6.16 MIXING HEIGHT COMPUTATION FROM A NUMERICAL WEATHER PREDICTION MODEL

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INTRODUCTION

Dispersion models require hourly values of the mixing height, H, that indicates the existence of turbulent mixing. The aim of this study was to investigate a model ability and characteristics in the prediction of H. The ALADIN, limited area numerical weather prediction (NWP) model for short-range 48-hour forecasts was used. The bulk Richardson number (R_{iB}) method was applied to determine the height of the atmospheric boundary layer at one grid point nearest to Zagreb, Croatia. This specific location was selected because there were available radio soundings and the verification of the model could be done. Critical value of bulk Richardson number R_{iBc}=0.3 was used. The values of H, modelled and measured, for 219 days at 12 UTC are compared, and the correlation coefficient of 0.62 is obtained. This indicates that ALADIN can be used for the calculation of H in the convective boundary layer. For the stable boundary layer (SBL), the model underestimated H systematically. Results showed that R_{iBc} evidently increases with the increase of stability. Decoupling from the surface in the very SBL was detected, which is a consequence of the flow ease resulting in R_{iB} becoming very large. Verification of the practical usage of the R_{iB} method for H calculations from NWP model was performed. The necessity for including other stability parameters (e.g., surface roughness length) was evidenced. Since ALADIN model is in operational use in many European countries, this study would help the others in pre-processing NWP data for input to dispersion models.

METHOD

There are different ways to estimate H from NWP model for practical applications. For this study, we have used R_{iB} method to determine hourly values of H from ALADIN model (Aire Limitee Adaptation Dynamique development InterNational), as well as from radio soundings. The R_{iB} method is the standard approach to derive H from the NWP models (e.g., Sørensen et al., 1996).

$$R_{iB} = \frac{\phi_j - \phi_1}{\overline{\theta}} \frac{\theta_j - \theta_1}{(\Delta u_j)^2 + (\Delta v_j)^2} \tag{1}$$

j= 2,..., 37 are the model levels.

The ϕ_1 is geopotential height and θ_1 is potential temperature on the lowest model level. The wind speed at the surface is taken as zero. The lowest level is the first model level which is around z_1=17 m in the average. Vertical resolution is not uniform, thus the next few levels are at about 65 m, 143 m, 251 m, etc. Space differences are gradually increasing with height, resulting in higher vertical resolution near the surface.

The level at which R_{iB} reaches the critical value, R_{iBc}, is considered as H. This has simplified the estimation of H, but R_{iBc} does not have the fixed value, universally applicable in all atmospheric conditions and for all surfaces (e.g., Stull, 1988; Zilitinkewich and Calanca, 2000). Here the R_{iBc} is tested from the interval of 0.1 to 1. Based on the radio soundings, a single value R_{iBc} = 0.3 is chosen as the most convenient choice corresponding best to the measurements.

ALADIN is spectral and hydrostatic limited area NWP model for short-range 48-hour forecasts. There are 37 model levels in the vertical and hybrid pressure-type η coordinate (Simmons and Burridge, 1981) is used with the finite difference method.
The Croatian domain contains 127 points in the x and 109 points in the y direction (or 144 in x and 120 in y, with an extension zone) with an 8-km resolution in both directions. This model setup is described in Tudor and Ivatek-Šahdan (2002) including an efficient dynamical adaptation to the wind field (Žagar and Rakovec, 1999).

RESULTS
Hourly model calculations are performed for the four seasons: 15 days in January - February, May, August and October 2002. Moreover, the same calculation is obtained from 10 April to 4 December 2003.
Results of R_{iB} calculations are in Figures 1 and 2 showing vertical evolution of the local R_{iB} in time for three NWP model runs at 00 UTC. The R_{iBc}= 0.3 is marked on those figures with thick black curve, representing H. The other marked curve, R_{iBc}= 1, is used as a reference to stress and illustrate the importance of the R_{iBc} selection. In Figure 1, the evolution for three winter days is displayed, and in Figure 2, it is done for three summer days. Summer and winter are selected to show the model sensitivity to seasonal changes and to represent how those differences affect H. Synoptic situation at the first days in February in 2002 was characterized with long stable periods with fog and low stratified clouds because of warm SW airflow at higher altitudes over the area. Vertical profiles of radio soundings indicated an elevated temperature inversion with thickness around 280 m during that period. This peaked on 3 February when elevated inversion was 671 m thick. During the analysed winter period in 2002, the base of those measured inversions was approximately 200 m at 12 UTC. For that period ALADIN predicted low values of H mostly connected with the base of predicted elevated inversions, especially for period the from 1 to 5 February when the daily maximum H was only 65 m. Summer days in Figure 2 show higher H but also underestimate the night time values. An elevated cyclone formed westerly from Zagreb determining the synoptic situation on 13 August 2002. There was advection of moist, unstable and relatively warm air from southwest. On 14 August the synoptic situation stabilised and the next day, 15 August, the weather was again sunny and warm. At the switch into a new day, the curves in the Figures 1 and 2 are discontinuous due to the model re-initialisation.

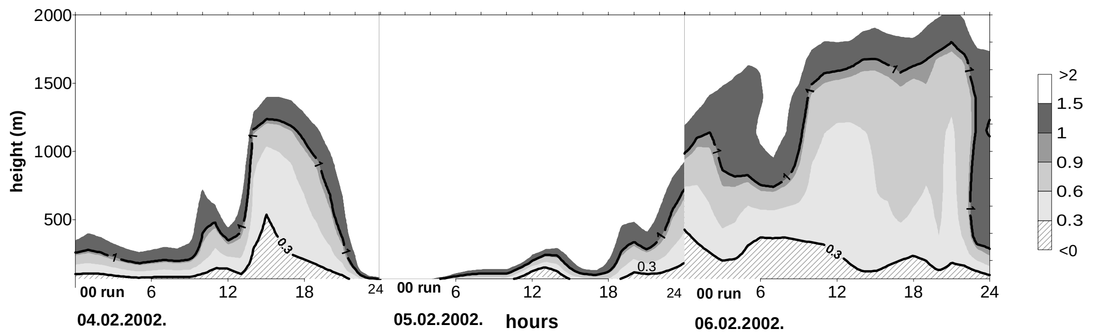

Figure 1. Spatio-temporal evolution of the bulk Richardson number, R_{iB}, calculated from ALADIN model output for three winter days in 2002, Zagreb, Croatia. Hatched areas represent $R_{iB} \leq 0.3$, shaded parts from grey to black $0.3< R_{iB}<2$, and there are also white areas of a very large $R_{iB} \geq 2$. Critical value of R_{iBc} = 0.3 is marked as thick black curve and it represents the mixing height H. The other marked black curve is R_{iBc} = 1.

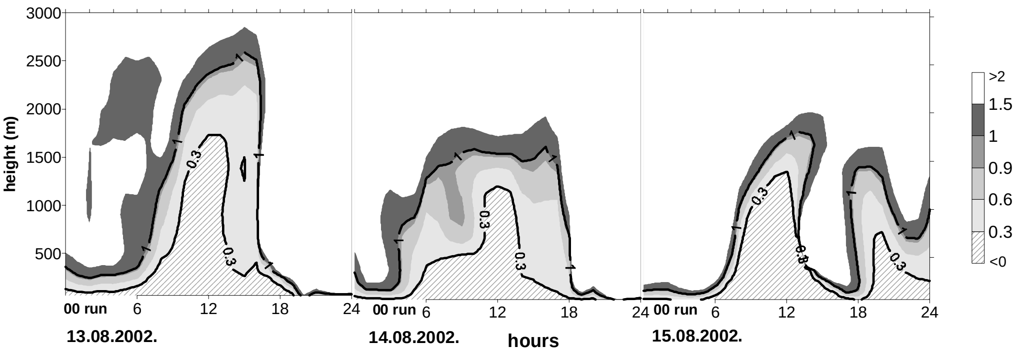

Figure 2. Same as Figure 1 but for the three summer days.

The analysed situations show that during stable conditions, the R_{iBc} = 1 and R_{iBc} = 0.3 do not differ significantly, but in unstable, convective conditions, heights determined with those critical values are considerably different. In the SBL, during the night or in winter (stronger temperature inversions), the model gives low values of H; and in the CBL or in unstable synoptic situations the modelled H is higher which is also an indication that H is a good parameter for the model sensitivity evaluation. Note a nearly collapsed SBL in ALADIN, around midnight between 4 and 5 February in Figure 1, and for summer days around midnight in Figure 2. This emphasizes one of the unsolved turbulence parameterisation problems when the flow eases, $U \approx 0$ and $R_i \rightarrow \infty$ (e.g., Zilitinkevich and Calanca, 2000; Grisogono and Oerlemans, 2001).

RELATION BETWEEN OBSERVED AND MODELLED H FOR CBL

Unrealistic underestimation of night time H values is found, connected with very stable conditions e.g., on 5 February in Figure 1 or around midnight in Figure 2. The need for correction is obvious and future steps will be made to improve model results for the SBL. From this point here, only H values at 12 UTC are validated.

Scatter plot comparing the evaluation of H from radio soundings and from ALADIN data at 12 UTC is shown in Figure 3.

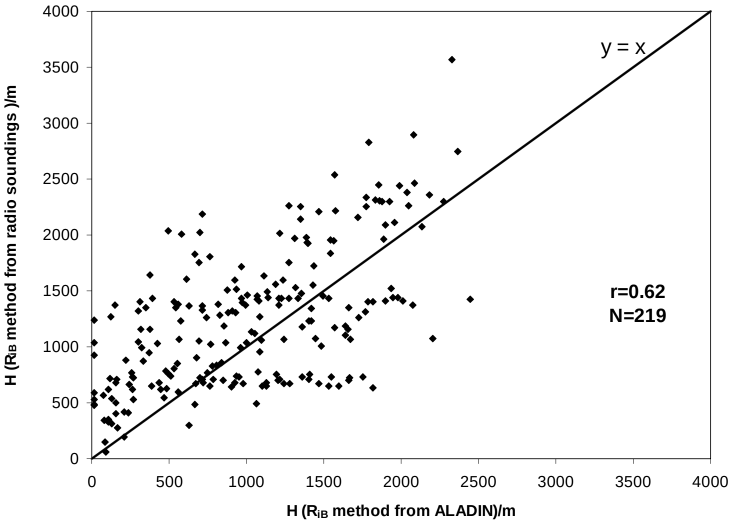

Figure 3. Scatter plot comparing the evaluation of H at 12 UTC based on radio soundings and on the modelled data from 10 April to 4 December 2003 in Zagreb, Croatia.

The comparison of the daytime H indicates good agreement between the model data and radio soundings. The correlation coefficient for 12 UTC is 0.62 based on 219 cases. In Figure 4, the $H_{soundings}$ and H_{ALADIN} at 12 UTC are shown.

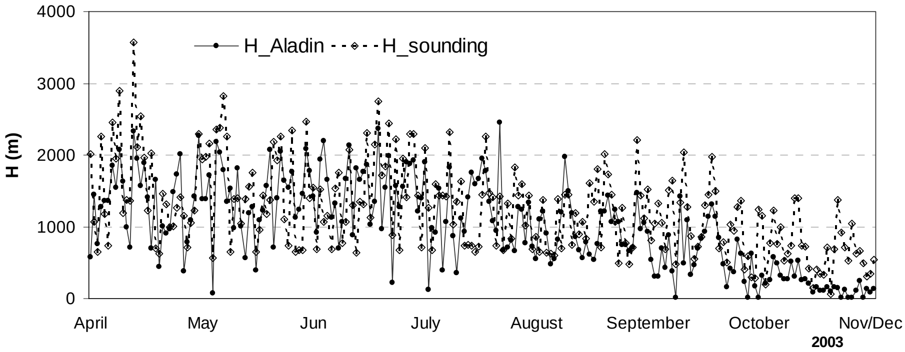

Figure 4. $H_{soundings}$ and H_{ALADIN} at 12 UTC are represented from 10 April to 4 December 2003, Zagreb, Croatia.

Basic statistic between the measured and modelled data $\Delta = H_{soundings} - H_{ALADIN}$ is performed. The average of these differences is $\overline{\Delta}$ = 219.7 m and standard deviation is σ_Δ = ±540.6 m. Further, statistics was made by calculating the mean absolute error, MAE, root-mean squared error, RMSE and the difference between the averages of two data sets, BIAS. They are represented in Table1.

Table 1. Statistics for differences $\Delta = H_{soundings} - H_{ALADIN}$ between the measured and modelled data for spring, summer, autumn 2003 and for period calculated from 10 April to 4 December 2003, Zagreb, Croatia.

	MAE (m)	RMSE (m)	BIAS (m)	MAX (m)	MIN (m)	N
SPRING	504.2	611.8	166.4	1474.7	21.2	63
Summer	461.0	586.3	78.0	1186.0	1.0	89
Autumn	476.3	592.3	458.2	1542.9	15.4	67
10/04-04/12/03	479.6	582.4	219.7	1542.9	1.0	219

N-number of data

From the Table 1 it can be concluded that the errors are smaller during summer, which is a natural consequence of intensive buoyant mixing resulting in higher H_{ALADIN}. The greater errors can be expected during spring and autumn; but since MAE and RMSE are sensitive on number of data this should be tested on a longer period. On the other hand, BIAS does not give information about the typical magnitude of individual modelled errors, and therefore is not an accuracy measure. We find BIAS > 0 for all seasons meaning that for averaging periods the predictions, H_{ALADIN}, underestimate the measured values $H_{soundings}$. The BIAS has its minimum in summer and it is significantly larger for autumn when more stable situations have occurred, again indicating inadequacy in applying R_{iB} method in very SBL. The model underestimated H in 70.3% cases, which is an indication that R_{iBc} could be greater than 0.3.

CONCLUSION

The relation between the observed and modelled H at 12 UTC, through the correlation coefficient of 0.62, showed that ALADIN data can be used to estimate H of the CBL with the R_{iB} method. There is also an indication that a higher R_{iBc} ought to be used for the estimation of H from the model since the underestimation of the measured H was detected. The correlation coefficient must be considered in terms that ALADIN is still a hydrostatic model with horizontal resolution of 8 km in both directions x and y, in this application, while radio soundings give instantaneous local measurements on their often complicated path up through the atmosphere. It is shown that R_{iBc} apparently increases with an increase of stability. For the CBL there is still a large spread of possible H values depending on the chosen R_{iBc} e.g., for R_{iBc}= 0.3 and R_{iBc} = 1, H's can vary within 1000 m (Figures 1 and 2). Needless to say, this is of considerable importance for practical applications.

On the contrary, under the SBL, those H values, having R_{iBc} = 0.3 or 1, nearly overlap and the model frictional decoupling (FD) from the surface is often detected. The FD, connected with an increase of stability when the flow laminarises near the surface, occurs when friction fails as the dominant generator of turbulent fluxes. The FD may result in numerical instabilities and it must be excluded from the model.

It is important to point out that most of NWP models, and ALADIN as well, have problems when stratification changes (sunrise/sunset). To avoid this weakness, in pre-processing of H from the models, interpolations could be used. Smoothing corrections of the daily H course for the SBL can be done with expressions for the temporal evolution of the H (a sort of relaxation procedure), or by taking higher values of R_{iBc} during the night. Nevertheless, this is also an indication that the turbulence parameterisation in the model should be improved.

Finally, ALADIN can be used in calculating H with the R_{iB} method for the CBL with proper choice of $R_{iBc,}$ which showed seasonal and daily variability and was found dependent on surface characteristics. For the SBL, model underestimated H values systematically. Decrease in the modelled wind gave an almost unlimited growth of R_{iB}. Consequently, R_{iB} cannot be the only relevant parameter determining stratified turbulent structures or the value of H when $R_{iB} \rightarrow \infty$. The results of this study, we hope, would help to give a better input for dispersion models needing H and ought to be taken into account when dealing with NWP data of ALADIN or alike models.

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