Clear-Air Turbulence Parameterisation for Long-Range Applications of a Lagrangian Particle Model

Petra Seibert and Andreas Frank
Institute of Meteorology and Physics, University of Agricultural Sciences, Vienna, Austria
WorldWideWeb http://www.boku.ac.at/imp/envmet/
E-mail: petra.seibert@boku.ac.at - andreas.frank@boku.ac.at

Introduction
Transport and dispersion models usually include parameterisations for turbulence in the atmospheric boundary layer (ABL). However, long-range transport often takes place above the ABL (I), and studies of transport processes in the free atmosphere, e.g., of stratospheric intrusions in the troposphere, are becoming more common (7). Presently, offline transport models either ignore turbulence outside the ABL or treat them in a very crude way. For example, the Lagrangian particle dispersion model (LPDM) Flexpart (7), which we are using, applies a "background" turbulence characterised by standard deviations $n_u$, $n_v$, $n_w$ of the wind components proportional to the variance of the mean wind, plus a horizontal turbulent mixing. The latter is constant in time and horizontally uniform. In the ABL, it depends on the gradient of the mean wind. Here, a parametrisation for subgrid-scale convective transports was added (7).

We have now developed a parameterisation for shear-induced turbulence. This type of turbulence is often subsumed under the term clear-air turbulence or CAT (in contrast to turbulence in convective clouds). However, CAT events can also be caused by breaking of gravity waves. Thus, we use the abbreviation sCAT for shear-induced CAT. The scheme is described on this poster. It consists of two steps:

1. Determination of turbulent regions
2. Quantification of turbulence in these regions

We present examples and a 1-month climatology of sCAT as diagnosed by this scheme.

Determination of turbulent regions
The determination of the turbulent regions is based on a modified version of the CAT index T2 after I. It emerged as one of the best indicators in a comparative study of CAT indicators based on aircraft turbulence data and pilot reports (7). The original T2 index is defined as:

$$T2 = (n_v - n_u) / 3$$

where $n_v$ is the vertical component of turbulence intensity and $n_u$ is the horizontal component. As we have used a constant structure (which is the inverse of $n_u$), we are mainly concerned with the vertical component. To reduce the amount of "false alarm" cases, a few smaller modifications were also made:

- Elimination of all isolated one-grid cell patches (corroborated by findings in the validation studies that CAT probability is smaller for small contiguous area diagnosed as CAT-patches).
- Consideration of static stability. The Richardson number contains both components proportional to the variance of the mean wind.

We see that at the 8 km level sCAT is concentrated along the mid-latitude jet positions, whereas at the 9 km level, sCAT is mostly found in high and mid-latitudes, tied to synoptic systems (jet streams). Some turbulence is also found close to the ABL top. This could be due to low-level jets. The fact that high turbulence is related to high vertical wind shear (which is the inverse of $n_u$) is clearly visible in the scatter plot.

Quantification of turbulence
For the implementation in a LPDM, turbulence needs to be quantified in terms of the standard deviation of the shear, $S_{v-w}$, and the related Lagrangian time scale, $\tau$. Explicit horizontal turbulence is not considered, as the combined effect of $n_u$ and $VWS$ is expected to dominate the horizontal mixing.

We rely on one of the standard turbulence parameterisation schemes of the MM5 model, successfully applied for the simulation of turbulent decay of stratiform intrusions in an idealised set-up. It calculates the vertical turbulent diffusion coefficient $\kappa'/'$ for regions where the numerically approximated, grid-scale Richardson number $\text{Ri}_g$ exceeds its critical value $\text{Ri}_c$, as

$$\kappa'/' = K = \frac{S_{v-w}}{\tau}. \frac{\text{Ri}_g}{\text{Ri}_c}$$

where $\text{Ri}_c$ is a dimensionless constant of the order of 1 and is a length scale, assigned a constant value of 40 m by T2. It would be desirable to make $\tau$ dependent on the static stability, but we have not yet found a suitable approach.

As numerous aviation meteorology studies have shown that $\kappa'/'$ derived from NWP products is not a good CAT predictor in practice, we replace this term by the inverse of our turbulence index. We have $\kappa'/' = \frac{1}{\text{Ri}_g}$ and scaling arguments for $\tau$, get

$$\frac{S_{v-w}}{\tau} = \frac{1}{\text{Ri}_g} \left( \frac{n_u}{n_v} \right), \quad \text{Ri}_g = \frac{n_v}{n_u}$$

where $n_v$ transmits constant of the order of 1. Lacking better information, for the moment we assume $\text{Ri}_g = 1$.

We see that at the 8 km level sCAT is concentrated along the mid-latitude jet positions and over some polar areas (the reason for the latter phenomenon is not clear). It is absent in the tropical region.

At 15 km, sCAT is much less frequent and seems to be related to the subtropical jet.

References

Results - Single case
Application to ECMWF fields, 1° x 60 km
Example of the $\kappa'/'$ field (2000-01-05, 00UTC)

Horizontal field of $\kappa'/'$ in $\text{m}^2 \text{s}^{-1}$ at 8700 m agl

Results - Regional Climatology
These results are based on 1° x 31 level ECMWF data of the years 1995-1997. They show the percentage of sCAT occurrence in spring and summer at three different levels.

Results - Global Climatology
The mean frequency of sCAT at 8 km agl during October 2000.

Conclusions and outlook
A scheme has been developed to diagnose regions of shear-induced turbulence in the free atmosphere from NWP model output, and to derive the necessary quantities for implementation in a LPDM. A basis for better determination of the constants (I, $\text{Ri}_g$, $\kappa'/'$) and a stability-dependent formulation for $\kappa'/'$ would, however, be desirable. The next steps will be to collect practical experience with the scheme. However, validation is hampered by the fact that most long-range tracer experiments include only a few useful measurements in the free atmosphere, if at all.

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