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CLEAR-AIR TURBULENCE PARAMETERISATION FOR LONG-RANGE APPLICATIONS OF A LAGRANGIAN PARTICLE MODEL

Petra Seibert* and Andreas Frank
University of Agricultural Sciences Vienna, Austria

1. INTRODUCTION

Transport and dispersion models usually include parameterisations for turbulence in the atmospheric boundary layer (ABL). However, longrange transport often takes place above the ABL (Stohl, 1999), and studies of transport processes in the free atmosphere, e.g., of stratospheric intrusions in the troposphere, are becoming more common (Stohl, 2001). Presently, off-line 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 (Stohl et al., 1998), which we are using, applies a "background" turbulence characterised by standard deviations $\sigma_{u,v,w}$ of the wind components proportional to the variance of the mean wind components around the point under consideration and a fixed Lagrangian time scale T_l plus a horizontal meandering with a fixed $\sigma_{u,v}$=0.3 ms^{-1} and a T_l of 3600 s. Recently, a parameterisation for subgrid-scale convective transports was added (Seibert et al., 2001).

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.

2. DETERMINATION OF TURBULENT REGIONS

A lot of studies about sCAT have been performed by aviation meteorologists. Aircraft turbulence data and pilot reports have been collected and analysed to develop and validate turbulence indices for use in aviation forecasts. Therefore, we base our parameterisation on the outcome of these studies. The index TI2 after Ellrod and Knapp (1992) is one of the best indicators of CAT (Bysouth, 1998). It is defined as the product of the absolute value of vertical shear of the horizontal wind (VWS) and the sum of deformation and convergence. It is a parameterisation of a kinematic quantity, namely the frontogenetic intensity $\partial|\nabla\theta|/\partial t$. We reverted to a formulation for this quantity which involves fewer simplifications than the original one. It reads

$$\Theta = \frac{-1}{\sqrt{{\theta_x}^2+{\theta_y}^2}}\,[(\theta_x)^2 u_x + \theta_x(\theta_y v_x + \theta_y u_y) + (\theta_y)^2 v_y],$$

**Corresponding author address:* Dr. Petra Seibert, Institute of Meteorology und Physics, University of Agricultural Sciences Vienna, Türkenschanzstr. 18, A-1180 Wien, Austria; e-mail: seibert@boku.ac.at

where Θ is our modified turbulence index, θ denotes potential temperature and u, v are the horizontal wind components. Subscripts denote partial derivatives which are taken on pressure levels.

A few smaller modifications were also made. We eliminated all isolated one-grid cell patches, corroborated by findings in the validation studies that the probability of aircraft encountering CAT is smaller if the contiguous area diagnosed as CAT-prone by the turbulence index is small. The original index does not include a measure of the static stability although the Richardson number, which indicates the potential for turbulent kinetic energy production, contains both VWS and stability. Therefore, sCAT is diagnosed frequently in the stratosphere, a region where the index was not validated and for which it is not meant. To avoid that, we excluded all regions where the static stability exceeds the value assumed for the thermal tropopause definition, –0.2 K / 100 m.

3. IMPLEMENTATION IN A LAGRAGIAN PARTICLE DIFFUSION MODEL

For the implemenation in a LPDM, turbulence needs to be quantified in terms of σ_w and T_l. No explicit horizontal turbulence is considered as the combined effect of σ_w and VWS is expected to dominate. Here we rely on one of the standard turbulence parameterisation schemes of the MM4 model, which has successfully been applied for the simulation of turbulent decay of stratospheric intrusions in an idealised set-up (Hartjenstein, 2000). It calculates the vertical turbulent diffusion coefficient K for regions where the numerically approximated, grid-scale Richardson number Ri exceeds its critical value Ri_c as

$$K = Al^2 \left|\frac{\partial\vec{V}}{\partial z}\right| \frac{Ri_c - Ri}{Ri_c}$$

where A is a dimensionless constant of the order of 1, and l is a length scale, assigned a constant value of 40 m by Hartjenstein (2000). It can easily be modified to become dependent on the static stability. As numerous aviation meteorology studies have shown that Ri derived from NWP products is not a good CAT predictor in practice, we replace this term by the inverse of our turbulence index. The vertical turbulent velocities are calculated as $\sigma_w = K/l$. Thus, we get:

$$\sigma_w = Al \left|\frac{\partial\vec{V}}{\partial z}\right| \left(1 - \frac{\Theta^{-1}}{\Theta_c^{-1}}\right).$$

Note that the length scale has only linear impact on σ_w. Scaling arguments lead to $T_l = B\left|\partial\vec{V}/\partial z\right|^{-1}$ where B is another constant of the order of 1. Lacking better information, we assume $A = B = 1$.

4. RESULTS

We have applied this procedure to fields from ECMWF with 1° resolution and 60 levels. An example of the resulting fields of the diffusion coefficient K with a horizontal section at 8700 m a**g**l and a vertical section at 10°W (Fig. 1) shows that sCAT regions are mainly tied to synoptic structures in midlatitudes. This is confirmed by the mean sCAT frequency (Fig. 2) at 9000 m a**s**l. The values of K (Figs. 1 and 3) typically range between 0.1 and 20 $m^2 s^{-1}$. As we have used a constant l here, σ_w values (Fig. 3) directly correspond to K values (multiply by 40 m). The fact that high turbulence is related to high vertical wind shear (which is the inverse of T_l) is clearly visible. Some turbulence is also found close to the ABL top. This could be due to low-level jets.

5. 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. 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 few useful measurements in the free atmosphere, if at all.

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REFERENCES

Bysouth, C., 1998: A comparison of clear air turbulence predictors. Meteorological Office, Bracknell, United Kingdom, Forecasting Research Technical Report, No. 242, 15 pp.

Ellrod, G. P. and D. I. Knapp, 1992: An objective clear-air turbulence forecasting technique: verification and operational use. *Wea. Forecast.*, **7**(3), 150–165.

Hartjenstein, G., 2000: Diffusive decay of tropopause folds and the related cross-tropopause mass flux. *Mon. Wea. Rev.*, **128**(8), 2958–2966.

Seibert, P., B. C. Krüger, and A. Frank, 2001: Parameterisation of convective mixing in a Lagrangian particle dispersion model. In *Proceedings of the 5th GLOREAM Workshop*, on-line at http://people.web.psi.ch/keller_j/GLOREAM/WS2001/Final/.

Stohl, A., 1999: A textbook example of long-range transport: simultaneous observation of ozone maxima of stratospheric and North American origin in the free troposhere over Europe. *J. Geophys. Res.*, **104**(D23), 30,445–30,462.

Stohl, A., 2001: A one-year "climatology" of airstreams in the northern hemisphere troposphere and lowermost stratosphere. *J. Geophys. Res.*, **106**, 7263–7279.

Stohl, A., M. Hittenberger, and G. Wotawa, 1998: Validation of the Lagrangian particle dispersion model Flexpart against large-scale tracer experiment data. *Atmos. Environ.*, **32**(24), 4245–4264.

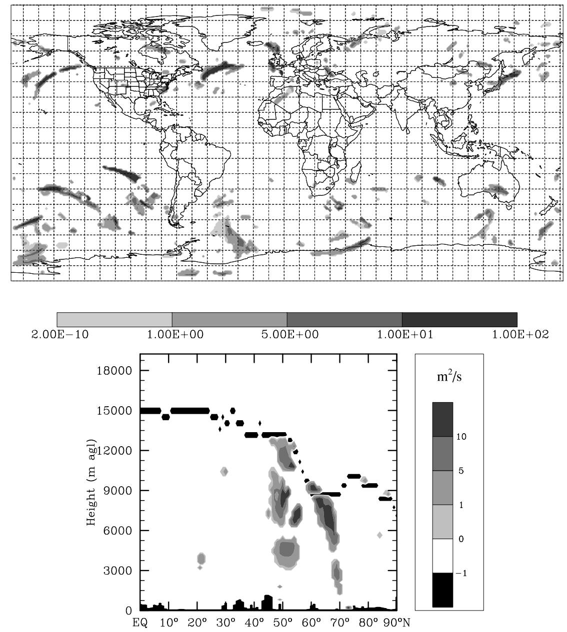

FIG. 1: Example of the K field (1995-10-01/00UTC). ABL and tropopause are marked black in the cross-section.

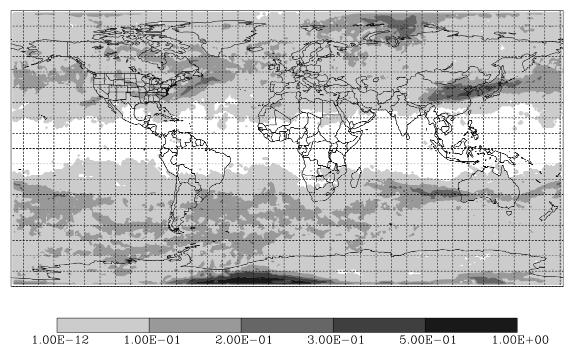

FIG. 2: Mean frequency of sCAT at 9 km asl during October 2000.

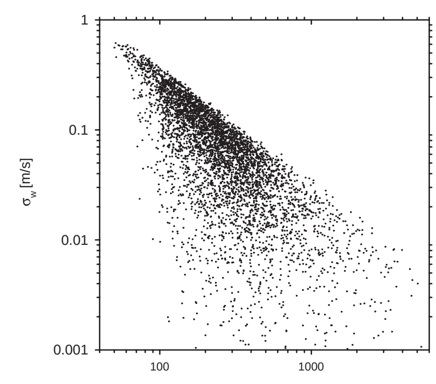

FIG. 3: Scatter plot of vertical turbulent velocity versus Lagrangian time scale (1995-10-01/00UTC, all levels).