September 8, 2006 to near 30W by September 13, 2006. This wave ultimately developed into Hurricane Helene. The axis of the wave trough was tilted northeast to southwest throughout, and the wind maximum was located *ahead of* the trough axis.

The barotropic energy conversion for wave #7 is diagnosed on September 9, 2006 in Fig. 2. Note the northeast to southwest tilt to the trough axis in Fig. 2a. With strong northeasteries ahead of the wave trough axis and weak southerlies behind this axis, uprime (Fig. 2b) is negative (positive) ahead (behind) the trough axis, and vprime (Fig. 2c) is negative (positive) ahead (behind) the trough axis. This produces a positive product of uprime*vprime both ahead of and behind the trough axis. The meridional profile of ubar in Fig. 2d shows that the AEJ is a maximum near 16N, such that the patterns just diagnosed are occurring to the south of this jet. This makes the meridional profile of ubar negative in our region of concern. All of this yields a positive result for the barotropic conversion term in Fig. 2f. This means that zonal kinetic energy of the jet is being converted into eddy kinetic energy of the wave, or the wave is barotropically unstable. This conversion occurs on both sides of the trough axis, which is a very interesting result. There is one more region of interest, and this is the region of negative barotropic conversion (barotropic stability) seen near 3W, 18N in Fig. 2f. This region is to the north of the AEJ maximum, and the configuration of uprime, vprime, and the meridional profile of ubar is such that the kinetic energy of the jet is increasing at the expense of the kinetic energy of the eddy (wave). Thus, a barotropic mechanism is in place to the north of the jet to help maintain the jet. This pattern was seen repeatedly for developing NAMMA waves. Specifically, uprime and vprime are both negative, and the meridional profile of ubar is positive in the cited region, which produces the negative barotropic conversion.

4. SUMMARY

The same signatures, described in Figs. 1 and 2, were seen repeatedly for all of the NAMMA non-developing and developing waves, respectively. Thus, it is very reasonable to conclude that the barotropic conversion term as calculated here is a robust and definitive tool for assessing the potential for development of a given AEW. Specifically, the barotropic instability of developing waves was seen to be very active as the wave developed from the wave to the depression stage. The term was less important after the depression formed, and presumably not important for the further development of the system into a tropical storm. It is reasonable to view this further development to tropical storm stage as being critically dependent on convective processes. However, the role of dynamics appears very important in the earlier stages. Satellite images often show convective clouds in developing waves but those are generally not organized on the scale of the wave itself.

5. REFERENCES

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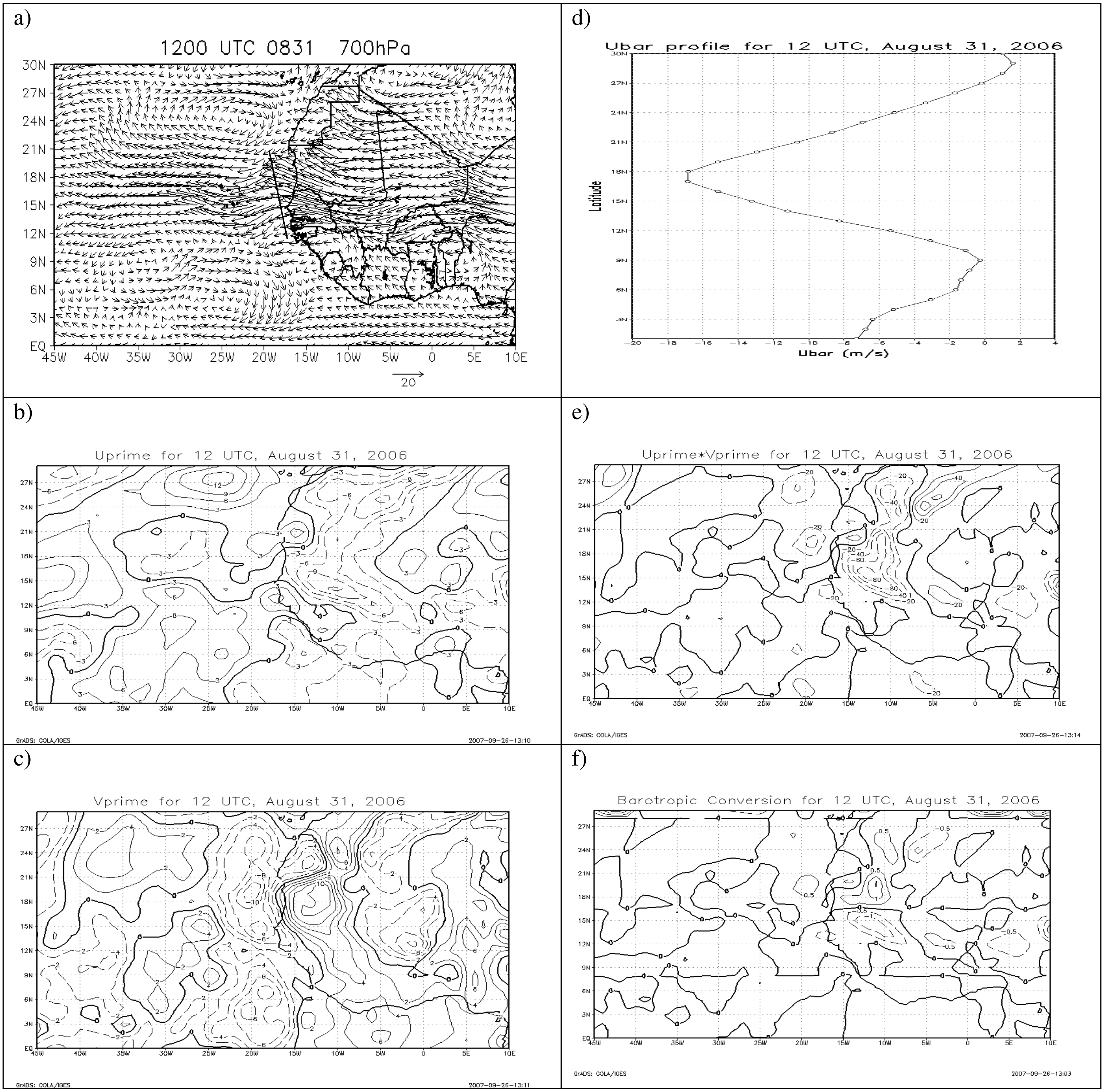

Fig. 1. Barotropic conversion depiction at 700 hPa for 12 UTC, 31 August 2006: (a)wind vectors (b) Uprime (c) Vprime (d) Ubar profile (e) Uprime*Vprime (f) barotropic conversion term. Bold line in (a) indicates trough axis of NAMMA non-developing Wave #4. Wind units are ms^{-1} and energy conversion units are 10^{-2} Wkg^{-1}.

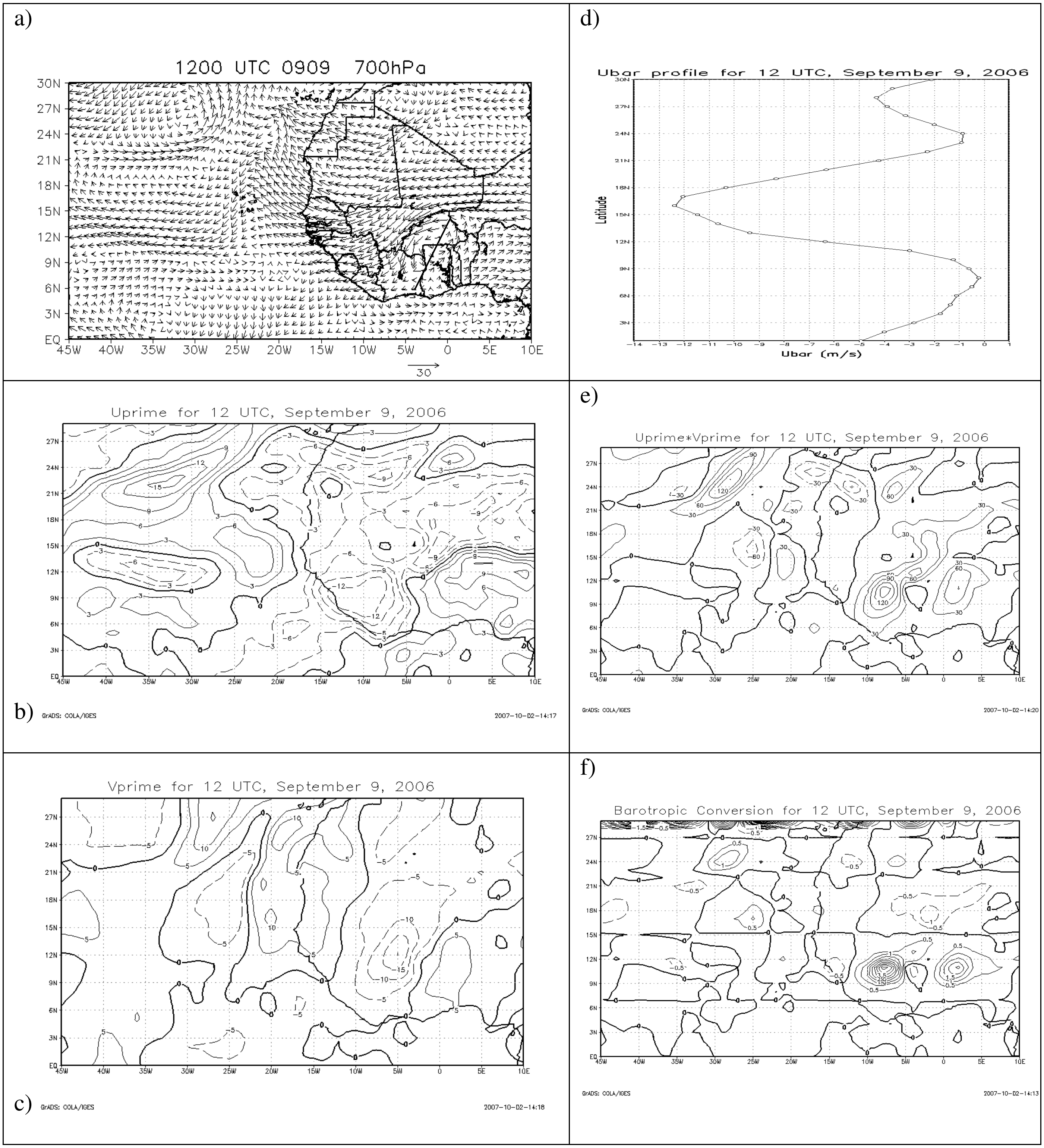

Fig. 2. Barotropic conversion depiction at 700 hPa for 12 UTC, 9 September 2006: (a) wind vectors (b) Uprime (c) Vprime (d) Ubar profile (e) Uprime*Vprime (f) barotropic conversion term. Bold line in (a) indicates trough axis of NAMMA developing Wave #7. Wind units are ms^{-1} and energy conversion units are 10^{-2} Wkg^{-1}.