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COMPARISON OF EMEP AND WRF_CMAQ MODELLING RESULTS FOR DEPOSITION ESTIMATES IN BULGARIA FOR 2016 AND 2017

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Abstract: The results from two chemical transport models (EMEP MSC-W and the Bulgarian Chemical Weather Forecast System, BgCwFs) are compared for the territory of Bulgaria for sulphur, reduced and oxidized nitrogen depositions (wet and dry) in 2016 and 2017. Although the models differ in their meteorological driver, emissions input and model formulations, the result reveal some common features – prevalence of sulfur wet depositions (S-WD) over the nitrogen depositions and higher deposition levels for south-east Bulgaria. BgCwFS annual S-WD, mean for the country, are by factor of 1.5 higher, reflecting the higher SO_x emissions used. The comparison to observed wet and dry depositions at three sites for the period June –November 2017 suggest better performance of BgCwFS.

Key words: *CMAQ, EMEP, depositions, comparison, model validation, precipitation chemistry*

INTRODUCTION

Chemical transport models have been widely used for estimation of the spatial distribution of deposition fluxes in global and regional scales (Schwede et al., 2018, Vivanco et al, 2018, Kanakidou et al., 2016), for analysing trends and relations to emissions' changes and impacts on different habitats. These studies are supported by deposition monitoring networks (e.g. Torseth et el., 2012), with scarce coverage in south-east Europe.

In Bulgaria, monitoring of atmospheric deposition is carried out only for short time periods and at a few sites. The Bulgarian Chemical Weather Forecast System, (BgCwFs), operationally running at the National Institute of Meteorology and Hydrology (NIMH), has been recently set up for simulations of wet and dry depositions in Bulgaria (Syrakov, et al., 2019a). The EMEP MSC-W model (Simson et al., 2012) is applied on a routine basis for the deposition of acidifying and eutrophying compounds in Europe, and modelled data for the years 2016 and 2017 are freely available.

The main objective of this study is to compare the results for sulphur and nitrogen depositions by the two modelling systems, focussing on estimates for seasonal and yearly depositions, both as mean values for the country and as spatial distribution for identification of hot-spot areas. Model performance is checked based on comparison to observed depositions from field campaigns at three sites in Bulgaria.

METHODS AND DATA

Modelling results

The BgCwFS is based on the US-EPA WRF (3.6.1) and CMAQ (4.6) models, and runs over 5 nested domains: from European scale (81 km grid resolution), through Bulgaria domain (9 km), down to Sofia city (1 km), (Syrakov et al, 2014). The results analysed here are for domain Bulgaria. Extensively tested parameterisations schemes are selected for the models, details are given by Syrakov et al., 2019a.

The emissions are prepared using TNO inventory for 2009 (Kuenen et al. 2014), and Bulgarian national emission inventory for 2010. The sulphur (S) depositions are estimated as the sum of sulphate (SO_4^{2-}), sulphur dioxide (SO_2) and sulfuric acid, the reduced nitrogen (RN deposition) - sum of ammonia (NH_3) and ammonium (NH_4^+) and the oxidised (oxN) depositions as the sum of nitrate (NO_3), nitrogen oxide (NO), and nitrogen dioxide (NO_2). The wet depositions are largely influenced by the model precipitations In our previous studies it was found that the model results (9 km grid) are overestimating the observed precipitations (Syrakov et al. 2019a, Georgieva et al., 2019). Thus, a precipitation bias adjustment (PBA) method (Appel et al., 2011) is applied as post-processing to model monthly wet depositions for domain Bulgaria (Syrakov et al., 2019b). The procedure requires gridded data of observed precipitations. This is achieved by a precipitation analysis method, based on Cressman analysis for combining data from the operational numerical weather prediction model at NIMH (ALADIN) and data from the precipitation monitoring network. Here, modelling results for wet depositions with PBA are analysed.

The EMEP MSC-W modelling results (EMEP, 2018) include monthly values for dry and wet depositions of S, RN and oxN on a grid with 0.1° resolution. For comparison purposes the data for the territory of Bulgaria were extracted and interpolated to the coordinates of the 9 km grid of BgCwFS.

Both models differ in their parameterising schemes, initial and boundary conditions, and emissions input. The EMEP model results are obtained with 2016 emission inventory, while BgCwFS uses one for 2010. The model results have been inter-compared on seasonal and annual basis for the years 2016 and 2017.

Observational data

The observational data used to check model performance were obtained during field experiments at three sites in Bulgaria – at the Central Meteorological Observatory Sofia (42.655 N, 23.384 E, 586 m a.s.l., at the High Mountain Observatory - Cherni vruh (42.616 N 23.266 E, 2230 m a.s.l.) southwest of Sofia and at the synoptic Station Ahtopol at the southern Black Sea coast (42.084 N, 27.952 E, 26m a.s.l.). Daily wet depositions in Sofia and Ahtopol were samples with an automatic wet only device (WADOS), at Cherni Vruh a passive bulk sampler was operated. Dry deposition samples were collected on monthly basis in Sofia and Ahtopol. The collected samples are further analysed for acidity-pH, conductivity-EC, main anions Cl^-, SO_4^{2-} , NO_3^-, cation NH_4^+ and elements Ca, Mg, K, Na, Fe, Si, Zn. For comparison to modelling results data for the period from June to November 2017 are used.

RESULTS AND DISCUSSION

Wet depositions – model results

Figure 1 shows the comparison between BgCwFS (CMAQ) and EMEP wet depositions on seasonal and annual basis (averaged over 2016-2017). Both models simulate prevalence of S-WD and CMAQ values are higher by a factor of 1.5 on annual basis. oxN-WD by CMAQ values are also higher, especially for the winter and autumn periods. Seasonal depositions are shown in Table 2, along with the precipitations. Annual precipitations by the EMEP model are close to the observed fields, with mean seasonal NMB less than 9%, while for CMAQ there is about 15% overestimation in spring and underestimation in summer.

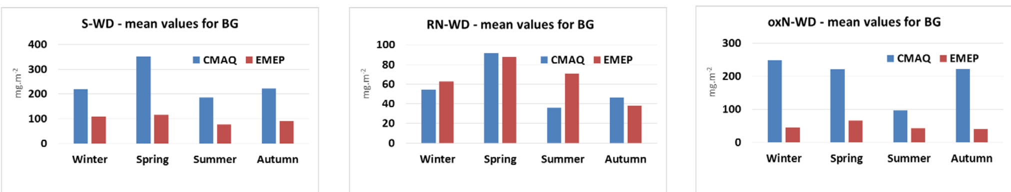

Figure 1. Seasonal wet depositions (mg.m^{-2}) of S (right), reduced N (centre) and oxidized N (right), mean values for Bulgaria based on simulated depositions for 2016 and 2017

The spatial distribution of wet depositions differs for the two models (Figure 2). Both models indicate higher values for S and oxN in the most south-eastern part of the country, where also the experimental site Ahtopol is located. This region is treated as nature protected area.

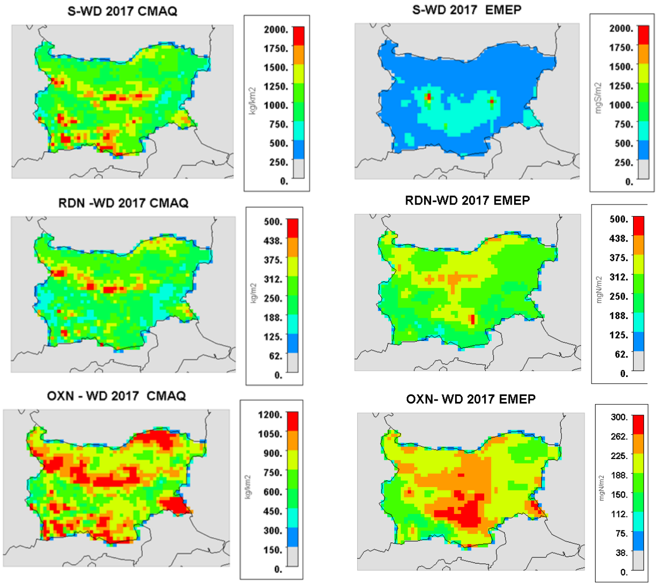

Figure 2. Spatial distribution of wet depositions for 2017, BgCwFS – left, EMEP – right

Dry depositions – model results

Figure 3 shows model results for mean annual dry deposition values. The highest model discrepancies are for sulfur, where BgCwFS annual values are by a factor of 6 higher. It has to be mentioned that Bulgarian SO_x emissions were reported as 388 $Gg.y^{-1}$ (2010), and 105 $Gg.y^{-1}$ (2016). Values for the single seasons and years are given in Table 1.

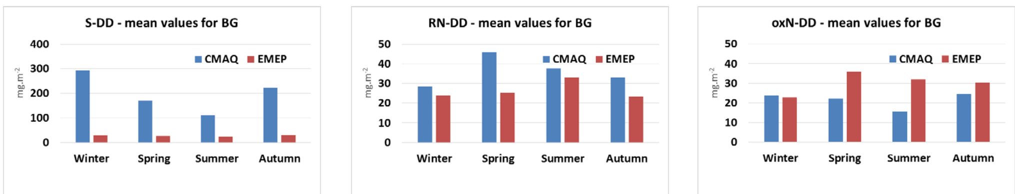

Figure 3. As for Figure 1 but for dry depositions

Comparison to observed depositions

The comparison of simulated depositions go observed ones was carried out on monthly basis for the period from June to November 2017 – for wet depositions at all three stations, for dry depositions at Sofia and Ahtopol. Both models correctly simulate higher S wet depositions at the three sites, Figure 4. The absolute value of the mean NMB is about 15% for BgCwFS and about 58% for EMEP.

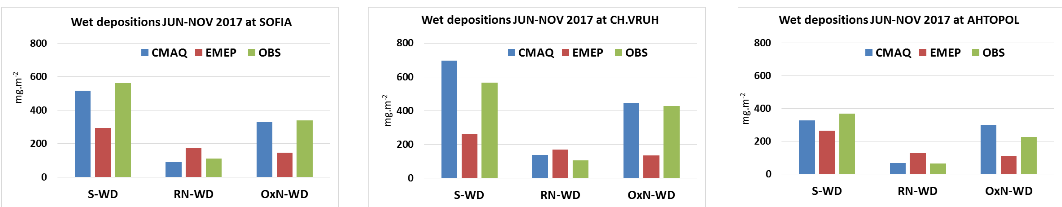

Figure 4. Wet depositions– model and observed values for (Jun-Dec 2017) at Sofia (left), Cherni Vruch (centre) and Ahtopol (right)

The comparison for dry depositions accumulated in the period June-December 2017 (Figure 5) shows that BgCwFS largely overestimates S-DD in Sofia, and underestimates oxN-DD in Ahtopol. The observed S and N dry depositions are higher at the Black Sea site Ahtopol than in Sofia. Further studies are needed to interpret this result, as Ahtopol is far away from big domestic pollution sources. One possible reason might be linked to influence from nearby big cities outside Bulgaria as well as from shipping emissions.

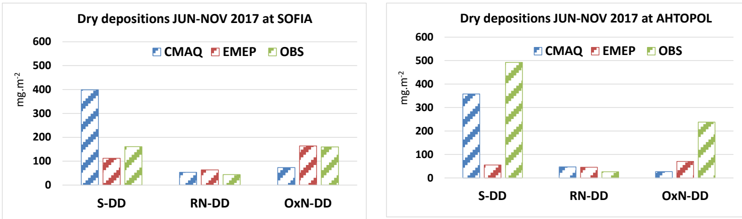

Figure 5. Dry depositions– model and observed values for (Jun-Nov 2017) at Sofia (left), and Ahtopol (right)

Table 1. BgCwFS and EMEP depositions of sulfur, reduced and oxidized nitrogen: mean values for Bulgaria

		Sulphur deposition (mg.m^{-2})		**Nitrogen deposition** (mg.m^{-2})				**Precipitation** (mm)
				2016				
		S-Wet	S-Dry	RN-Wet	RN-Dry	OxN-Wet	OxN-Dry	PR-mod
Winter	BgCwFS	224	313	55	27	273	22	204
	EMEP	113	28	59	23	50	23	246
Spring	BgCwFS	319	167	89	43	213	21	296
	EMEP	118	27	85	25	67	35	263
Summer	BgCwFS	163	109	31	35	76	16	86
	EMEP	64	21	71	33	41	32	122
Autumn	BgCwFS	177	245	40	37	183	28	150
	EMEP	61	30	34	23	35	29	142
Annual	BgCwFS	883	834	215	142	745	86	736
2016	EMEP	356	105	249	104	192	118	773
				2017				
		S-Wet	S-Dry	RN-Wet	RN-Dry	OxN-Wet	OxN-Dry	PR-mod
Winter	BgCwFS	213	271	55	30	222	25	203
	EMEP	105	29	67	25	42	23	150
Spring	BgCwFS	383	174	95	49	230	24	270
	EMEP	115	27	90	26	65	37	228
Summer	BgCwFS	210	113	41	40	118	16	150
	EMEP	90	25	71	33	45	32	155
Autumn	BgCwFS	268	199	52	29	261	22	254
	EMEP	119	31	42	24	46	32	236
Annual	BgCwFS	1074	757	242	148	830	86	877
2017	EMEP	429	111	270	108	199	124	769

CONCLUSIONS

Results from two modelling systems (BgCwFS, based on WRF-CMAQ, and EMEP-MSC-W) were compared for wet and dry depositions of sulfur, reduced nitrogen and oxidized nitrogen for the territory of Bulgaria in 2016 and 2017. The models have similar grid resolutions (about 10 km), but very different inputs and parameterisation schemes. Especially the emission inventories used (for 2010 and 2016) lead also to different depositions both as magnitude and spatial distribution. Despite this, the model intercomparison revealed that sulfur depositions are prevailing for Bulgaria in both simulated years. Both models suggest also that the most south-eastern part of the country has relatively high values both for dry and wet sulfur and oxidized nitrogen depositions. BgCwFS annual S wet deposition values, mean for the country, were higher by a factor of 1.5, while reduced nitrogen wet depositions were similar to EMEP values.

The comparison of modelled to observed depositions at three sites in Bulgaria showed that the models capture the prevalence of S wet depositions in the period from June to November 2017 at all sites. BgCwFS S wet deposition results have better mean NMB in terms of absolute value, 15% and 58%, respectively for BgCwFS and EMEP. The comparison on monthly wet depositions for the same period, presented in an accompanying paper of this proceedings, confirms that sulfur wet depositions are the highest ones at the three stations.

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REFERENCES

Appel, K.W., K. M. Foley, J. O. Bash, R. W. Pinder, R. L. Dennis, D. J. Allen, K. Pickering, 2011: A multi-resolution assessment of the Community Multiscale Air Quality (CMAQ) model v4.7 wet deposition estimates for 2002–2006. *Geosci. Model Dev.*, **4**, 357–371.

Georgieva E., E. Hristova, D. Syrakov, M. Prodanova, E. Batchvarova, 2019: Preliminary evaluation of CMAQ modelled wet deposition of sulphur and nitrogen over Bulgaria, *Intern. J. Env. Pollut.* (in press)

EMEP, 2018 EMEP Status Report 1/2018, "Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components", Joint MSC-W & CCC & CEIP Report, MET Norway, 204pp.

Kanakidou, M., S. Myriokefalitakis, N. Daskalakis, G. Fanourgakis, A. Nenes, A.R. Baker, K. Tsigaridis, and N. Mihalopoulos, 2016: Past, Present, and Future Atmospheric Nitrogen Deposition. *J. Atmos. Sci.*, **73**, 2039–2047.

Kuenen, J.J.P., Visschedijk, A.J.H., Jozwicka, M., Denier van der Gon, H.A.C., 2014: TNO-MACC II emission inventory; a multi-year (2003–2009) consistent high resolution European emission inventory for air quality modelling. *Atmos. Chem. Phys*. **14**, 10963–10976.

Simpson, D., Benedictow, A., Berge, H., Bergström, R., Emberson, L. D., Fagerli, H., Flechard, C. R., Hayman, G. D., Gauss, M., Jonson, J. E., Jenkin, M. E., Nyíri, A., Richter, C., Semeena, V. S., Tsyro, S., Tuovinen, J.-P., Valdebenito, Á., and Wind, P., 2012: The EMEP MSC-W chemical transport model– technical description', *Atmos. Chem. Phys*., **12**, 7825–7865

Syrakov, D., M. Prodanova, I.Etropolska, K.Slavov, K.Ganev, N.Miloshev, T.Ljubenov, 2014: A multi-domain operational chemical weather forecast system. In: Lirkov, I., et al. (Eds.) LSSC 2013. LNCS, **8353**, 413–420. Springer Verlag, Heidelberg.

Syrakov, D., Prodanova, M., Georgieva, E., Hristova, E. 2019a: Applying WRF-CMAQ models for assessment of sulphur and nitrogen deposition in Bulgaria for years 2016 and 2017. *Intern. J. Env. Pollut.* (in press)

Syrakov D., Georgieva E., Prodanova M, Hristova E., Gospodinov I., Slavov K., and Veleva B. 2019b: Application of WRF-CMAQ Model System for Analysis of Sulfur and Nitrogen Deposition over Bulgaria, Application of WRF-CMAQ Model System for Analysis of Sulfur and Nitrogen Deposition over Bulgaria. In: Nikolov G., Kolkovska N., Georgiev K. (eds) Numerical Methods and Applications. *Lecture Notes in Computer Science*, **11189**,474-482, Springer, Cham

Torseth, K., Aas, W., Breivik, K., Fjaeraa, A.M., Fiebig, M., Hjellbrekke, A.G., Lund Myhre, C., Solberg, S., Yttri, K.E., 2012: Introduction to the European monitoring and evaluation programme (EMEP) and observed atmospheric composition change during 1972-2009. *Atmos. Chem. Phys*. **12**, 5447-5481

Vivanco, M.G., Theobald, M.R., García-Gómez, H., Garrido, J.L., Prank, M., Aas, W., ... Galmarini, S. 2018: Modeled deposition of nitrogen and sulfur in Europe estimated by 14 air quality model systems: evaluation, effects of changes in emissions and implications for habitat protection. *Atmospheric Chemistry and Physics,* **18**, 10199-10218.