Forecasting Upper Tropospheric Turbulence within the Framework of the Mellor-Yamada 2.5 Closure

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The role that vertical turbulent fluxes of momentum above the boundary layer should play in affecting a model's performance has recently been a part of a comprehensive budget study. As a result, ECMWF has reduced to "practically zero" the tendencies due to vertical fluxes above the boundary layer in its operational model (Klinker and Sardeshmukh 1992). With models increasingly containing complex turbulence kinetic energy (TKE) schemes prospects are arising of not only gaining more direct information on such issues but also of using models' TKE predictions in their own right. One effort in this vein is that of Richard et al. (1989). In another, aiming inter alia to compare pilot reports of turbulence against predictions of the U.S. National Meteorological Center's (NMC's) Eta Model, Marroquin et al. (1992) found no upper tropospheric TKE worth any mention in forecasts they looked into. Note that the Eta Model includes the Mellor-Yamada 2.5 turbulence closure (Janjić 1990) with TKE as one of the prognostic variables.

This being somewhat disturbing, upper tropospheric TKE plots for a total of four 48-h "80 km / 17 layer" Eta Model integrations were produced at NMC and inspected. Examining forecasts at 12-h intervals, in three out of four cases substantial amounts of upper tropospheric TKE were noted. Turbulence speed maxima were as high as more than 1 to 3 m s^{-1}.

One difference between the model as used for the forecasts that Marroquin et al. investigated and that used for the four cases subsequently run at NMC was that the latter contained the stability dependent parameterization of the master length scale, l, (Mesinger, this issue) instead of the earlier boundary-layer type Blackadar scheme. However, this seemed a poor candidate to explain the apparent difference in the behavior of the two models since both the shear and the buoyancy TKE production terms

$$P_s = S_M G_M q^3 l^{-1}, \qquad P_b = S_H G_H q^3 l^{-1}, \tag{1}$$

in view of

$$G_M \equiv l^2 q^{-2} [(\partial U/\partial z)^2 + (\partial V/\partial z)^2], \qquad G_H \equiv -l^2 q^{-2} \beta g \,\partial\Theta_v/\partial z, \tag{2}$$

are proportional to l, and the stability dependent l scheme was in the upper troposphere with no appreciable TKE giving values of l more than two orders of magnitude smaller than the Blackadar scheme. Even so, when one of the three TKE endowed cases was rerun with the Blackadar scheme, instead of the substantial upper tropospheric TKE which at one of the four output times previously was present, negligible TKE values were obtained.

The missing link of this puzzle was found in the clipping imposed on G_H and G_M (Janjić 1990; see also Mellor and Yamada 1982)

$$G_H \leq 0.024, \qquad G_M \leq 0.36 - 15\, G_H. \tag{3}$$

Since the first restriction of (3) is imposed only when G_H is positive, and enforcement of either one or both of (3) leaves G_H as well as G_M non-negative, one can see from (2) that an exercise of (3) is equivalent to a reduction in l. Yet, in the final evaluation of the sum of the production and dissipation terms,

$$P_s + P_b - \varepsilon = (S_M G_M + S_H G_H - B_1^{-1})\, q^3 l^{-1}, \tag{4}$$

an unreduced l was used. When the code was ammended so that the enforcement of (3) be achieved via a reduction in l, use of the Blackadar scheme with its much larger upper tropospheric values of l indeed resulted in turbulence speeds (Fig. 1, left hand panel) which tended to be greater than those obtained with the stability dependent l scheme (right hand panel).

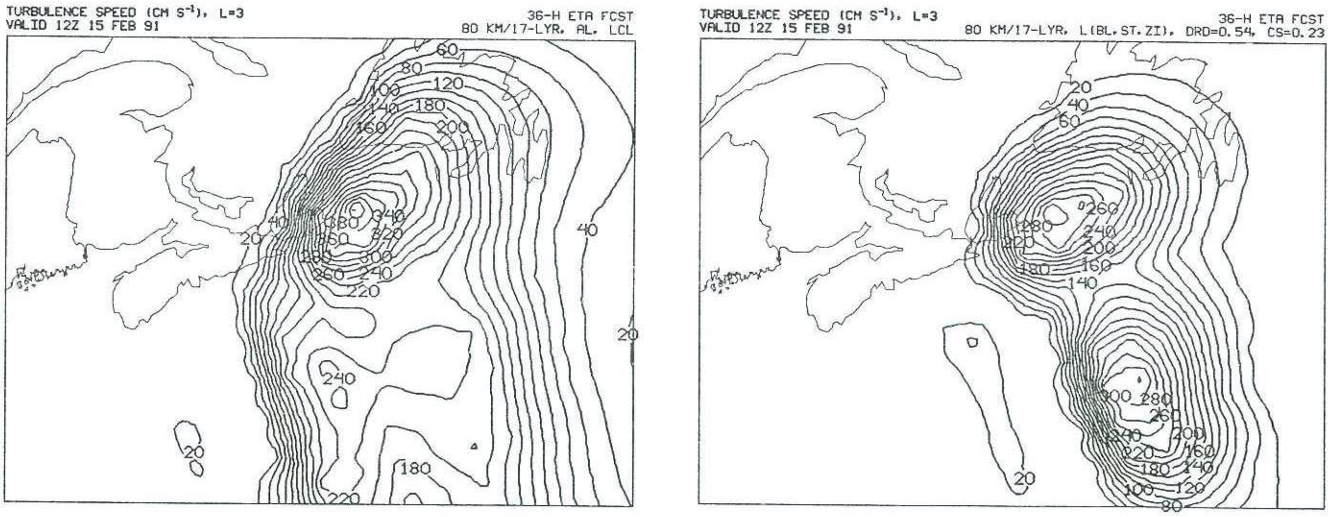

Fig. 1. Turbulence speed (cm s^{-1}) at the interface 3/4 (about 250 mb) of the "80 km / 17 layer" Eta Model, obtained using the Blackadar scheme for the prescription of l and clipping of l to enforce (3), left hand panel; and same, but with the stability dependent scheme for the prescription of l (Mesinger, this issue), right hand panel. The sections of the model domain shown encompass 10 deg of latitude from their southern to northern boundaries.

With the definition of the master length scale being perhaps the weakest point of the Mellor-Yamada closure scheme, one can take some comfort in noting that schemes which before a turbulence episode gave drastically different values of l still resulted in upper tropospheric turbulence at the same time and place and with patterns as similar as those in the figure.

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