Review of "A Climatology of Tropical Wind Shear Produced by Clustering Wind Profiles from a Climate Model" by Muetzelfeldt et al. (2020)

The procedure for producing a climatology of tropical wind shear from the UK Met Office Unified Model (UM) is a significant step forward regarding quantification of the physical and dynamical efficacy of global climate models (GCMs). Arguably, it should be a standard diagnostic for GCMs regarding the treatment of moist processes, such as convection and the atmospheric water cycle. It is likely that behavior will vary among GCMs because the unification of observations and models is a significant challenge. Observations, convection-resolving models, and dynamical theory show that vertical wind plays a key role in organized moist convection. But organized convection such as mesoscale convective systems (MCS) are missing from GCMs -- not represented by contemporary convective parameterizations and GCMs have insufficient resolution to adequately simulate them.

I strongly advocate this manuscript, but it has deficiencies that require attention:

1) Distinction between vertical-shear/cold-pool interaction in the tropics and mid-latitudes. Thorpe et al. (1982; TMM) pertains to mid-latitudes where mesoscale downdrafts and cold pools tend to be strong. Cold-pools are much weaker in the tropics (especially over oceans) so the balance mechanism between low-level shear and cold-pool vorticity (Rotunno et al. 1988; RKW) is significantly different (see item 4). It is therefore misleading to cite TMM and RKW in the first sentence of a manuscript pertaining to tropical conditions. See Grant et al. (2020) for more information on such concerns.

2) The remark on line 101 "could lead to the development of shear-aware convective parameterization schemes" is redundant or misleading. That subject has been comprehensively addressed using two world-class GCMs. Moncrieff et al. (2017; MLB) and Moncrieff (2019) are shear-aware. In MLB approximations of the heat and momentum transport tendencies are based on dynamical models of squall-lines, MCSs and tropical superclusters with particular attention to "slantwise layer overturning" that primarily distinguishes organized systems in shear from ordinary cumulus convection. (See item 5 below for some detailed comments.) When implemented in the atmosphere-only NCAR CAM, slantwise overturning improves the tropical distribution of precipitation, the Madden-Julian Oscillation, and convectively coupled Kelvin waves. It has even stronger impact when implemented with different shear triggers in Department of Energy (DOE) Exascale Energy Earth System Model (E3SM) atmosphere-only and coupled versions (Chen et al. 2021, in review). A key category of organization involves systems that propagate upshear e.g., squall lines and MCS (also tropical superclusters Moncrieff & Klinker 1997) which indicates an interesting scale-invariance. The upscale effects of upshear propagating tropical systems have been recently quantified in an idealized GCM (Yang et al. 2019).

3) Section 3.1: There is surprisingly little sign of lower-tropospheric tropical easterly jet-like shear in the Indian Ocean, Maritime Continent, tropical Western Pacific which are primary regions for squall-lines, MCSs, and superclusters in association with vertically sheared (tropical easterly jet) environments. This is anticipated to negatively impact the occurrence of MJOs and convectively coupled Kelvin waves in these locations.

4) Section 4.2 Venezuelan squall lines. This application of field-measurements and dynamical model verification strengthens the scientific case. Note that Betts et al. Fig. 6 shows the system-relative inflow is entirely from ahead of the squall-lines for bot updrafts and downdrafts and cool mesoscale downdrafts are replaced by forced ascent adiabatic cooling.. The weak mesoscale inflow from the rear of the squall lines does not reach the Earth's surface. This organized structure is represented by the Moncrieff & Miller (1976) propagating squall-line model, but is not consistent with TMM and RKW ideas.

5) The key role of vertical shear on organized convection is summarized by nonlinear dynamical models, which provide the momentum and heat fluxes for slantwise layer overturning. a) Moncrieff and Green (1972) showed long-lived organized convective overturning in constant vertical shear is controlled by CAPE and inflow available kinetic energy (AKE) supplied by sheared inflow and system propagation. These two categories of energy are interdependent in the form of a convective Richardson number Ri = CAPE/AKE. The vertical shear is strong because Ri ~ 1. The organized convective system slants downshear and mesoscale downdrafts do not exist. b) The Moncrieff and Miller (1976) three-dimensional propagating tropical squall-line model features a third category of energy -- work done by a convectively generated horizontal pressure change across the system. This organization is controlled by the Bernoulli number defined as pressure work divided by AKE. c) TMM mid-latitude squall lines model is controlled by the Bernoulli number and the convective Froude number (proportional to the inverse convective Richardson number). d) The Moncrieff (1992) two-dimensional archetypal model features three categories of organization: wave-like propagation; hydrodynamic limit of TMM; and a system whereby jump-like ascent replaces the mesoscale downdraft.

6) The above classes of model indicate that CAPE and vertical shear are interdependent quantities, and mean-flow conditions exist whereby kinetic energy of system propagation and work done by the horizontal pressure gradient are the principal sources of energy rather than CAPE. Summarizing, strong upper-tropospheric shear is problematic because the convective system slants downshear and downdrafts are suppressed. When the upper-tropospheric shear is weak, the updrafts can slant upshear, so precipitation falls into sub-saturated air and generate mesoscale downdrafts in squall lines and MCSs. It is maximally beneficial when the upper-tropospheric shear reverses direction (i.e., tropical jet-like wind profiles). Families of cumulonimbus then get initiated at the leading edge of the mesoscale downdraft outflow and travel rearward relative to the MCS, a procedure continually repeats and generate the key horizontal pressure gradient (see Lafore and Moncrieff 1989). This optimal category of upshear slantwise overturning is the workhorse of the MLB shear-aware organized convection parameterization scheme.

Signed: Mitchell W. Moncrieff (February 9, 2021)

References:

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