Evaluation of ozone deposition models over a subalpine forest

Dalma Szinyei [1]
Györgyi Gelybó [2]
Alex Guenther [3]
Andrew A. Turnipseed [3]
Szabolcs Czigány [4]
Ervin Pirkhoffer [4]
Peter Builtjes [5,6]
dszinyei@gamma.ttk.pte.hu

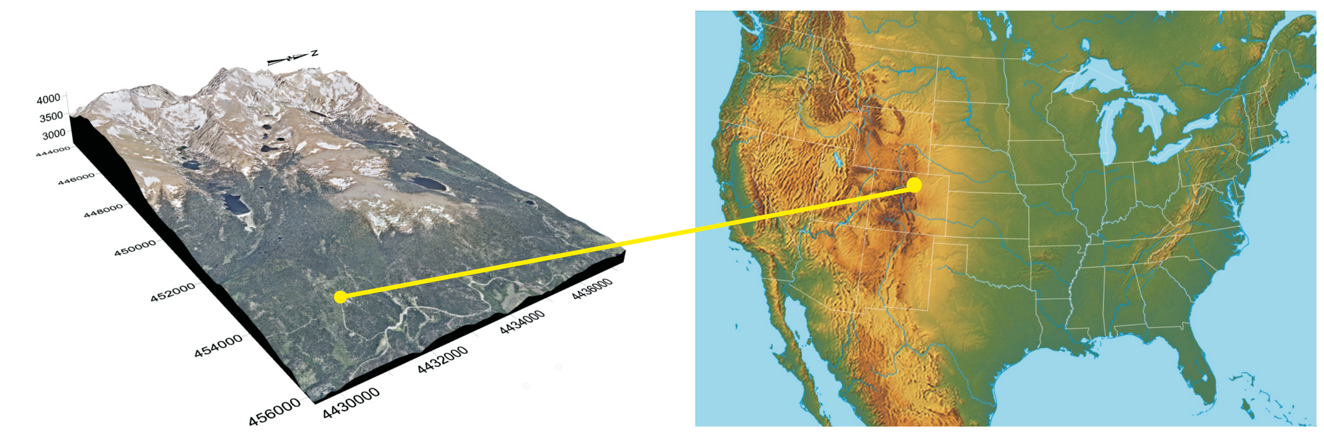
[1] Air Chemistry Research Group of Hungarian Academy of Sciences, Veszprem, Hungary; [2] Institute for Soil Sciences and Agricultural Chemistry, Centre for Agricultural Research, Hungarian Academy of Sciences, Budapest, Hungary; [3] Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, USA; [4] Department of Soil Sciences and Climatology, University of Pécs, Hungary; [5] TNO–Utrecht, the Netherlands; [6] Freie Univesität Berlin, Germany

Introduction

Forests can play an important role in long-term carbon storage and it is of high relevance to investigate all the effects which could influence this role. Since the heating effect of CO_2 is well-known recent calculations are showing an indirect atmospheric heating effect of ozone as well. The process in the background of this hypothesis is that ozone entering into the plants through stomata modifies the cell exchange processes and the efficiency of photosynthesis. It decreases the amount of CO_2 taken by plants and thus forces the greenhouse effect.

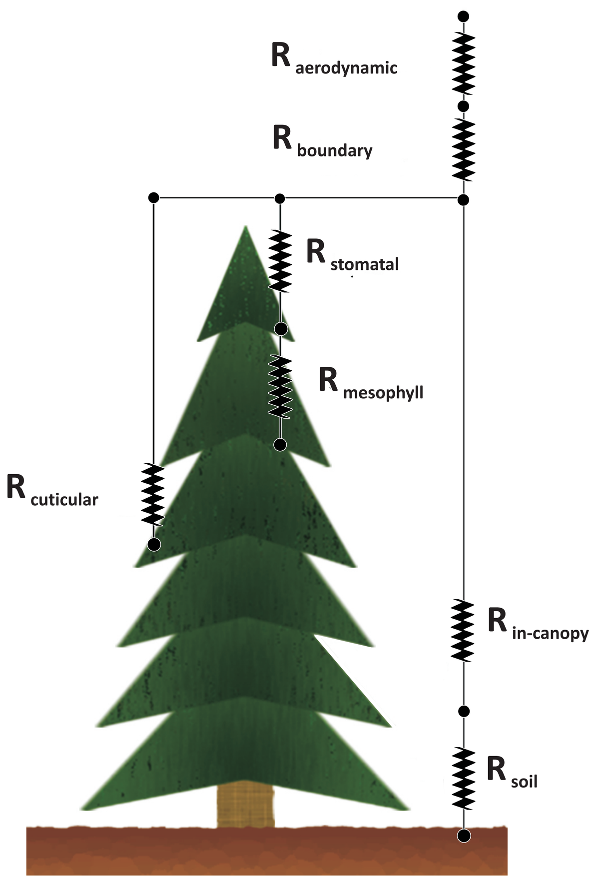
One possible application of deposition models is the investigation and monitoring of the effects of air quality on ecosystems. The aim of this study is to evaluate the performance of three selected deposition models that are based on the big-leaf concept and characterized by different parameterization schemes. The investigated models are commonly applied in regional chemical transport models (AURAMS, REM-CALGRID, LOTOS-EUROS, WRF Chem, GEOS Chem, TAMP). Therefore it is important to investigate the accuracy of their estimation on ozone deposition. The model estimations of ozone deposition over subalpine forest were validated using a six-month long dataset measured during the 2003 growing season using the eddy covariance technique at the Niwot Ridge AmeriFlux site (40°1'58.4"N, 105°32'47.0"W, 3050 m altitude) in the Roosevelt National Forest in the Colorado Rocky Mountains.

Eddy covariance flux tower of Niwot Ridge, Colorado



Methods

A main part of a deposition model is in general the resistance submodel, which simulates the deposition or exchange of the given species between the atmosphere and surface. The fluxes of trace elements in the model are controlled by the concentration and by the deposition velocity of the elements via parameterization of the aerodynamic, the quasi-laminar boundary layer and the canopy resistance, where this latter term includes stomatal, mesophyll, surface and cuticular resistances. The models used in this study are described in Zhang et al., 2003 (referred as the 'ZHANG' model later on) and Erisman et al., 1994 (DEPosition of Acidifying Compounds, DEPAC). The main difference of these submodels are in the detail of parametrizations (see the table below).

Resistance network and parametrizations	ZHANG model	DEPAC model (Baldocchi/Wesely)
$F = -c \cdot v_d$ $v_d = \frac{1}{R_a} + \frac{1}{R_b} + \frac{1}{R_c}$	$\frac{1}{R_c} = \frac{1}{R_{soil} + R_{inc}} + \frac{1}{R_{cut}} + \frac{1 - W_{st}}{R_{st} + R_{mes}}$	$\frac{1}{R_c} = \frac{1}{R_{soil} + R_{inc}} + \frac{1}{R_{cut}} + \frac{1}{R_{st} + R_{mes}}$
	$R_a = \frac{1}{\kappa \cdot u^*}\left[0.74 \cdot \ln\left(\frac{z_r}{z_0}\right) - \psi_h\right]$	$R_a = \frac{1}{\kappa \cdot u^*}\left[\ln\left(\frac{z_r}{z_0}\right) - \psi_h\right]$
	$R_b = 1{,}31 \cdot \frac{5}{u^*}$	$R_b = 1{,}31 \cdot \frac{5}{u^*}$
	$R_{st} = \frac{1}{G_s(PAR) \cdot f(t) \cdot f(vpd) \cdot f(\psi) \cdot 0.637}$	**Baldocchi:** $R_{st} = \frac{1}{G_{st}(PAR) \cdot f(t) \cdot f(vpd) \cdot f(\psi) \cdot LAI \cdot 0.637}$ **Wesely:** $R_{st} = 1{,}571 \cdot R_i \cdot \frac{400}{t \cdot (40 - t)} \cdot \left(1 + \left(\frac{200}{SR + 0.1}\right)^2\right)$
	$R_{mes} = 0 \left[\frac{s}{m}\right]$	$R_{mes} = 0 \left[\frac{s}{m}\right]$
	$R_{cut} = \frac{4000}{u^* \cdot LAI^{0.25} \cdot e^{0.03RH}}$ **t < -1°C:** $R_{cut} = R_{cut} \cdot e^{0.2(-1-t)}$	$R_{cut} = 1000 \left[\frac{s}{m}\right]$
	$R_{inc} = \frac{100 \cdot LAI^{0.25}}{(u^*)^2}$	$R_{inc} = 8 \cdot h \cdot \frac{LAI}{u^*}$
	$R_{soil} = 200 \left[\frac{s}{m}\right]$ **t < -1°C:** $R_{soil} = R_{soil} \cdot e^{0.2(-1-t)}$	$R_{soil} = 200 \left[\frac{s}{m}\right]$ **t < 0°C:** $R_{soil} = 2000 \left[\frac{s}{m}\right]$

To explore the real performance of the these models, the resistance schemes were adapted but the meteorological and astronomical parameterizations were synchronized using one common scheme and measured meteorological variables were used. One modification was the use of measured soil moisture instead of water potential to calculate the soil moisture stress during stomatal resistance estimation.

Statistical and local sensitivity analysis were carried out to investigate the model performance of model input data. Besides the modeling work we investigated the driving variables (soil moisture, global radiation, photosynthetically active radiation, vapor pressure deficit and temperature) of ozone deposition for hourly, daily and monthly time steps based on eddy covariance field measurements.

Results

Our results show that none of the investigated models could simulate ozone deposition appropriately. The model performance varies with time of the day and the errors also have a seasonal pattern (Fig. 1). The ZHANG model produced the best results in capturing the ozone flux magnitude and dynamics however, one should be aware of the poor correlation (Fig.3, R^2=0.26, RMSE = 4.45 $nmol \cdot m^{-2} s^{-1}$; R^2= 0.17 for daytime, R^2= 0.07 for nighttime) between the half-hourly measured and modelled deposition velocities. To improve the model performance the correction factor in water vapour stress function of stomatal resistance was optimalized based on strong correlation between ozone flux and air humidity (Fig.3, R^2= 0.27, RMSE = 4.0 $nmol \cdot m^{-2} s^{-1}$, R^2= 0.2 for daytime; R^2= 0.07 for nighttime). The DEPAC-Baldocchi model overestimates the measured fluxes (Fig.4, R^2= 0.16, RMSE = 9.86 $nmol \cdot m^{-2} s^{-1}$). The main reason could be due to the soil moisture stress which is in optimum state all the time, so there is no water stress for the canopy. With adaption the soil moisture stress function of ZHANG method the mean diurnal bias decreased visually (Fig.4, R^2= 0.06, RMSE = 4.68 $nmol \cdot m^{-2} s^{-1}$). The DEPAC-Wesely model underestimates the measured fluxes (Fig.4, R^2= 0.08, RMSE = 4.54 $nmol \cdot m^{-2} s^{-1}$), since in this method the stomatal resistance depends on temperature exclusively. To explore the dependency from environmental factors the mean absolute bias of measured and modelled ozone fluxes were compared to measured meteorological inputs but no correlation was found any of meteorological inputs.

The results showed that measured gross primary production and measured accumulated gapfilled ozone flux has an obvious correlation (Fig.2, R^2= 0.17) although this relationship is not included in any of the formulas of ozone deposition calculation. It is clarified in the literature that photosyntetically based methods can estimate the stomatal resistances with higher accuracy, so the effect of gross primary production on ozone deposition should be consider also in improvement of these formulas.

In spite of their wide the models have not been calibrated for some important land cover types e.g none of the above models have been calibrated for evergreen forests. Before calibration these models are not incongruent to further investigations but can help to determinate the direction of model developments.

Erisman, J. W., Van Pul, A. and Wyers, P., 1994: Parameterization of surface resistance for the quantification of atmospheric deposition of acidifying pollutants and ozone, Atmos. Environ., 28, 2595–2607.
Zhang, L., Brook, J. R. and Vet, R., 2003: A revised parameterization for gaseous dry deposition. Atmos. Chem. Phys., 3, 2067–2082.

Fig.1: Monthly means of ozone flux

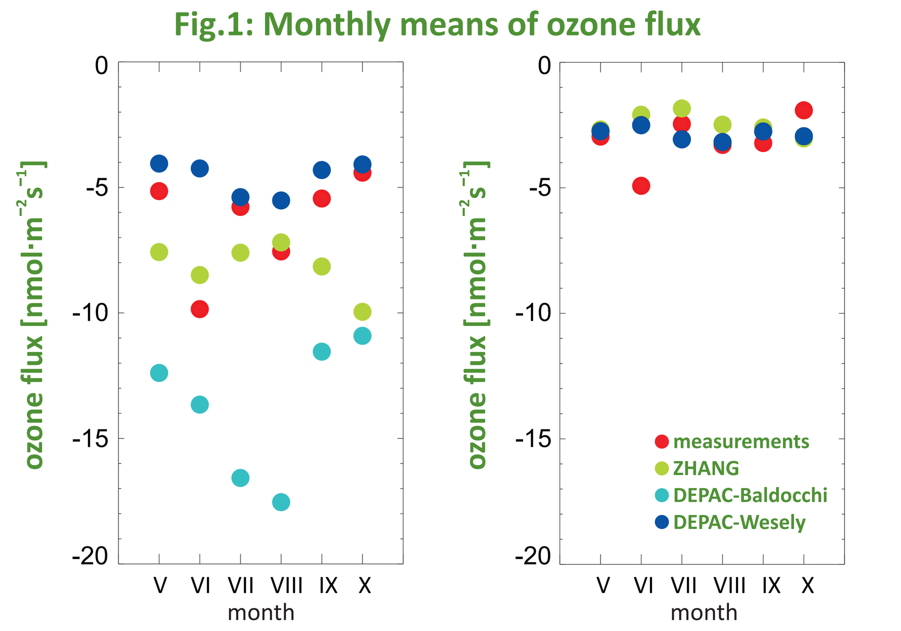


Fig.3: Mean diurnal variation of ozone flux (May-Oct 2003)

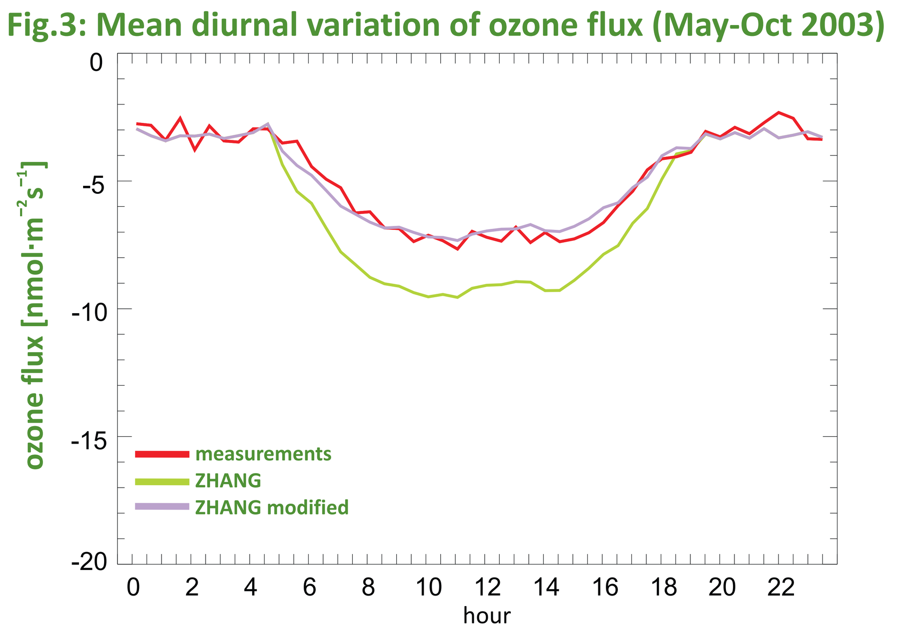


Fig.2: Accumulated ozone flux against GPP (May-Oct 2003)

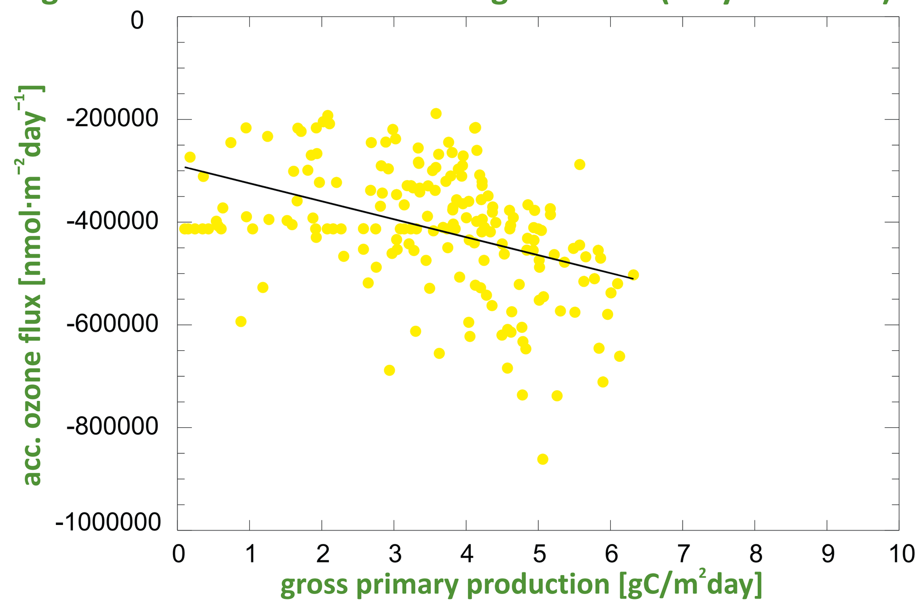
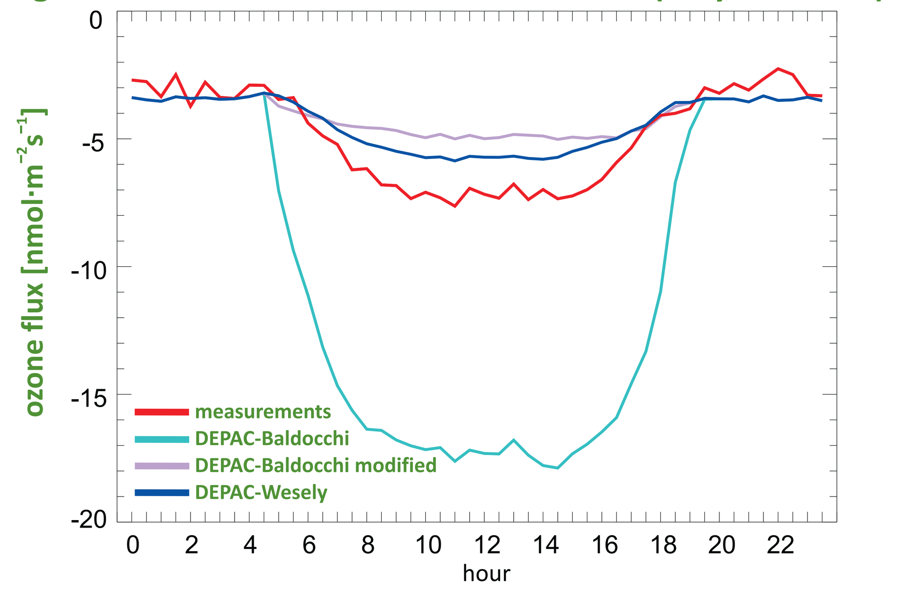


Fig.4: Mean diurnal variation of ozone flux (May-Oct 2003)



The authors would like to thank Prof. Russell Monson and the Niwot Ridge AmeriFlux site for access to their data. The project is realized with the support of the European Union, with the co-funding of the European Social Fund. Györgyi Gelybó's research contributing to this publication was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP 4.2.4. A/-11-1-2012-0001 'National Excellence Program'.