1. INTRODUCTION

This presentation describes a scheme which provides an integrated description of turbulent transport in free-convective boundary layers with shallow cumulus. The scheme uses a mass-flux formulation, as commonly found in cumulus schemes, and an eddy diffusivity. It is called "mass flux - diffusion" or "M-K" for short. Both components are active in both the subcloud and cloud layers. Results of simulations of the ARM 21 June 1997 case, which has been used for other model intercomparisons (Brown et al. 2001; Lenderink et al. 2004) will be shown.

The motivation to work on this problem comes from its importance for atmospheric chemistry and regional air quality applications. Models without cumulus will produce incorrect profiles of chemical constituents, whether those constituents are emitted at the surface or transported aloft. The scheme's ability to simulate the profile of a conserved scalar is applied to a case from the 1999 Southern Oxidants Study Nashville experiment, where it is used to simulate vertical profiles of carbon monoxide in a cloud-topped boundary layer.

Siebesma and Teixeira (2000) introduced the idea of an integrated scheme for turbulent vertical transport in cloud-topped convective boundary layers, which they called an "advection-diffusion" scheme. Variations of this idea have been presented by Soares et al. (2004) and Jakob and Siebesma (2003). The scheme presented here owes a great deal to their work, but differs at some points.

Brevity precludes going into detail of the extensive history and taxonomy of turbulence schemes for the dry boundary layer here. The reader may refer to the standard textbooks. Dry boundary layer schemes fall into two basic categories, local and non-local. Local schemes are based on an analogy to molecular diffusion. Non-local schemes are based on the observation that most of the energy in convective

* Corresponding author address: Wayne M. Angevine, NOAA Aeronomy Lab R/AL3, 325 Broadway, Boulder, CO 80304 USA; e-mail Wayne.M.Angevine@noaa.gov
only a single maximum. Intermediate cases should require both local and non-local transport in varying proportions depending on the cloud fraction, or equivalently on the strength of the potential barrier between the two layers.

If one uses separate boundary layer (subcloud) and cumulus schemes, the closure assumption at cloud base is a difficult question (Siebesma and Holtslag 1996). In the M-K scheme, we simply assume that the mass flux is continuous across the cloud base. This is equivalent to assuming that the strongest updrafts are those that form clouds, which is precisely the basic idea of this scheme.

Several related approaches have appeared in the literature. Wang and Albrecht (1990) used a mass-flux parameterization in the dry boundary layer. Lappen and Randall (2001a,b,c) developed a parameterization for both the dry and moist convective PBL. Their approach combines mass-flux and higher-order closure, and uses assumed probability distributions. They also provide a review of previous similar work. Assumed probability density functions also underlie the work of Golaz et al. (2002). De Roode et al (2000) argue that mass-flux and (more common) Reynolds-averaged formulations are to some degree equivalent.

Previous work on chemical transport by clouds was reported by Lin et al. (1994). They incorporated a parameterization of subgrid convective cloud transport into a 3D regional chemistry model, and compared the results with aircraft observations. The primary emphasis was on deep convective cloud. Because of the relatively coarse vertical grid spacing in their model, they used a very simple representation of shallow cloud. However, their figure 7 shows some impact on the chemical profiles from the shallow cloud vertical transport.

Acknowledgements:

The author is most grateful for the generosity of Pier Siebesma, Roel Neggers, and Joao Teixeira, who spent considerable time introducing him to an unfamiliar specialty. This work was begun while the author was a visitor at the Royal Netherlands Meteorological Institute (KNMI), the hospitality of which is gratefully acknowledged.

References:


