VVTURB
Scientific Description

Background

Turbulence associated with convection is very ubiquitous. Most aviation products forecasting thunderstorms have disclaimers that any thunderstorm forecast implies severe turbulence. Byers and Braham (1949) analyzed 809 aircraft penetrations from the Thunderstorm Project and computed a positive linear correlation (r = 0.42) of maximum vertical gust velocity and updraft speed. They characterized most penetrations with maximum vertical gust velocity > 4.5 m sec^{-1} as heavy or severe. This corresponds to about a 10 m sec^{-1} updraft. Lightning in convective updrafts generally does not develop with updraft speeds less than about 8 m sec^{-1}, thus justifying the disclaimer.

Since significant updrafts typically do not occur outside of cloudy areas, one may infer that moderate turbulence can occur with updraft speeds at some threshold less than 10 m sec^{-1}. Furthermore, lightning usually does not develop until the updrafts reach the -15C to -20C isotherm, and even clouds with updrafts > 10 m sec^{-1} may not ingest enough moisture to produce particles large enough to create lightning. For these reasons, there are many convectively-generated clouds causing moderate turbulence and not producing lightning.

Wolff et al.(2002) showed that 40% of moderate or greater turbulence pilot reports are within clouds. After accounting for reports in cumulonimbus clouds, there likely is a substantial number of missed reports using typical turbulence forecasting methods.

The VVTURB Algorithm

Using the Thunderstorm Project data, Bates (1955) estimated a linear regression line fitting the data:

$$U_* = 0.3w + 2$$

where U_* is the maximum gust velocity and w is the draft velocity, both in m s^{-1}. Physically, the regression line should predict intersect the origin (0,0), i.e., there should be zero gust velocity with zero draft velocity. One can create a more realistic relationship from a line that both intersects (0,0) and (10,4.5):

$$U_* = 0.45w$$

Although the highest draft velocity in the data was about 20 m s^{-1}, Byers and Braham's fit of the data flattens with $w > 10$ m s^{-1}, suggesting a line

$$U_* = 4.5 + 0.2(w - 10.0) \quad w > 10.0$$

This pair of lines has a correlation coefficient, $r = 0.64$ with the data.

Since other experimental AWC turbulence algorithms quantify turbulence with turbulent kinetic energy dissipation (TKE), U_* may be converted to TKE by assuming that the U_* threshold for heavy/severe turbulence in Byers and Braham ($U_* = 4.5$ m s^{-1}) is the same as the McCann (1999) TKE threshold for severe turbulence ($TKE_\varepsilon = .035$ j s^{-1}) or

$$TKE_\varepsilon = 0.0078 U_*$$

By inference, a 4.5 m s^{-1} draft will produce moderate turbulence using the similar McCann threshold. Also, this yields a $TKE_\varepsilon = .098$ j s^{-1} for a 50 m s^{-1} vertical velocity, an amount probably equating to extreme turbulence which may be expected in such a strong updraft.

In order to diagnose the areas of thunderstorms from the numerical model forecast data, VVSTORM must compute all potential upward convective vertical velocities at all levels, even those less than thunderstorm strength. Therefore, VVSTORM straightforwardly computes the TKE_ε. Note that presently VVSTORM does not compute downdrafts so the TKE may be underestimated in lower levels where downdrafts are important.

Operational interpretation

Verification of turbulence associated with convection with pilot reports is nearly an impossible task because pilots rarely report the cause of the turbulence. In theory, one could gather pilot reports in convective areas and establish a false alarm ratio, but that would be incomplete verification. Only when turbulence and environmental conditions are purposely observed in convection can a relationship be found. The Thunderstorm Project turbulence/draft database is one of the largest known where aircraft purposely penetrated convection.

Given a storm top and an environmental sounding, the moist adiabat along which the lifted parcel rises is known and, therefore, the storm's updraft speed is known at all levels. Radar echo top data for 318 sample thunderstorm systems gathered during the spring and summer, 2001, show 86% of VVSTORM storm tops to be within plus or minus 10,000 feet with no significant bias. Since the VVSTORM updraft speeds are reasonable, the expected turbulence should also be reasonable.

Because TKE_{ε}, as computed by VVTURB, is scaled to the TKE thresholds found by McCann (1999), the interpretation is similar, i.e. 0.016 j s^{-1} for moderate turbulence and 0.035 j s^{-1} for severe turbulence.

References

Bates, F.C., 1955: A technique for predicting extreme turbulence related to thunderstorms. *Bull. Amer. Meteor. Soc.*, **36**, 379-383.

Byers, H.R. and R.R. Braham, 1949: *The Thunderstorm, Report of the Thunderstorm Project,* U.S. Weather Bureau, Dept. of Commerce, 287 pp.

McCann. D.W., 1999: A simple turbulent kinetic energy equation and aircraft boundary layer turbulence. *Natl. Wea. Digest*, **23(1,2)**, 13-19.