Comments on "Dry-Season Precipitation in Tropical West Africa and Its Relation to Forcing from the Extratropics"

THOMAS SPENGLER

Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland

JOSEPH EGGER

Meteorological Institute Munich, University of Munich, Munich, Germany

(Manuscript received 13 January 2009, in final form 12 May 2009)

Knippertz and Fink (2008, hereafter KF08) analyze the synoptic evolution of a precipitation event in the Sahel zone, which is proposed to be triggered by extratropical interactions. Their dynamical interpretation of the evolution is mainly based on an "alternative" predictive equation for the surface pressure, which is derived in their appendix and is adapted from Kong (2006). Their pressure tendency equation before vertical integration [Eq. (A10) in KF08] reads

$$\frac{\partial}{\partial z}\left(\frac{1}{\rho}\frac{\partial p}{\partial t}\right) = g\left[-\mathbf{v}\cdot\nabla_p \ln T_v + \frac{R}{g}\left(\frac{g}{c_p} + \frac{\partial T_v}{\partial z}\right)\frac{\omega}{p} + \frac{\dot{Q}}{c_p T}\right], \tag{1}$$

where $\dot{Q}$ is the heating rate and

$$\omega = \frac{\partial p}{\partial t} + \mathbf{v}\cdot\nabla p$$

is the vertical velocity in pressure coordinates.

The derivation of (1) in Kong (2006) and KF08 combines the first law of thermodynamics with the hydrostatic tendency equation,

$$\frac{\partial^2 p}{\partial t \partial z} = -g\frac{\partial \rho}{\partial t}. \tag{2}$$

Note that the terms on the right-hand side of (1) are expressed in pressure coordinates. We disregard moisture effects in the sequel, thus T_v is replaced by T (see however rain and evaporation equation below). Equation (1) appears to be formally correct and seems to imply that heat sources and vertical motions affect the hydrostatic surface pressure instantaneously. This contradicts the tendency equation for the hydrostatic surface pressure at $z = 0$ which, following from (2) assuming $\partial p/\partial t|_\infty = 0$, yields

$$\frac{\partial p_s}{\partial t} = -g\int_0^\infty \nabla\cdot(\rho\mathbf{v})\,dz, \tag{3}$$

according to which it is only the mass convergence aloft that has an effect on the hydrostatic surface pressure tendency.

The first point to be made is that the derivation in KF08 involves the following assumption

$$\frac{1}{\rho}\frac{\partial p}{\partial t} = 0 \tag{4}$$

at the top of the atmosphere ($z \to \infty$), which is not justified (see below).

Second, even though (1) appears to be an equation for the hydrostatic pressure tendency it should be noted that ω, which contains a local pressure tendency as well, appears on the right-hand side of (1). Thus, the tendency equation in KF08 is implicit, since a local pressure tendency is found on both sides of (1).

One could argue that ω is a generalized velocity in the pressure system and that, therefore, ω does not contain information on the pressure tendency at a certain location. However, the integration of (1) over z requires just this information. In particular, one has to know ω, thus the pressure tendency, at the surface, before calculating the tendency following (1).

Corresponding author address: Dr. Thomas Spengler, Institute for Atmospheric and Climate Science, ETH Zurich, Universitätsstrasse 16, ETH Zentrum, CH-8092 Zurich, Switzerland.
E-mail: thomas.spengler@env.ethz.ch

DOI: 10.1175/2009MWR2942.1

© 2009 American Meteorological Society

Unauthenticated | Downloaded 05/14/21 10:20 AM UTC

Another way to proceed along the lines of KF08, but in the z system, is to use the first law of thermodynamics as a prognostic equation for pressure:

$$\frac{dp}{dt} = -\gamma(p\nabla \cdot \mathbf{v}) + \rho R \frac{\dot{Q}}{c_v}, \qquad (5)$$

where $\gamma = c_p/c_v$.

Equation (5) demonstrates immediately that the assumption in (4) is invalid but even more importantly, (5) is the prognostic equation for the nonhydrostatic pressure that can, for example, be used to predict the nonhydrostatic surface pressure.

However, this equation cannot be converted to a hydrostatic pressure forecast equation. Instead we can derive an equation for w, the vertical velocity, from (5) yielding

$$\gamma p \frac{\partial w}{\partial z} = \gamma p \left(\frac{\dot{Q}}{Tc_p} - \nabla_h \cdot \mathbf{v}_h \right) - \mathbf{v}_h \cdot \nabla_h p - w \frac{\partial p}{\partial z} - \frac{\partial p}{\partial t}, \qquad (6)$$

which can be combined with the hydrostatic pressure tendency in (3) (assuming that $\partial p/\partial t|_\infty = 0$), where p now refers to the hydrostatic pressure, in order to obtain the Richardson equation (Richardson 1922),

$$\gamma p \frac{\partial w}{\partial z} = \gamma p \left(\frac{\dot{Q}}{Tc_p} - \nabla_h \cdot \mathbf{v}_h \right) - \mathbf{v}_h \cdot \nabla_h p + g \int_s^\infty \nabla_h \cdot (\rho \mathbf{v}_h)\, dz, \qquad (7)$$

which is needed to compute w in hydrostatic flow by integration over z.

In other words, the hydrostatic pressure tendency in (3) is the only equation that exists to compute the hydrostatic surface pressure tendency. If there were another equation we could immediately derive a diagnostic equation that would deviate from the Richardson equation, which to our knowledge is not possible.

It follows that synoptic advection, vertical motion, and diabatic heating do not play the assigned roles in causing a surface pressure tendency as proposed by KF08. Accordingly the interpretation of their Figs. 9, 12, and 13 needs adjustment.

Finally, we would like to comment on the effects of moisture and rain on the surface pressure tendency. Note that the atmospheric density in (3) contains moisture, where moisture transport convergences affect the surface pressure. Precipitation and evaporation are not included in (3). However, this can easily be done by adding two terms in (3)

$$\frac{\partial p_s}{\partial t} = -g \int_s^\infty \nabla \cdot (\rho \mathbf{v})\, dz - gP + gE, \qquad (8)$$

where P is precipitation rate and E the evaporation rate (kg s^{-1} m^{-2}) at the surface.

Acknowledgments. We thank P. Knippertz and A. Fink for some clarifying remarks on an earlier version of this comment.

REFERENCES

Knippertz, P., and A. H. Fink, 2008: Dry-season precipitation in tropical West Africa and its relation to forcing from the extratropics. *Mon. Wea. Rev.,* **136,** 3579–3596.

Kong, K.-Y., 2006: Understanding the genesis of Hurricane Vince through the surface pressure tendency equation. Preprints, *27th Conf. on Hurricanes and Tropical Meteorology,* Monterey, CA, Amer. Meteor. Soc., 9B.4. [Available online at http://ams.confex.com/ams/pdfpaper/108938.pdf.]

Richardson, L. F., 1922: *Weather Prediction by Numerical Process.* 1st ed. Cambridge University Press, 236 pp.

Unauthenticated | Downloaded 05/14/21 10:20 AM UTC