P1.16A CONVECTIVE BOUNDARY LAYER DEVELOPMENT OVER A MIDLATITUDE DECIDUOUS FOREST

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1. INTRODUCTION

The height of the planetary boundary layer is a fundamental parameter that characterizes the structure of the lower troposphere. It determines the volume available for the dispersion and concentrations of mass exchanges such as CO_2, H_2O, and pollutants. Studies that have examined the daytime growth of the convective boundary layer (CBL) over forests (e.g. Martin et al. 1988, Barr & Betts 1997, Davis et al. 1997, Wilczak et al. 1997, Levy et al. 1999), have been restricted to time periods of a single season or less. The objective here is to examine seasonal variability in CBL development during clear-sky, anticyclonic conditions over a deciduous forest in the midwestern USA. Vertical profiles of air temperature and humidity are analyzed and used to evaluate predictions of CBL growth from a simple mixed-layer slab model, as well as sensitivity of the model to initialization data.

2. PHYSICAL SETTING AND METHODOLOGY

Vertical profile data were collected using AIR tethersonde and airsonde systems (Vaisala, Boulder, CO), from a balloon release site located in a forest clearing near the Morgan-Monroe State Forest (MMSF, 39° 19'N, 86° 25'W south central Indiana) AmeriFlux tower. For this site z_d is 21 m, and z_{0m} is 2.1±1.1 m (Schmid et al. 2000). The mixing layer height (z_i) was determined for each profile using three independent methods: simple parcel method, critical inversion method, and inversion base method (Figure 1).

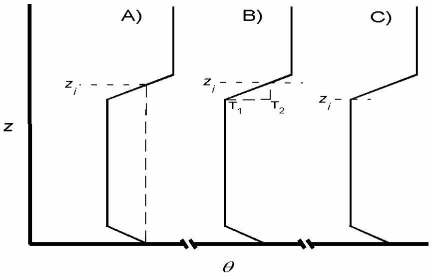

Figure 1: Three methods used to determine z_i, a) simple parcel, b) critical inversion (where T_2 - T_1 = 2 K), c) base of inversion

The daytime growth of z_i is modeled based on the slab model of Cleugh and Grimmond (2001), where z_i is governed by surface heat fluxes and entrainment, with the assumptions that the CBL is perfectly mixed, and large scale advection and subsidence are negligible.

The model was initialized with a pre-dawn vertical profile of potential temperature and specific humidity, and driven by surface micrometeorological data. Initialization profiles were taken from MMSF as well as the three nearest National Weather Service (NWS) profiling stations: Nashville, TN (BNA), Wilmington, OH (ILN), and Lincoln, IL (ILX). 15-min surface data from the MMSF flux tower 46 m level (~1.8 × canopy height) are used.

3. RESULTS

The observed vertical profiles have classic patterns: well developed surface inversions overlain by residual mixed layers in the early morning are eroded, and well mixed convective layers develop by the late morning (Zutter, 2002).

Daily maximum z_i (z_{imax}) estimated using the three methods for 26 profiling days throughout a year yield similar results (Figure 2). Of the three, the simple parcel method showed closest correspondence to the mean value (MAE=90 m for all profiles); whereas MAE for the critical inversion was 127 m and base of inversion method 145 m. The seasonal pattern of z_{imax} shows greatest vertical development in spring and early summer, with lower values in fall and winter. During the leaf-off period, there is a strong linear and positive relationship between daily total Q_H and z_{imax} (r^2=0.86, n=9), while the relationship during the growing season was significantly weaker. Some of this variability is explained by differences in synoptic control, determined by surface atmospheric pressure, the strength of the θ gradient above z_i, and length of time following passage of a cold front.

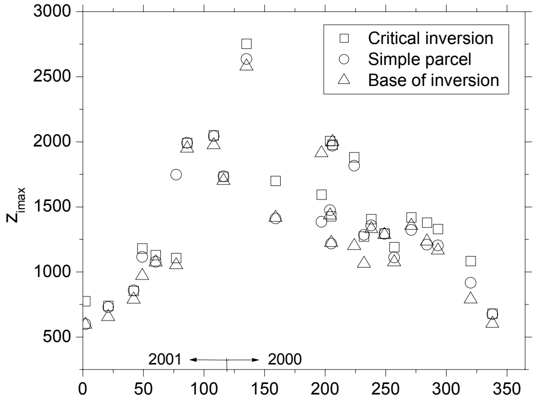

Figure 2: Estimation of z_{imax} determined using three methods from vertical profiling data over the MMSF for 26 days in 2000, 2001.

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Model runs were conducted for each of the profiling days using a range of input data, including surface and profile data from MMSF, modeled surface data, and profiles from the NWS profiling stations. Examples from each season of z_i observed using the three methods discussed earlier and modeled using initialization profiles from MMSF, BNA, ILN and ILX are presented in Figure 3. Overall, model results correspond reasonably well with observations, and ILN appears to provide the most representative initial profile of the three external sites.

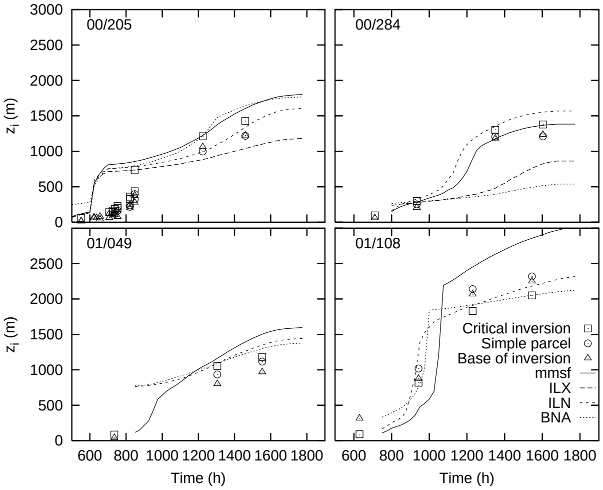

Figure 3: Comparison of observed and modeled daytime evolution of z_i at MMSF for four days when model was initialized with data from MMSF, ILX, ILN, BNA.

Statistical analyses indicate that using the MMSF profile to initialize the models, z_i was best determined by the simple parcel method, and in general z_i is under-predicted for all methods (mean slope of 0.86). Most of the error is unsystematic, suggesting an approach using surface forcing and entrainment to predict z_i has relatively few consistent problems. Instead, error is likely to result from day to day variability of parameters not included, such as subsidence and advection. The mixed layer mean potential temperature (θ_m) and specific humidity (q_m) are predicted with somewhat greater accuracy than z_i, with θ_m over-predicted by only 1%, while q_m was under-predicted by 11%. MAE in estimates of z_i when NWS profiling stations were used to initialize the model were only 20-30 m more than when MMSF profile data were used. Of the three sites, BNA and ILN provided the most appropriate initial profiles, with ILX performing relatively poorly by comparison, though patterns of systematic errors between sites were small, suggesting the accuracy of modeling was controlled by the day-to-day differences with which each profiling site was representative of MMSF.

Modeled fluxes - Q_E from a modified Penman-Monteith equation and Q_H determined as a residual - in general underestimated observed fluxes by 35% and 9% respectively, although again with significant seasonal variability. Incorporating modeled surface energy fluxes into the slab model, increased the z_i RMSE on average by 88 m compared with observed fluxes, corresponding to a 22% increase in error.

4. CONCLUSIONS

Seasonal analysis of boundary layer growth is examined for clear anticyclonic days throughout a one-year period. Observations of vertical profiles show significant seasonal variability with greatest vertical development occurring in spring. z_{imax} was found to correspond to daily total Q_H, but with significant day-to-day variability caused by synoptic controls. A slab model performed well in predicting boundary layer growth and magnitudes of θ and q. Furthermore, model accuracy did not weaken significantly when initialized by NWS profile data from surrounding stations and when driven by modeled surface fluxes, giving confidence in the ability to model boundary layer development in data-sparse regions.

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6. REFERENCES

Barr A.G., Betts A.K. 1997. Radiosonde boundary layer budgets above a boreal forest, *JGR.* **102**, 29205-29212.

Cleugh H.A., Grimmond C.S.B. 2001. Modeling regional-scale surface energy exchanges and CBL: Growth in a heterogeneous, urban-rural landscape, *Bound. Lay. Meteor.* **98**, 1-31.

Davis K.J., Lenschow D.H., Oncley S.P., Kiemle C., Ehret G., Giez A., Mann J. 1997. Role of entrainment in surface-atmosphere interactions over the boreal forest, *J. Geophys. Res.* **102**, 29219-29230.

Grimmond, C.S.B. Oke, T.R.: 1999. Heat storage in urban areas: local-scale observations and evaluation of a simple model, *J. Appl. Meteor.* **38**, 922-940.

Levy P.E., Grelle A., Lindroth A., Mölder M., Jarvis P.G., Kruijt B., Moncrieff, J.B. 1999. Regional-scale CO_2 fluxes over central Sweden by a boundary layer budget method, *Ag. For. Meteor.* **98-99**, 169-180.

Martin C.L, Fitzjarrald D., Garstang M., Oliveira A.P., Greco S., Browell E. 1988. Structure and growth of the mixing layer over the Amazonian rain forest, *JGR* **93**, 1361-1375

Schmid H.P, Grimmond C.S.B., Cropley F., Offerle, B., Su H.-B. 2000. Measurements of CO_2 and energy fluxes over a mixed hardwood forest in the mid-western United States, *AFM.* **103**, 357-374.

Wilczak J.M, Cancillo M.L, King C.W. 1997. A wind profiler climatology of boundary layer structure above the boreal forest, *JGR.* **102**, 29083-29100.

Zutter, H.N. 2002.Convective Boundary layer development over a mid-latitude deciduous forest. Unpublished MS Thesis, Indiana University, Dept. Geography.