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COST Action TD1105

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New Sensing Technologies for Indoor Air Quality Monitoring: Trends and Challenges

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COMPUTER SIMULATIONS OF THE ATMOSPHERIC COMPOSITION CLIMATE OF BULGARIA - SOME BASIC RESULTS



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Numerical Study of the Atmospheric Composition Climate in Bulgaria – Study objectives:

- Creating of statistically representative and well validated ensemble of the atmospheric composition status of the Balkan Peninsula and the country – “atmospheric composition climate”;
- Revising the main features of the atmospheric composition climate of the country typical and extreme configurations with their recurrence;
- Evaluating the contribution of different source categories to the air pollution of the country;
- Tracking and characterizing the main pathways and processes that lead to atmospheric composition formation in different scales ;
- Providing high quality scientifically robust assessments of the air quality and its origin – basis for formulation of air pollution mitigation strategies.

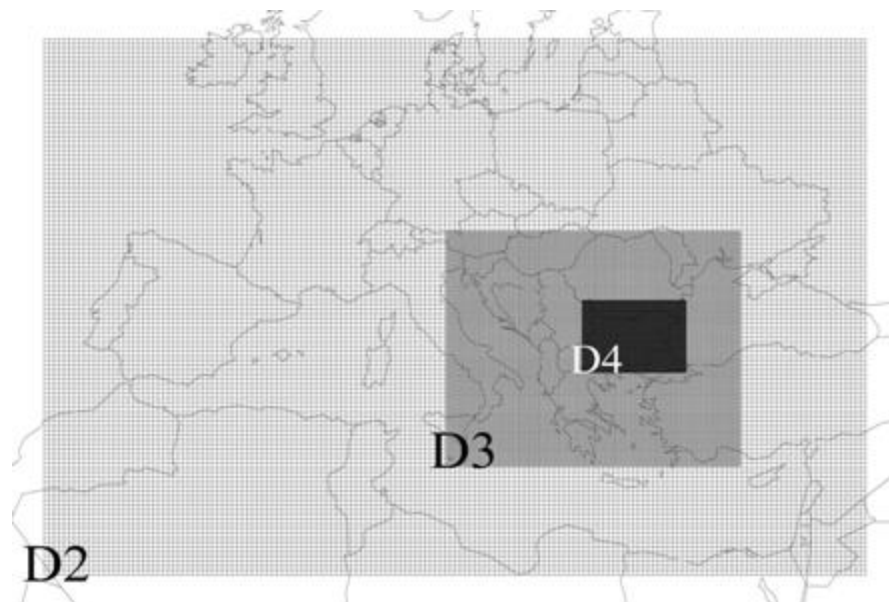
Numerical Study of the Atmospheric Composition Climate in Bulgaria : Modeling tools and input data:

- **MM5** - the 5th generation PSU/NCAR Meso-meteorological Model MM5 (Dudhia, 1993, Grell et al., 1994) used as meteorological pre-processor. This model is pretty often replaced by the next generation model WRF (Shamarock et al., 2007);
- **CMAQ** - the Community Multiscale Air Quality System being the Chemical Transport Model (CTM) of the system. A chlorine chemical mechanism has been added to CMAQ based on Tanaka et al. (2003);
- **SMOKE** - the Sparse Matrix Operator Kernel Emissions Modelling System (CEP, 2003) – the emission pre-processor of Models-3 system. SMOKE currently supports BEIS (Biogenic Emissions Inventory System) mechanism, versions 3.13
- **Large scale (background) meteorological data:** the NCEP Global Analysis Data with $1^{\circ} \times 1^{\circ}$ resolution
- **Emission data:** the TNO high resolution emission inventory and the Bulgarian national emission inventory

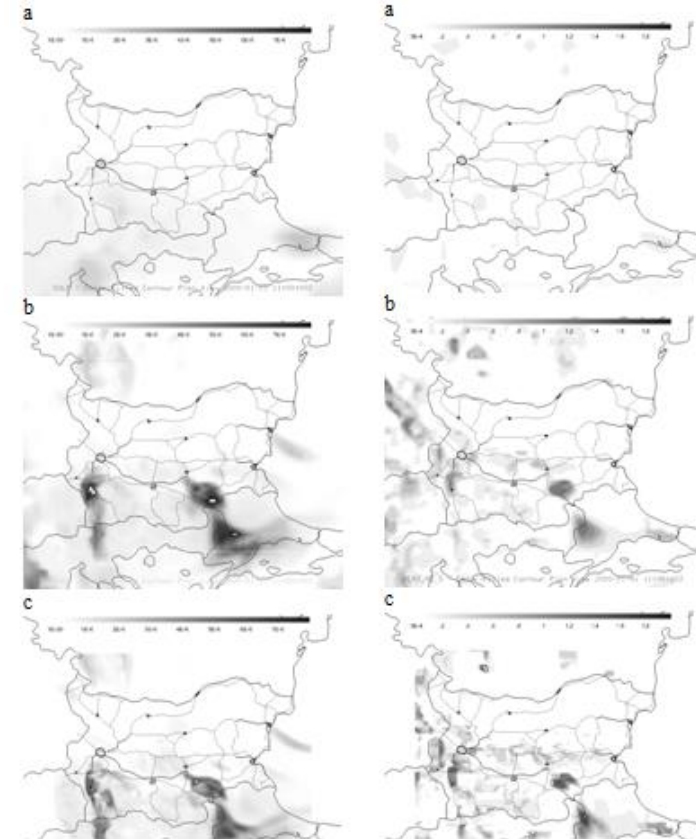
Numerical Study of the Atmospheric Composition Climate in Bulgaria : domains & “nesting”

The calculations are made for 8 years from 2000 to 2007 for 5 scenarios: with all the emissions, with reduced emission from SNAP-s 1,2 and 7 and with excluded biogenic emissions.

	<i>D1</i>	<i>D2</i>	<i>D3</i>	<i>D4</i>
<i>MM5 (km)</i> <i>2 way nesting</i>	81	27	9	3
<i>CMAQ (km)</i>		27	9	3
<i>Grid dimensions</i>		166X115	178x151	190x140



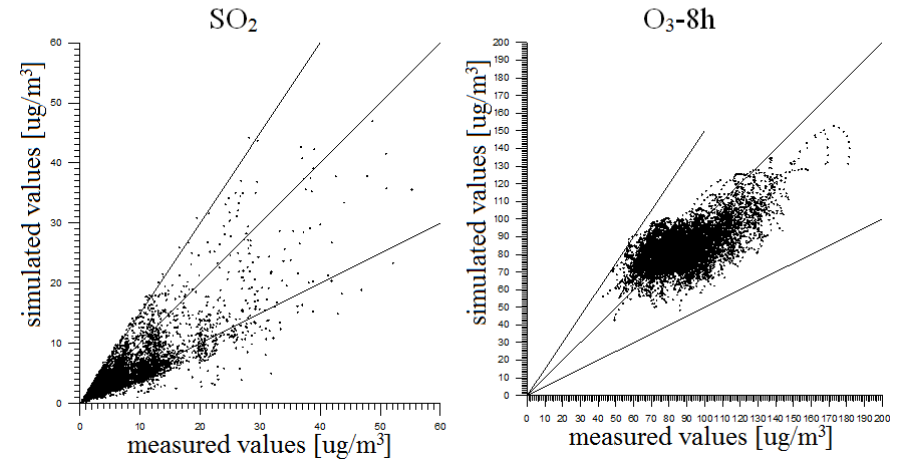
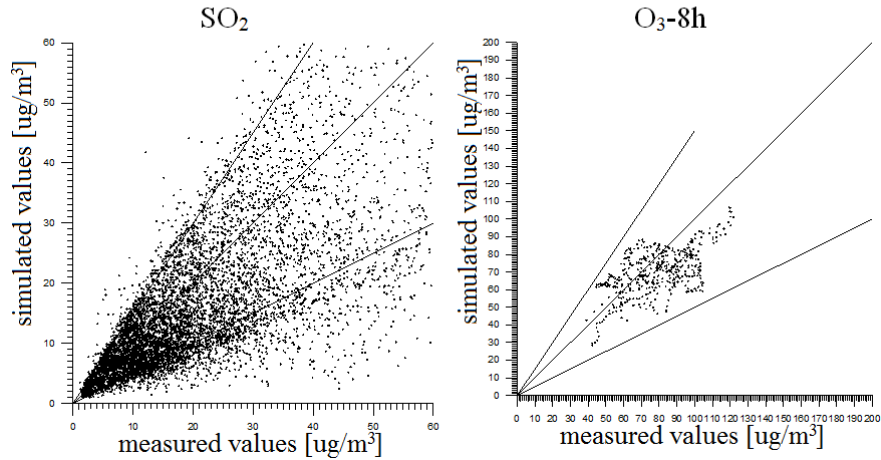
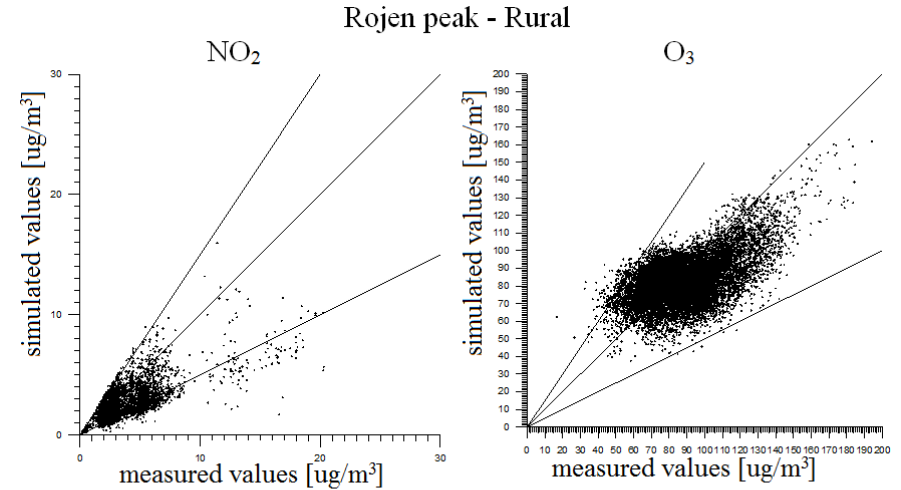
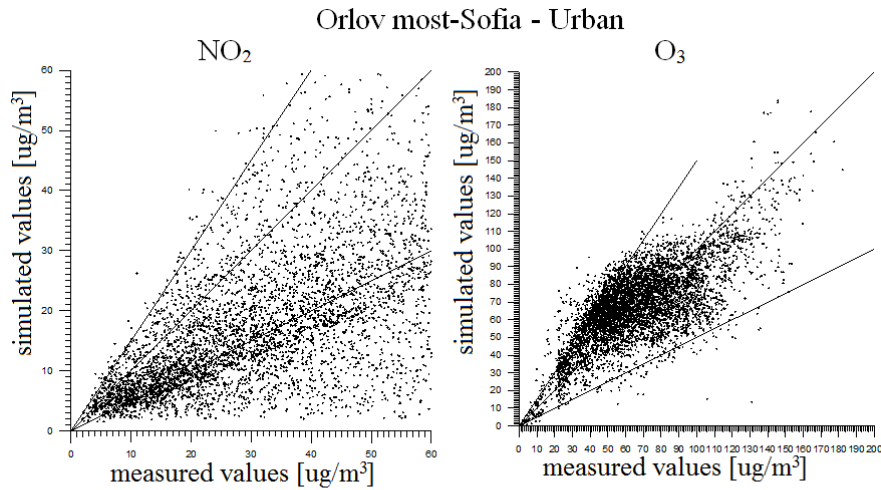
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Fields of surface sulfate [ppb] calculated by the second
D2 (a) D3 (b) and D4 (c) nesting steps,
01.01.2000, 11:00 UTC

Fields of the hourly contribution of aerosol
processes to the PM2.5
D2 (a), D3 (b) and D4 (c) nesting steps,
01.01.2000, 11:00 UTC

Numerical Study of the Atmospheric Composition Climate in Bulgaria: Validation of the simulation results (scatter diagrams)



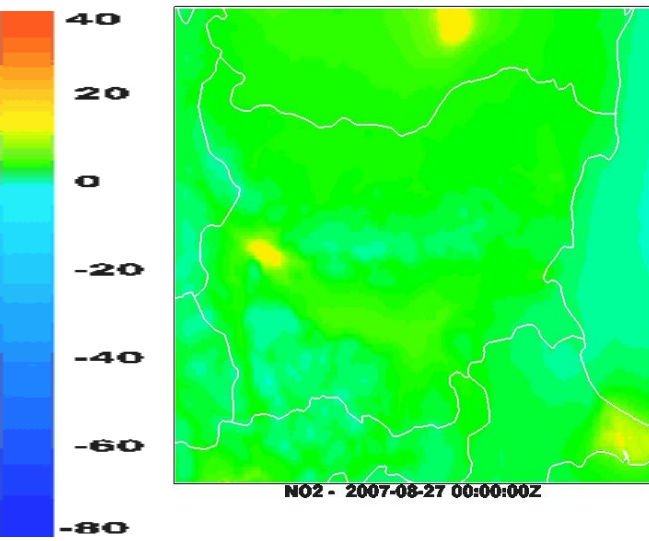
Numerical Study of the Atmospheric Composition Climate in Bulgaria: Validation of the simulation results- Some statistical evaluations for O3

station	MO ($\mu\text{g}/\text{m}^3$)	MP ($\mu\text{g}/\text{m}^3$)	NMB (%)	NRMSE (%)	FA2 (%)	PCC	NMSD (%)
12U	71.45	72.41	1.35	11.27	87.30	0.45	-41.04
13S	72.49	70.25	-2.56	12.71	91.45	0.49	-45.36
41U	72.92	71.67	-1.72	11.71	90.76	0.67	-32.95
43U	69.68	76.69	10.05	15.19	82.77	0.52	-44.87
44S	73.72	72.47	-1.70	12.46	88.26	0.72	-44.54
45S	70.48	71.99	2.14	12.34	88.97	0.67	-36.67
49S	67.43	73.00	8.27	6.92	85.27	0.53	-32.70
50S	60.08	75.18	25.13	12.77	75.90	0.69	-12.63
51U	67.19	72.37	7.71	10.35	86.06	0.68	-31.19
52S	61.34	66.92	9.09	9.85	86.14	0.68	-9.23
53R	88.96	82.64	-7.11	6.42	98.76	0.58	-33.87
54U	66.70	67.72	1.53	8.84	88.15	0.72	-19.60
55U	61.61	72.11	17.05	16.59	80.81	0.55	-27.91
56S	80.34	74.19	-7.65	14.02	94.91	0.62	-46.14

Numerical Study of the Atmospheric Composition Climate in Bulgaria: Validation of the simulation results- Some statistical evaluations for NO2

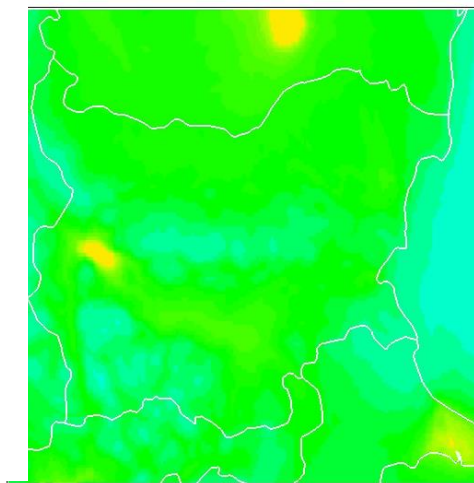
station	MO ($\mu\text{g}/\text{m}^3$)	MP ($\mu\text{g}/\text{m}^3$)	NMB (%)	NRMSE (%)	FA2 (%)	PCC	NMSD (%)
12U	15.47	7.11	-54.04	7.52	50.84	0.52	-57.49
13S	16.87	8.23	-51.22	5.07	53.82	0.38	-64.49
41U	25.32	11.10	-56.15	9.47	43.67	0.35	-68.54
43U	12.83	5.85	-54.45	9.63	49.29	0.51	-60.45
44S	9.98	5.99	-39.96	8.73	62.17	0.63	-38.77
45S	13.85	6.04	-56.35	9.25	49.21	0.46	-71.51
49S	22.66	9.51	-58.02	15.03	43.58	0.42	-56.48
50S	23.45	10.14	-56.76	9.56	43.20	0.47	-54.84
51U	18.55	7.48	-59.68	9.09	46.62	0.47	-74.09
52S	27.28	16.91	-38.01	7.57	64.52	0.67	-42.91
53R	3.83	2.71	-29.22	10.69	75.52	0.71	-39.38
54U	42.07	21.44	-49.04	10.07	52.10	0.65	-44.92
55U	14.01	5.12	-63.42	7.15	42.76	0.46	-78.92
56S	7.59	4.10	-45.91	7.84	56.96	0.61	-50.69

Numerical Study of the Atmospheric Composition Climate in Bulgaria : averaged concentrations



NO2 - 2007-08-27 00:00:00Z

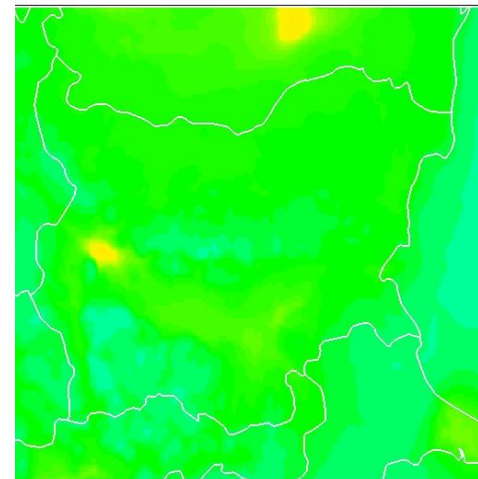
Annual



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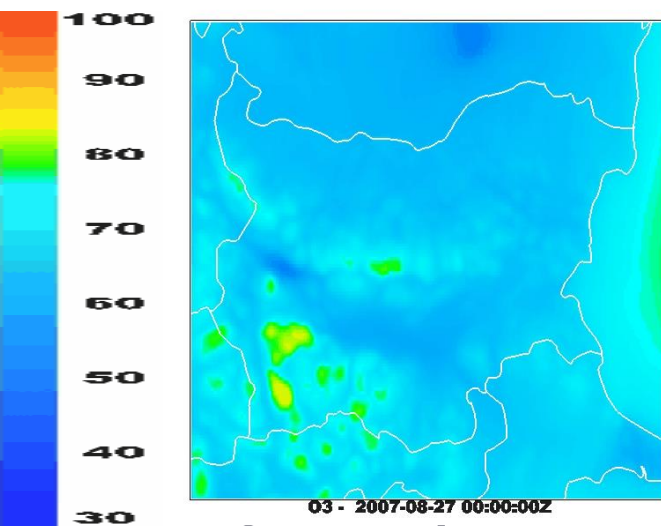
Summer

NO2

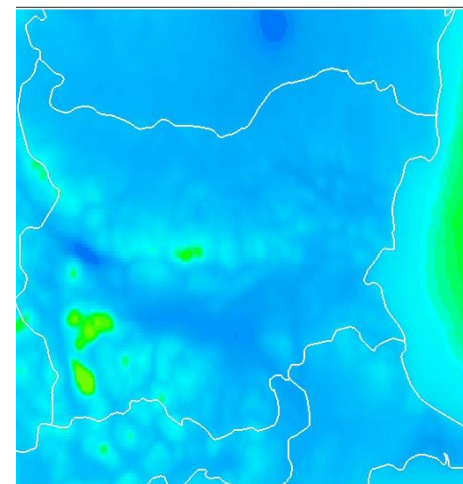


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Winter

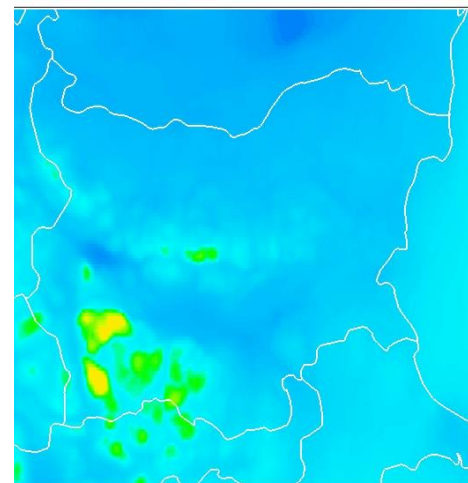


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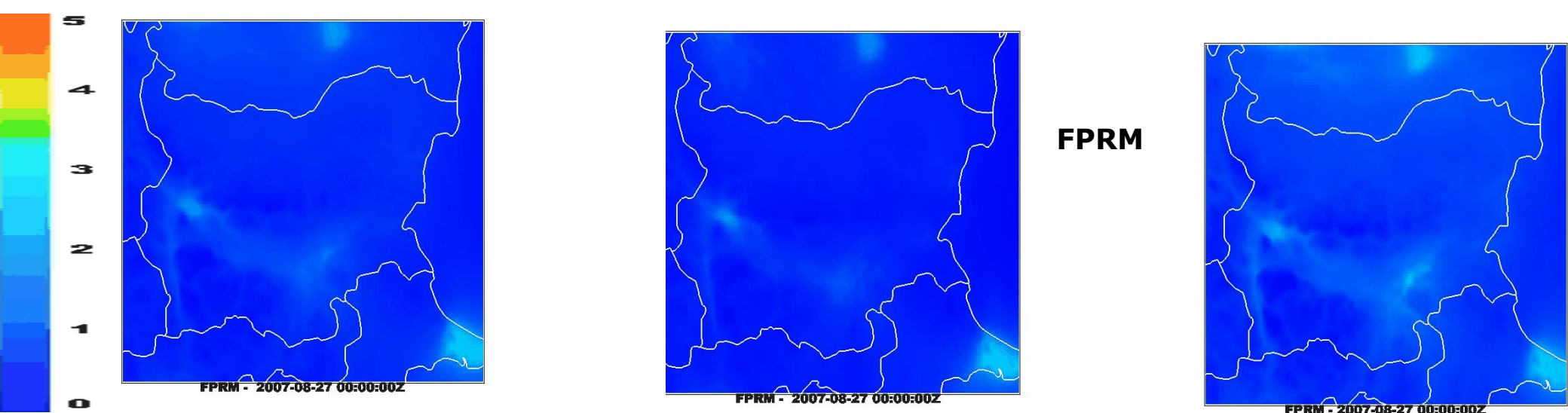
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O3



O3 - 2007-08-27 00:00:00Z

Numerical Study of the Atmospheric Composition Climate in Bulgaria : averaged concentrations

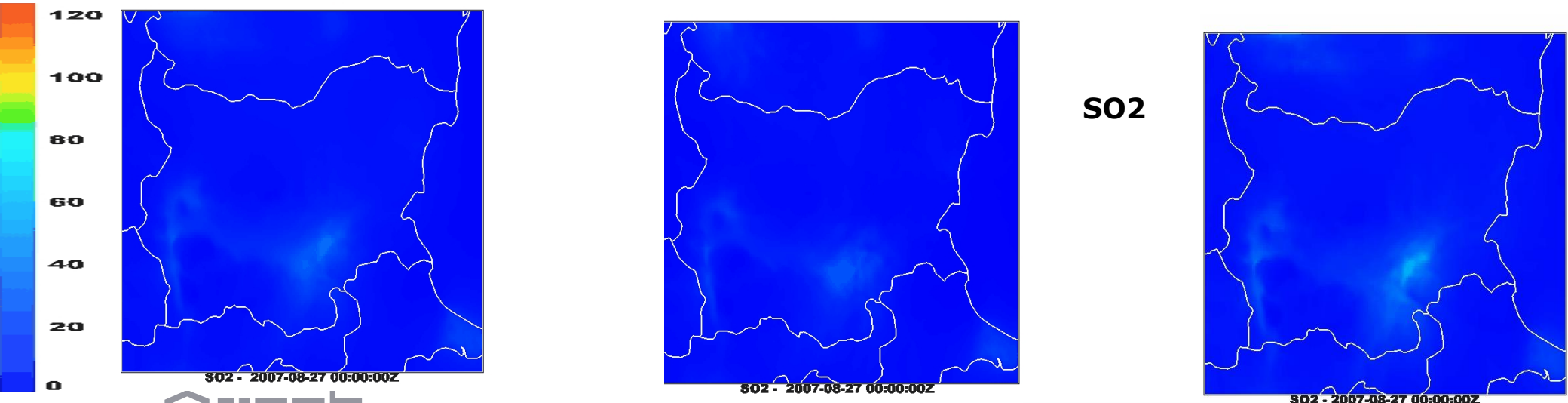


Annual

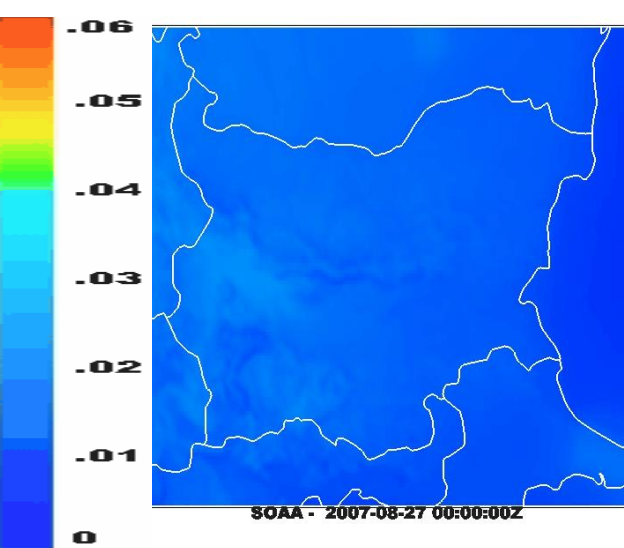
Summer

Winter

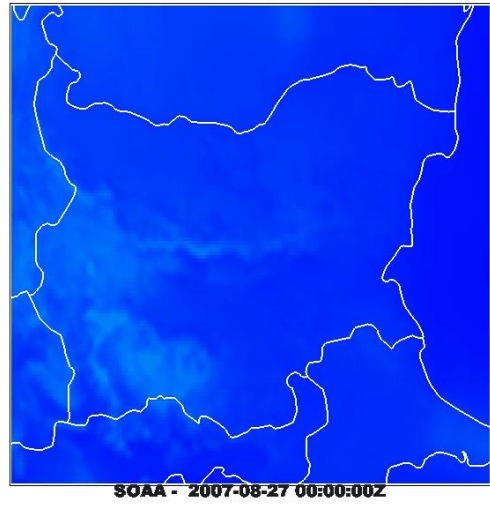
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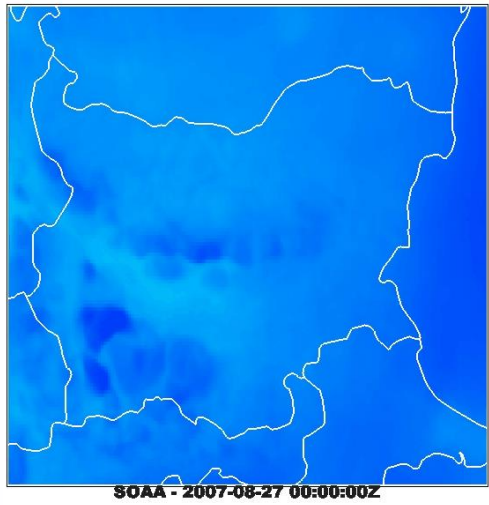
Numerical Study of the Atmospheric Composition Climate in Bulgaria : averaged concentrations



Annual

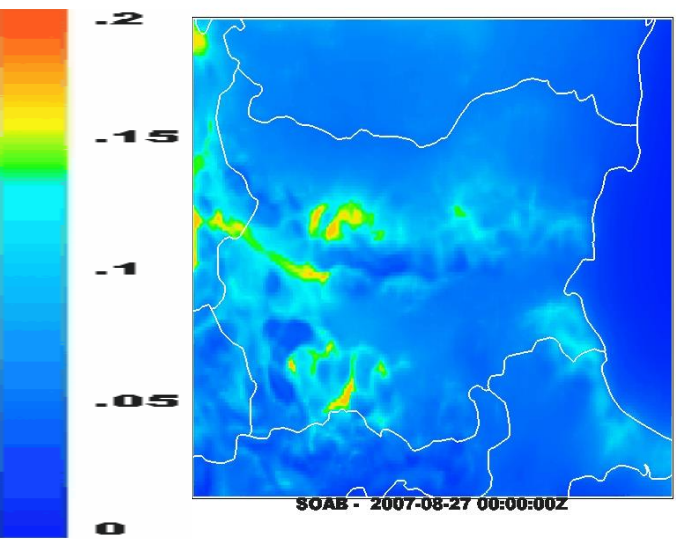


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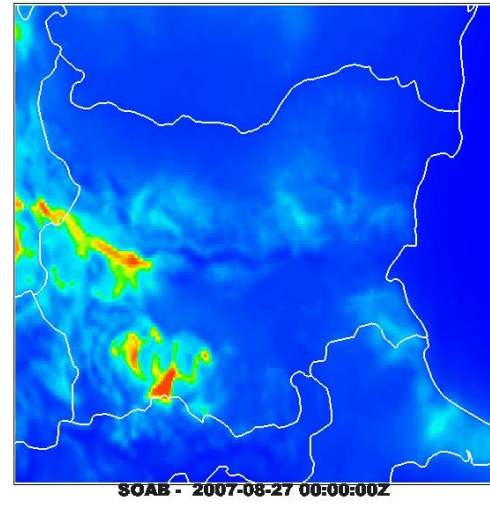


Winter

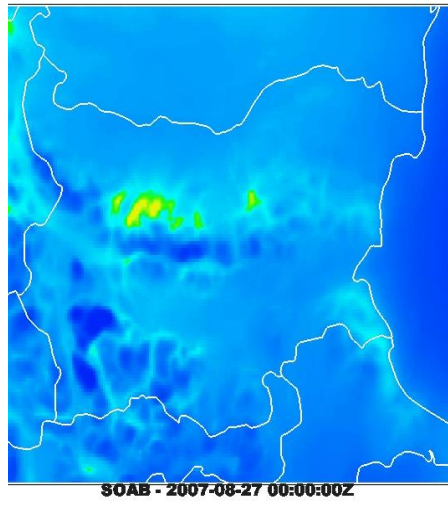
SOAA



Annual



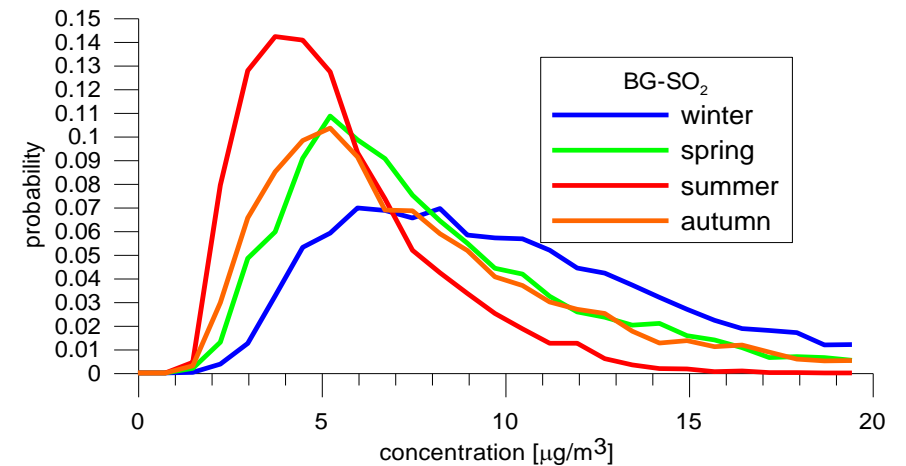
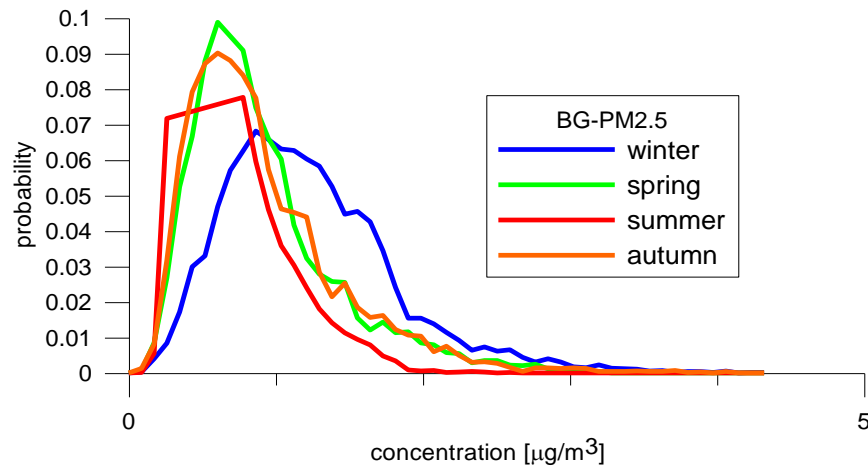
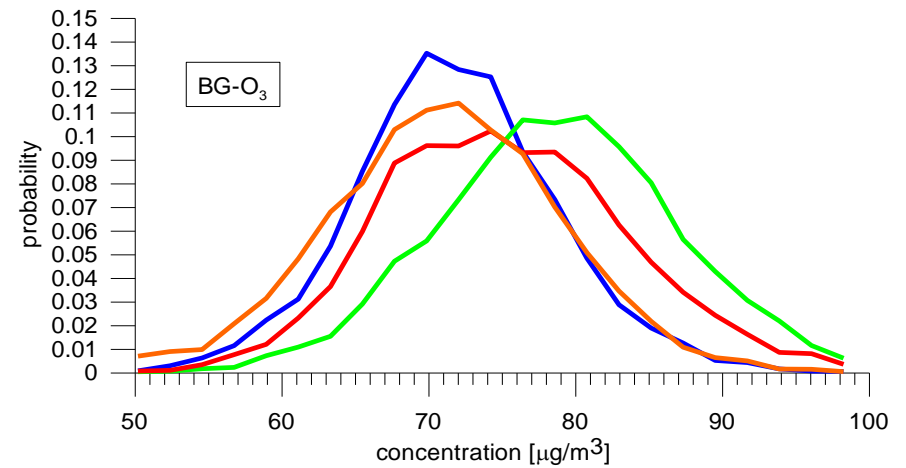
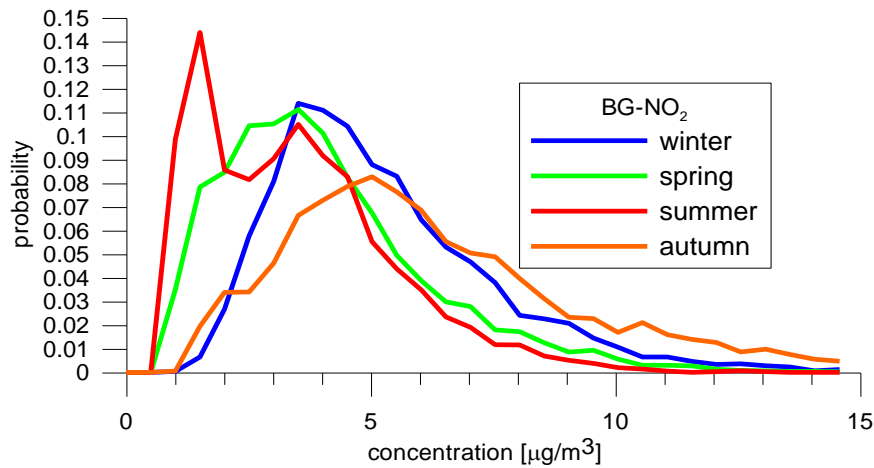
Summer



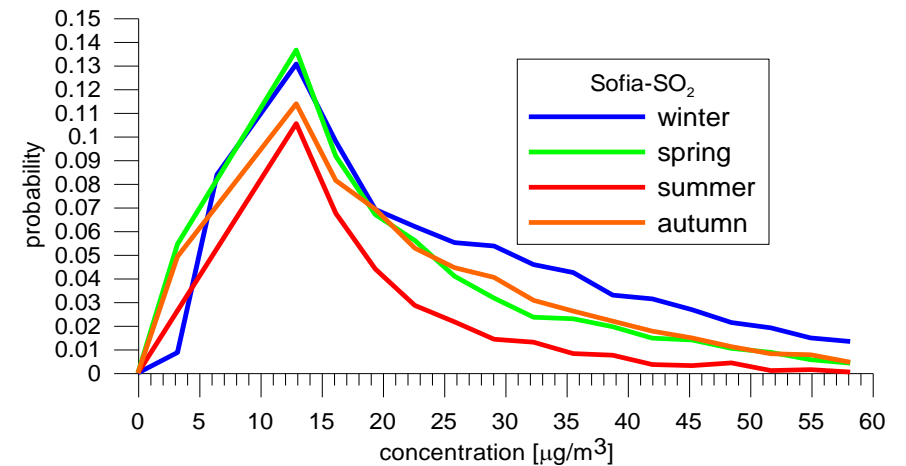
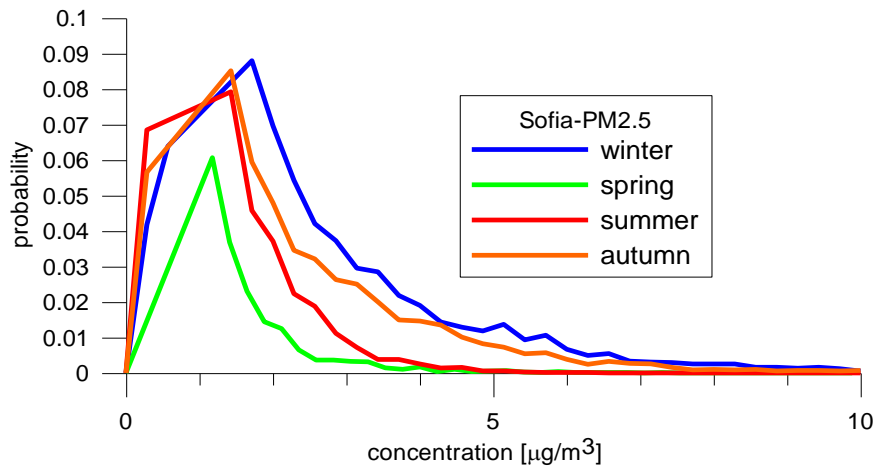
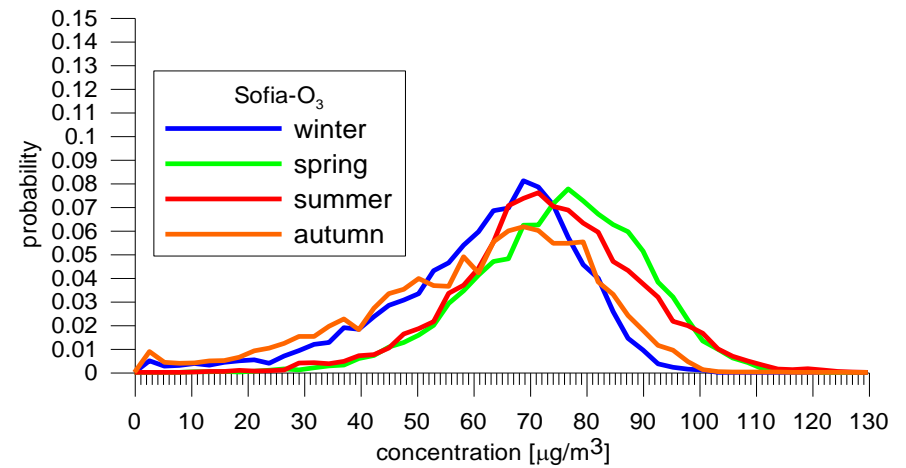
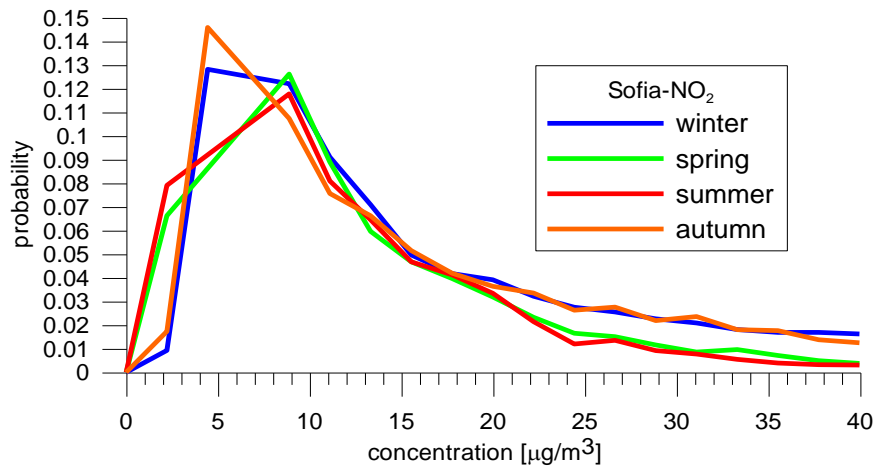
Winter

SOAB

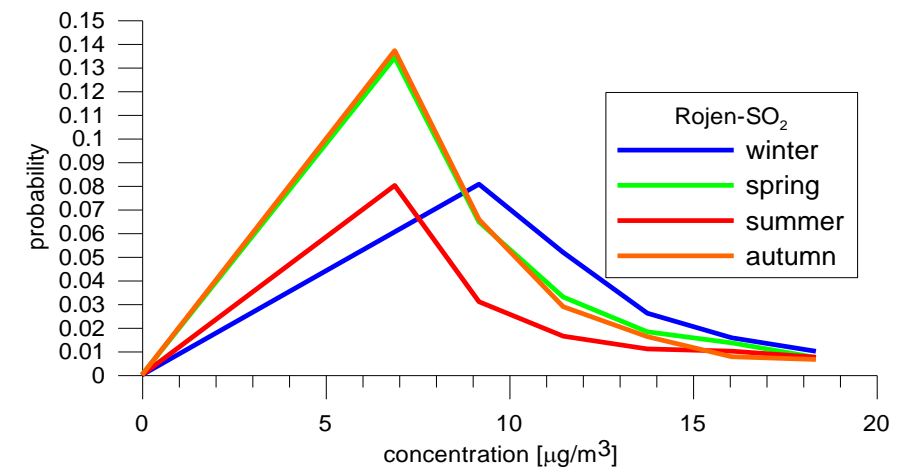
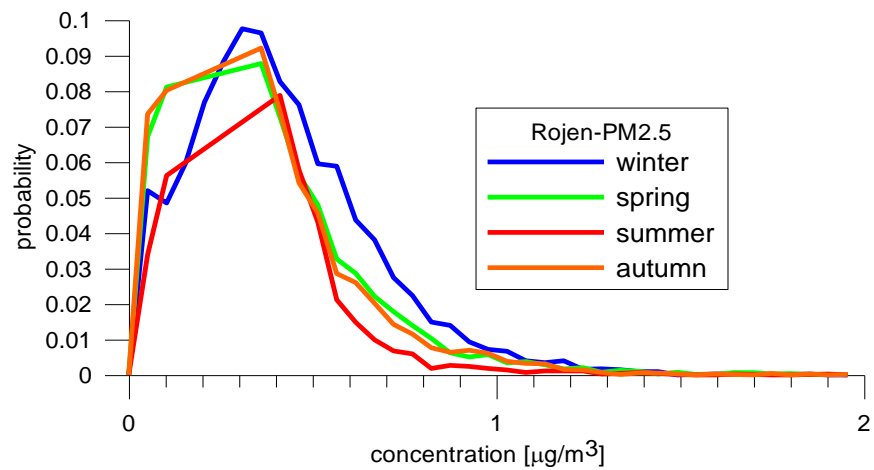
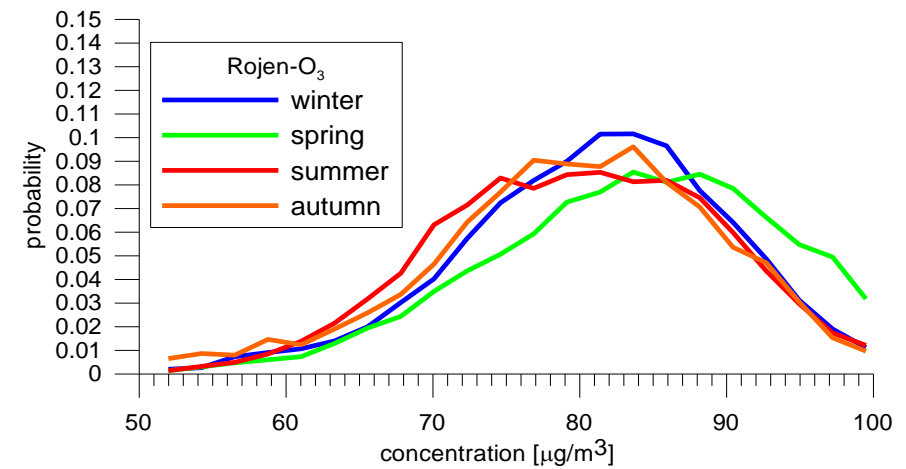
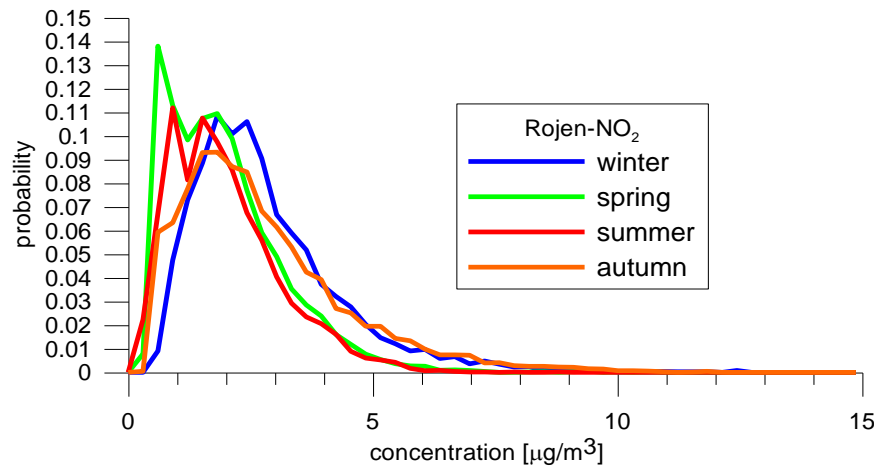
Numerical Study of the Atmospheric Composition Climate in Bulgaria : seasonal variations of concentration probability density for Bulgaria



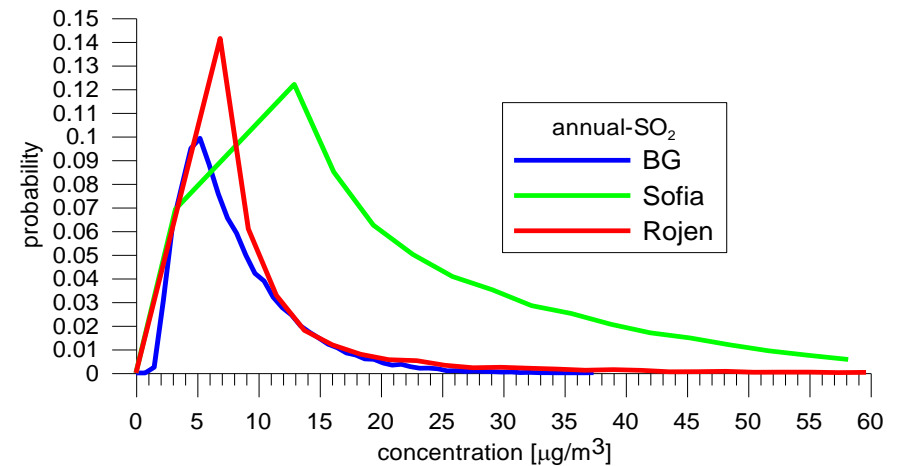
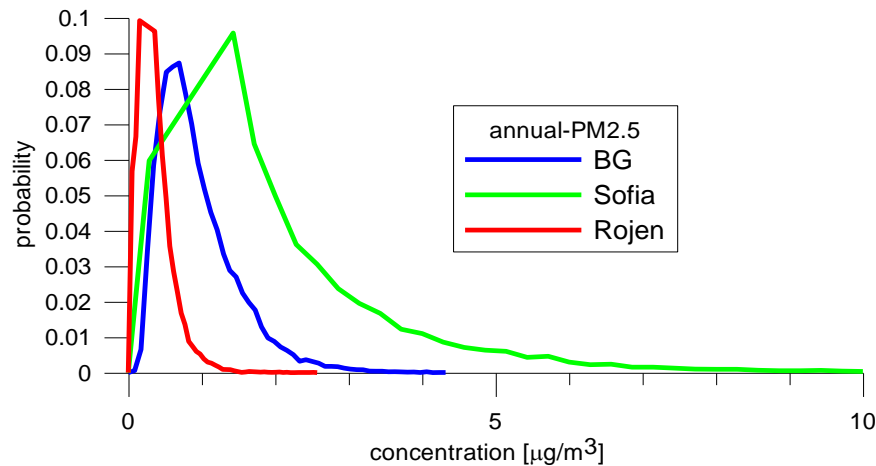
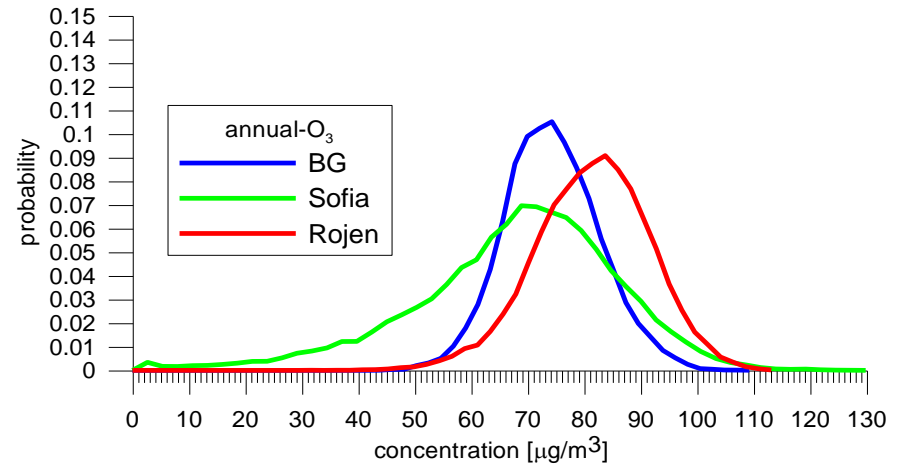
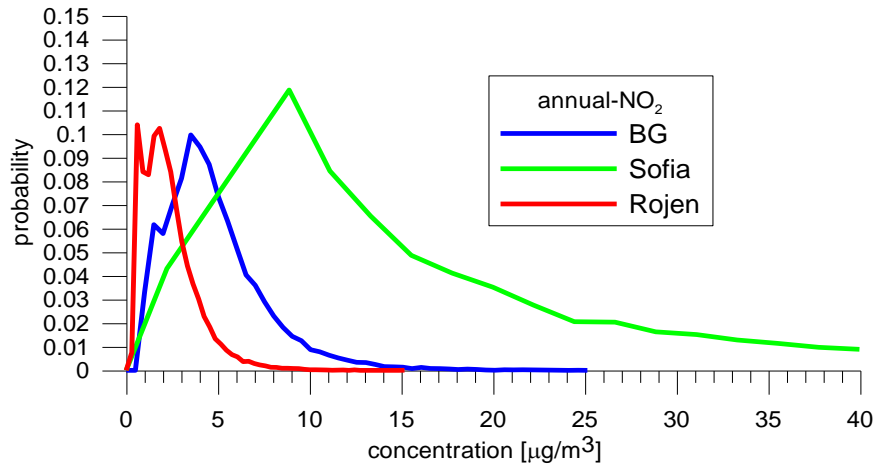
Numerical Study of the Atmospheric Composition Climate in Bulgaria : seasonal variations of concentration probability density for Sofia



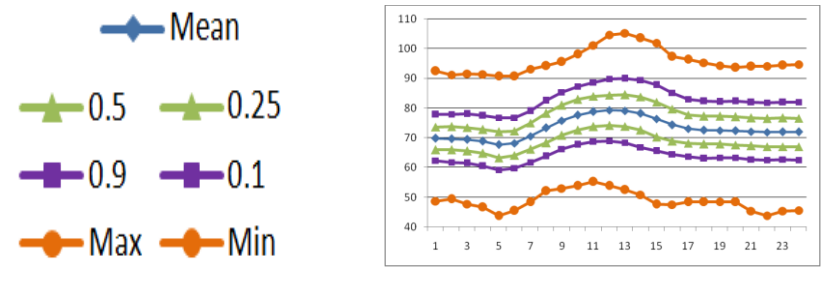
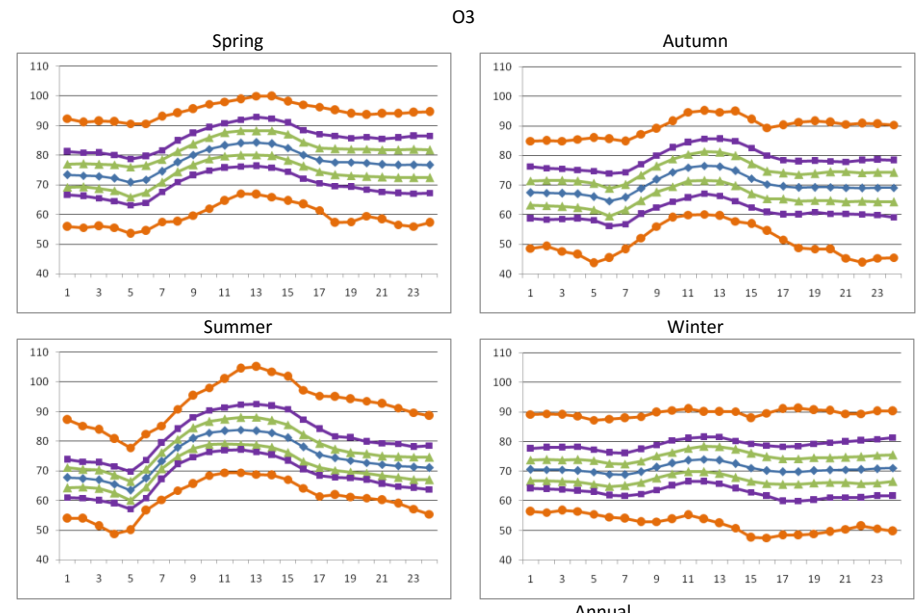
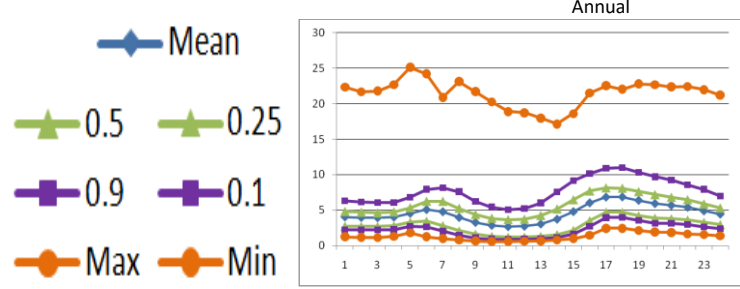
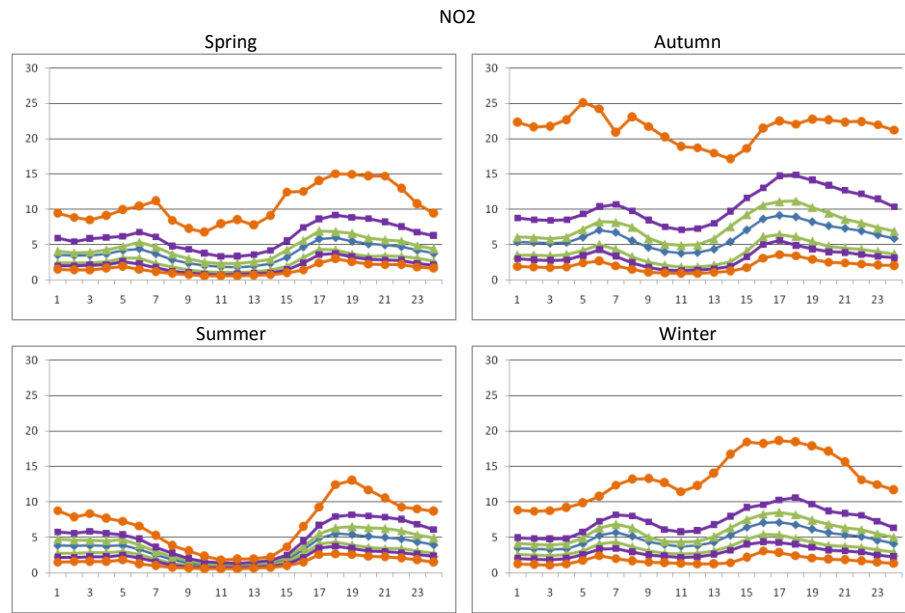
Numerical Study of the Atmospheric Composition Climate in Bulgaria : seasonal variations of concentration probability density for Rojen



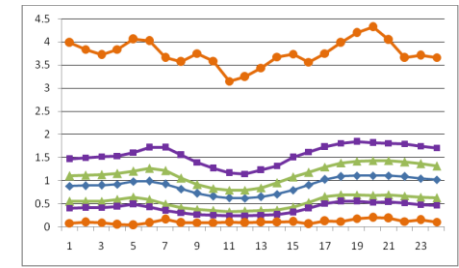
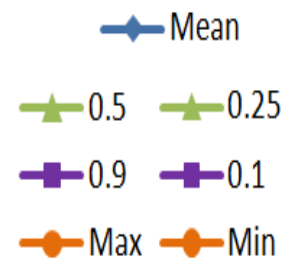
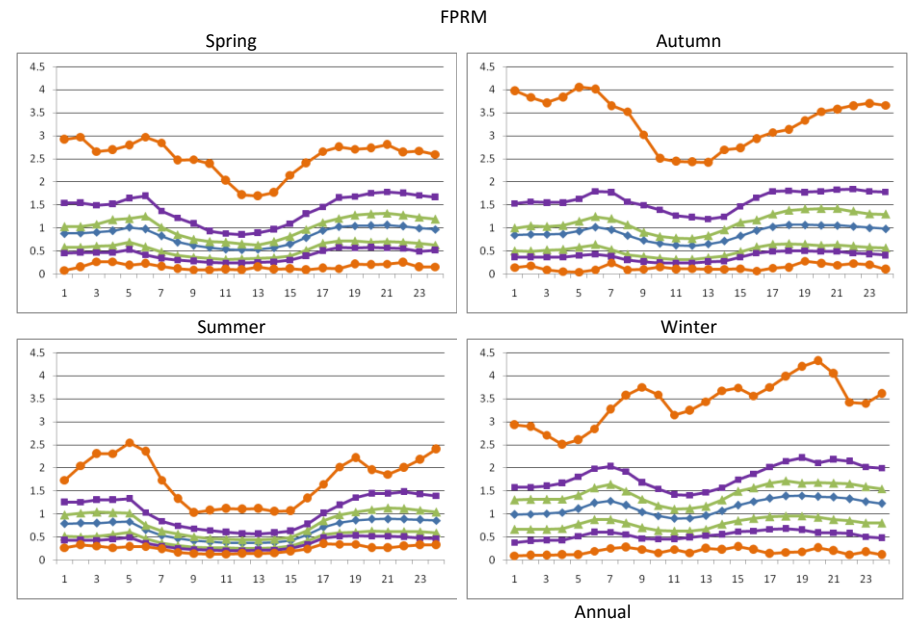
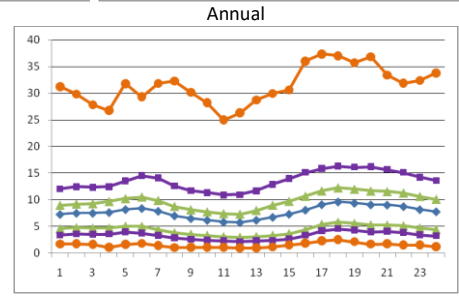
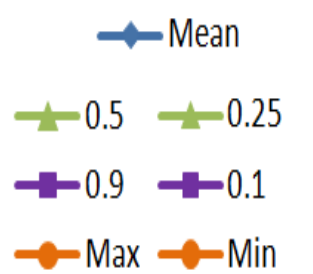
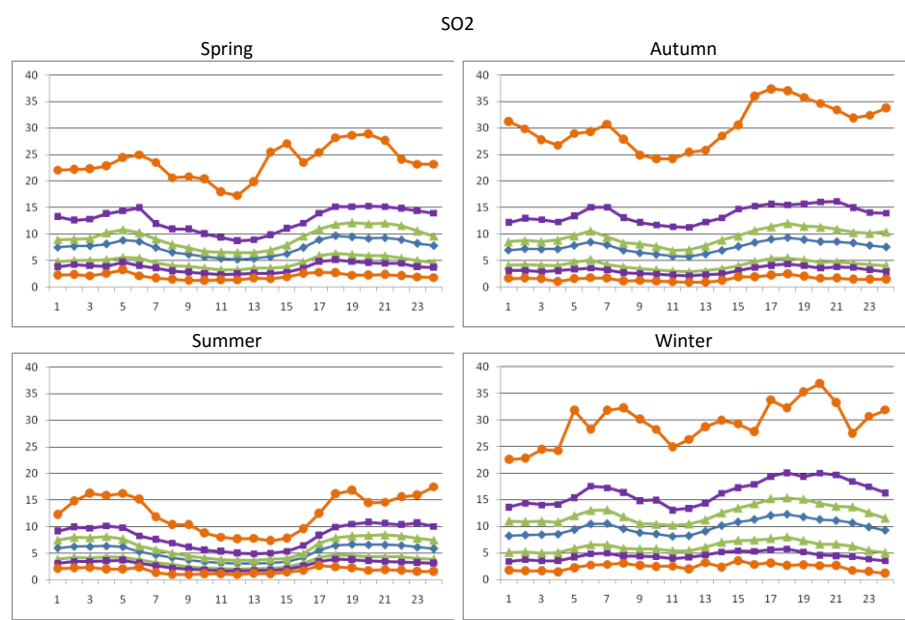
Numerical Study of the Atmospheric Composition Climate in Bulgaria : spatial variations of annual concentration probability density



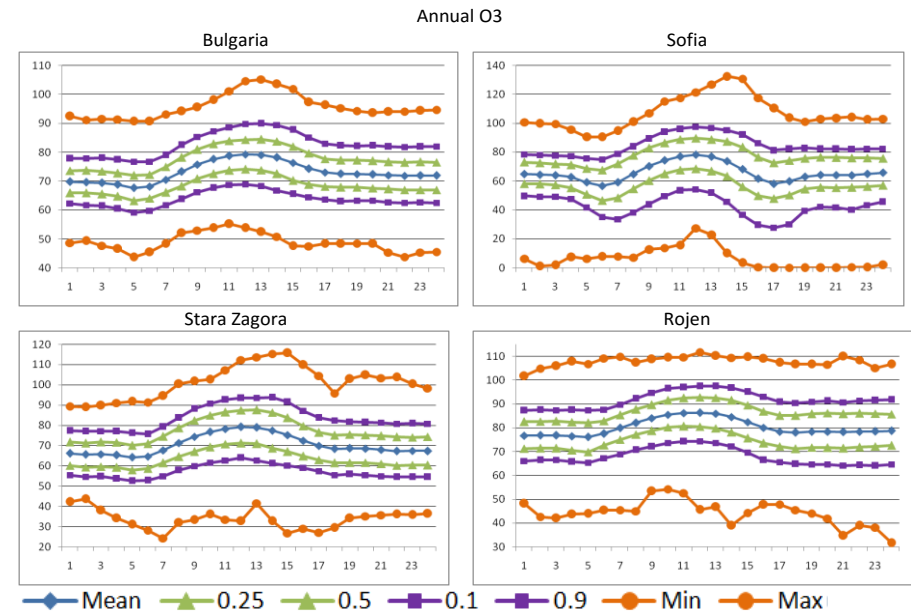
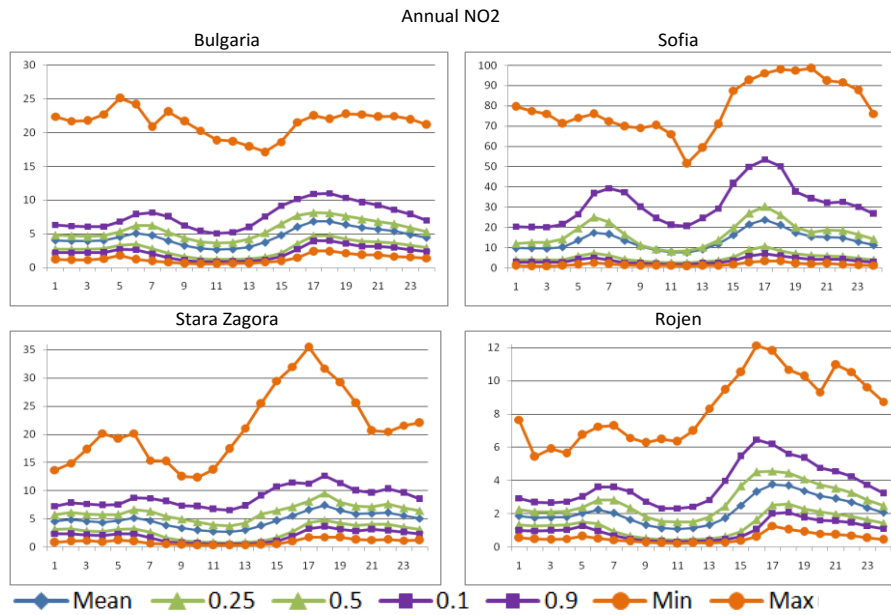
Numerical Study of the Atmospheric Composition in Bulgaria : diurnal/seasonal variations of averaged over Bulgaria concentrations



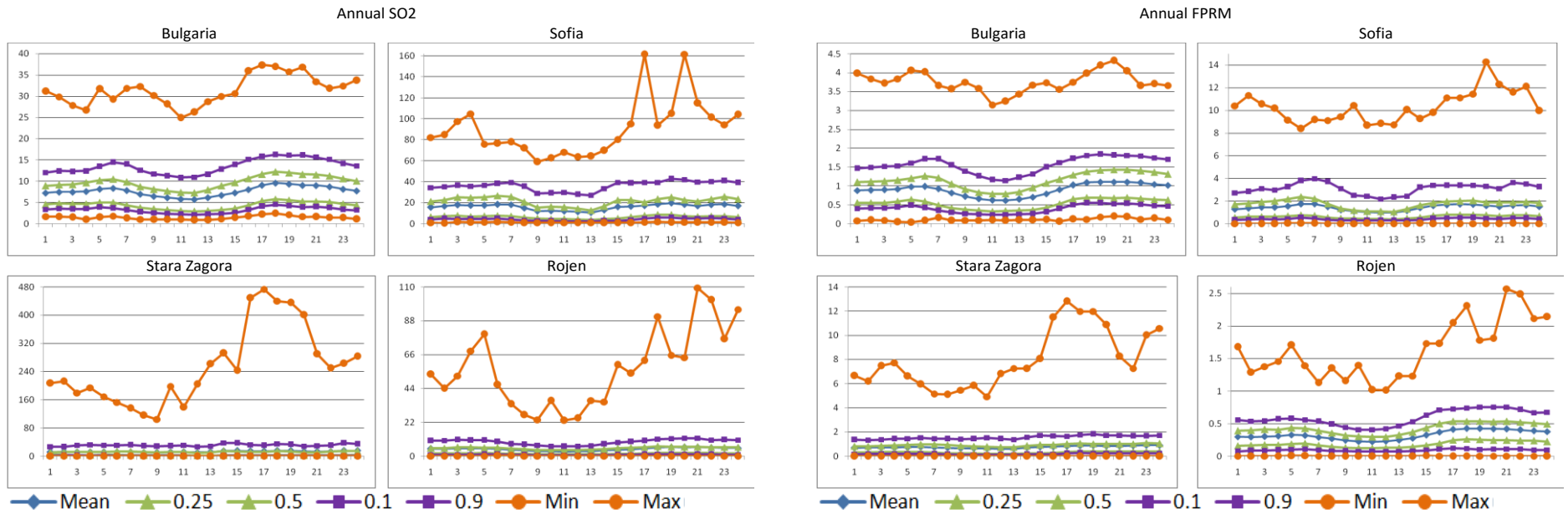
Numerical Study of the Atmospheric Composition in Bulgaria : diurnal/seasonal variations of averaged over Bulgaria concentrations



Numerical Study of the Atmospheric Composition in Bulgaria : diurnal and spatial concentration variations



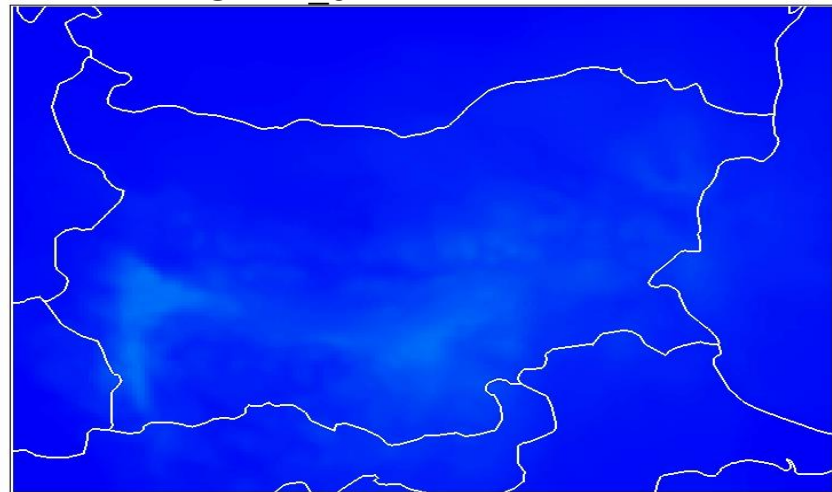
Numerical Study of the Atmospheric Composition in Bulgaria : diurnal and spatial concentration variations



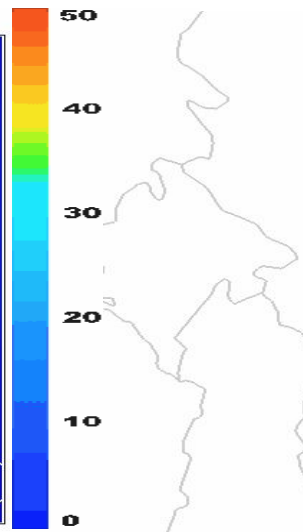
Numerical Study of the Atmospheric Composition in Bulgaria : annual SNAP contributions for NO2



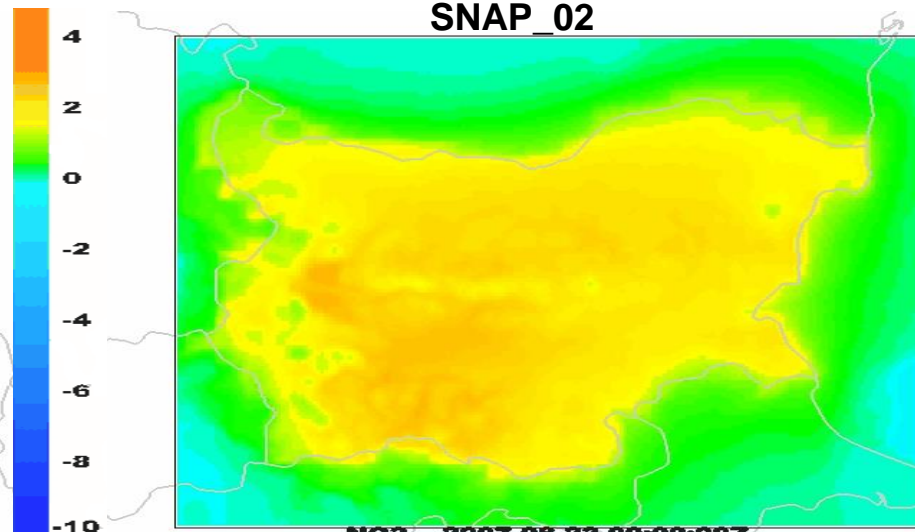
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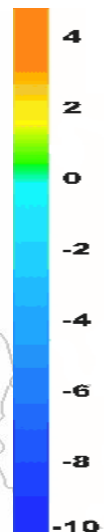
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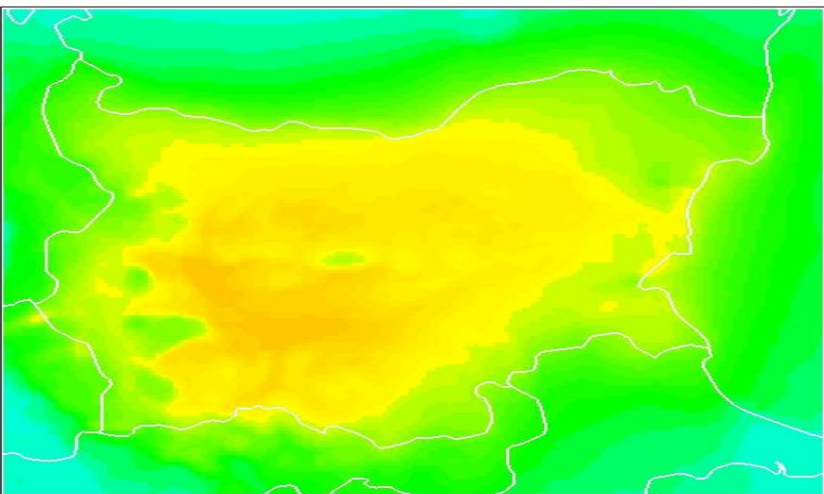
SNAP_02



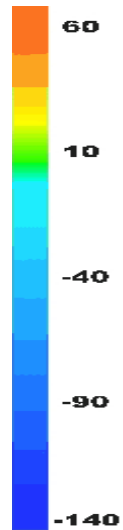
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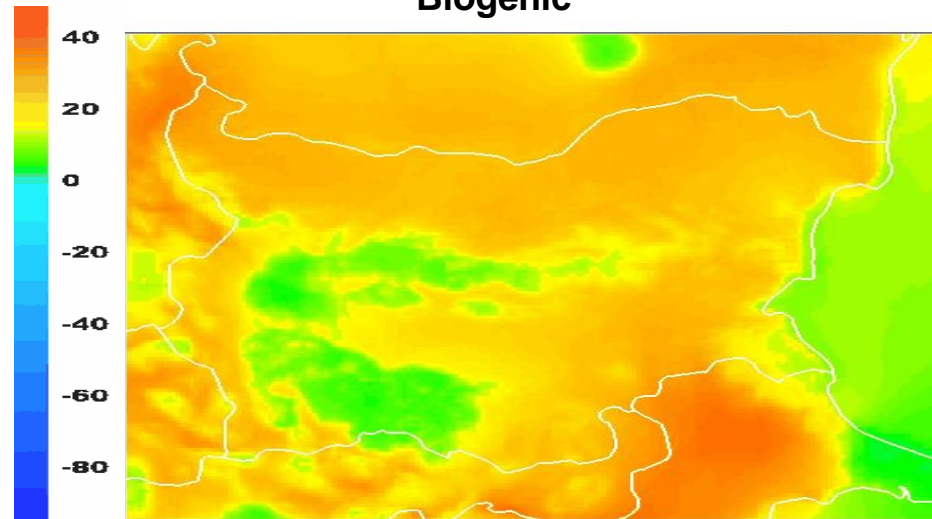
SNAP_07



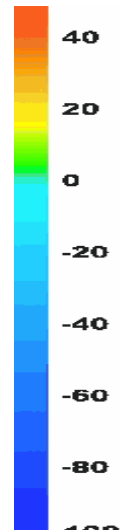
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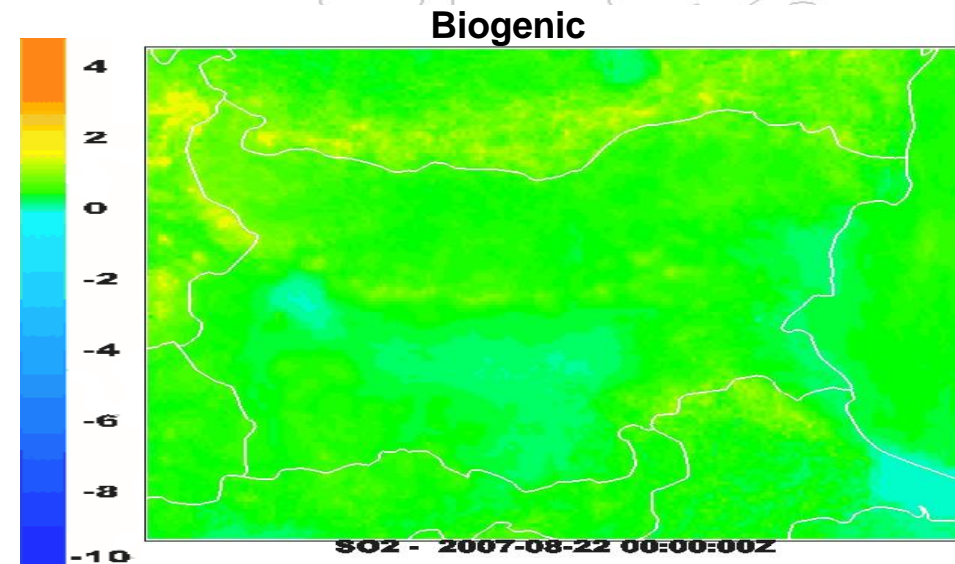
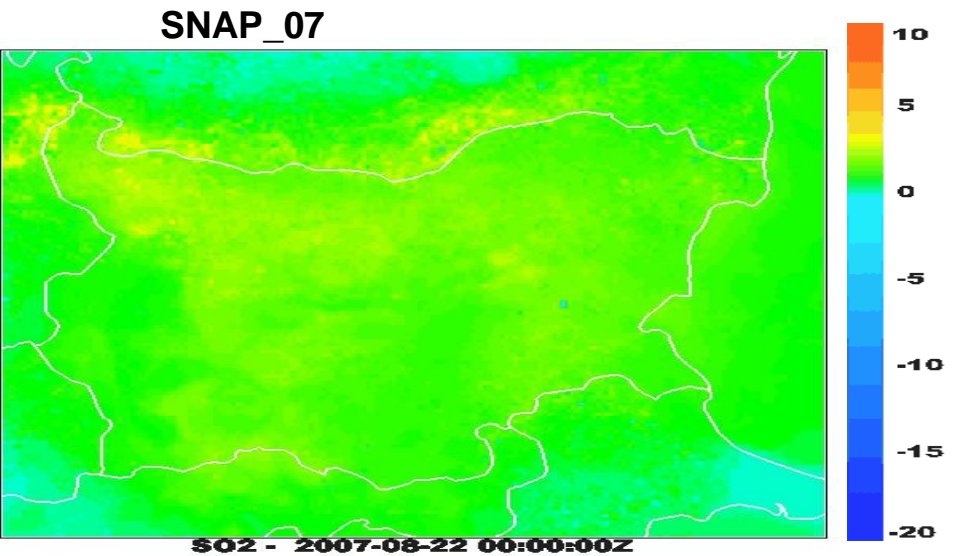
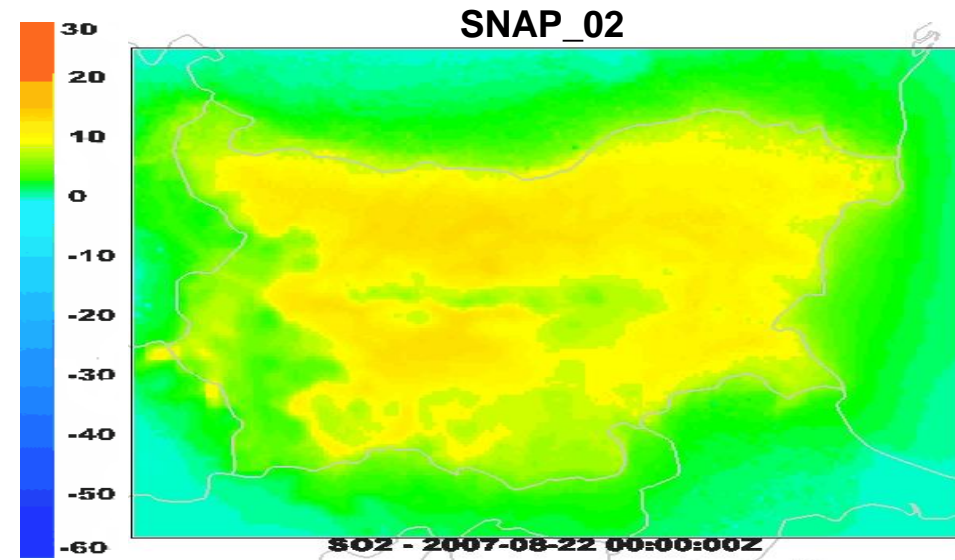
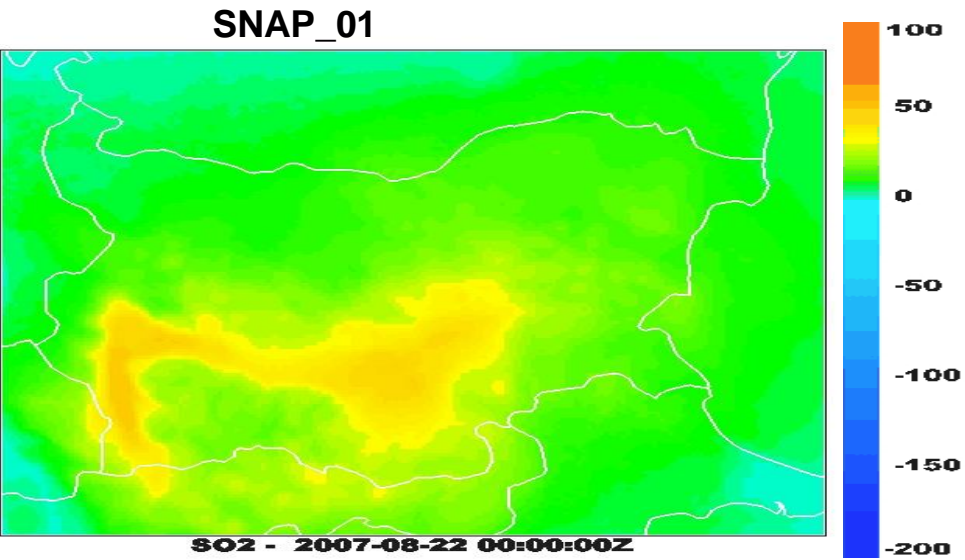
Biogenic



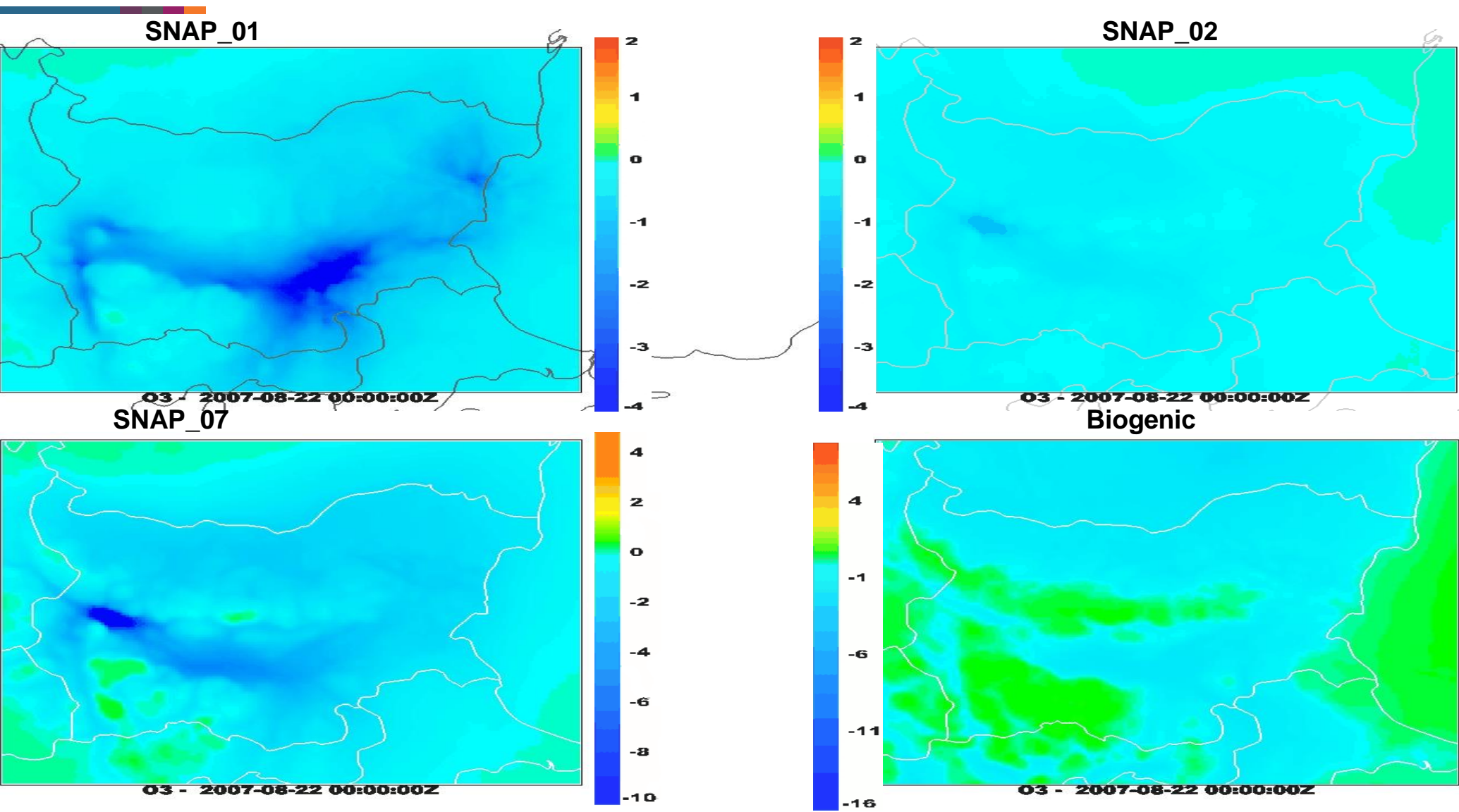
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Numerical Study of the Atmospheric Composition in Bulgaria : annual SNAP contributions for SO₂

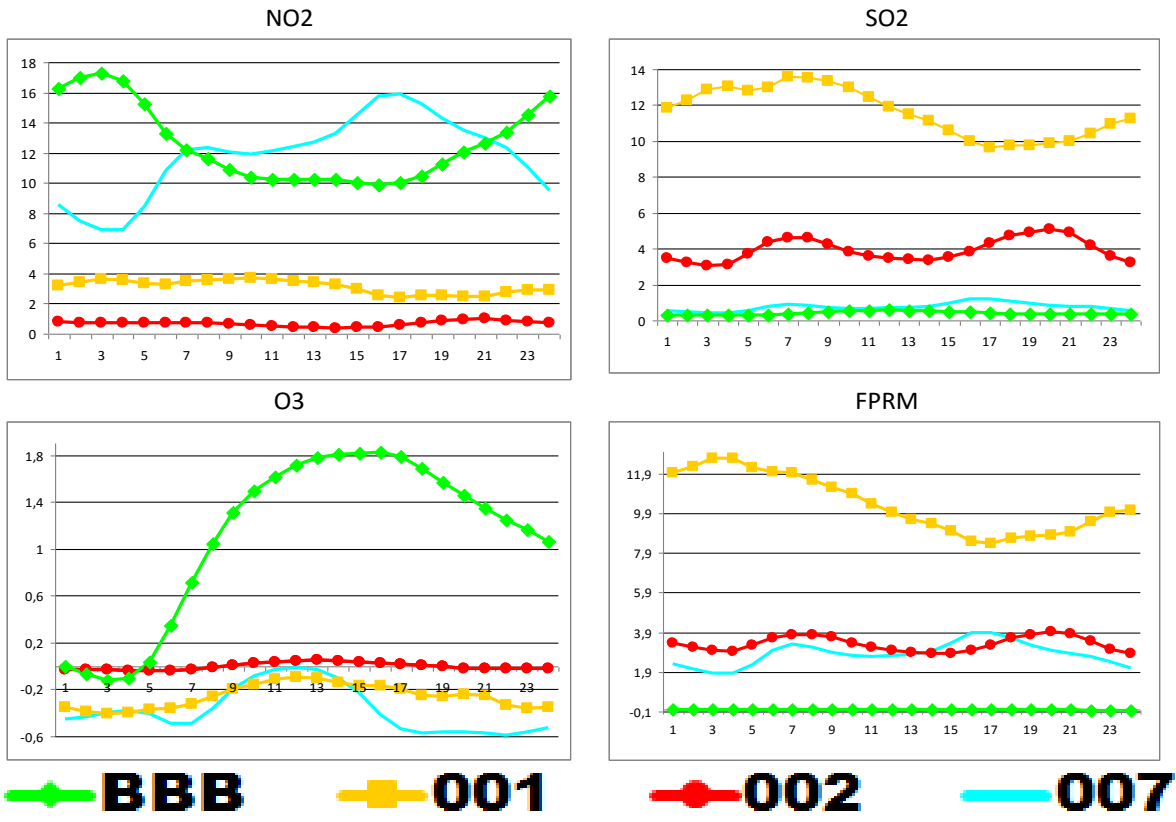


Numerical Study of the Atmospheric Composition in Bulgaria : annual SNAP contributions for O3



Numerical Study of the Atmospheric Composition in Bulgaria : annual SNAP contributions averaged for Bulgaria

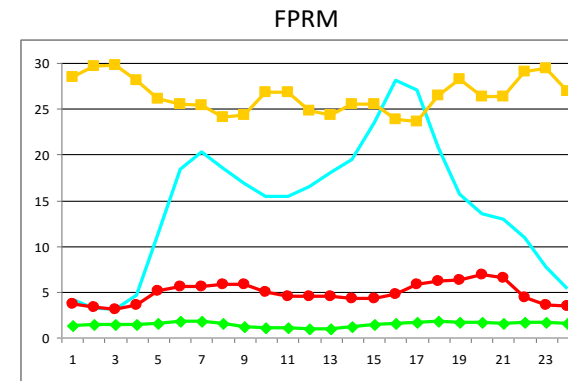
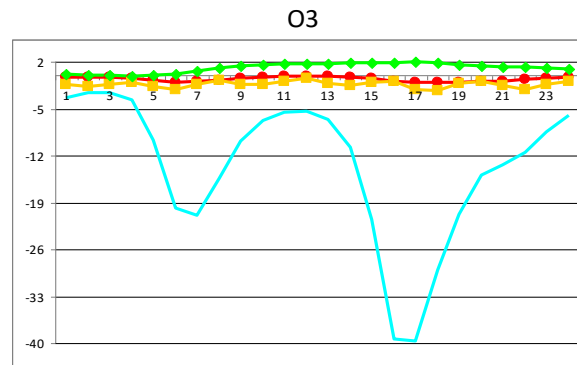
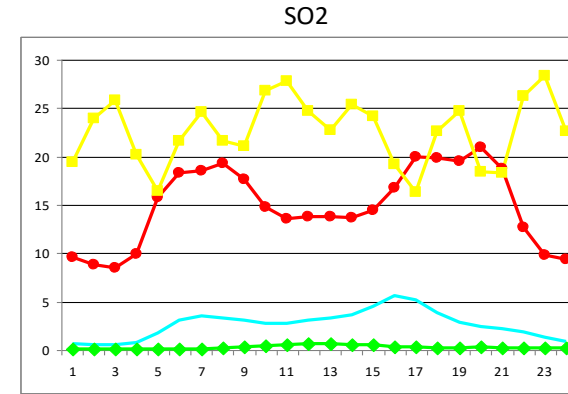
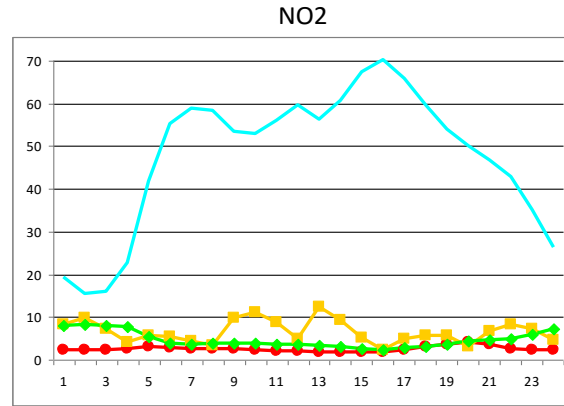
Bulgaria



Numerical Study of the Atmospheric Composition in Bulgaria : annual SNAP contributions for Sofia



Sofia

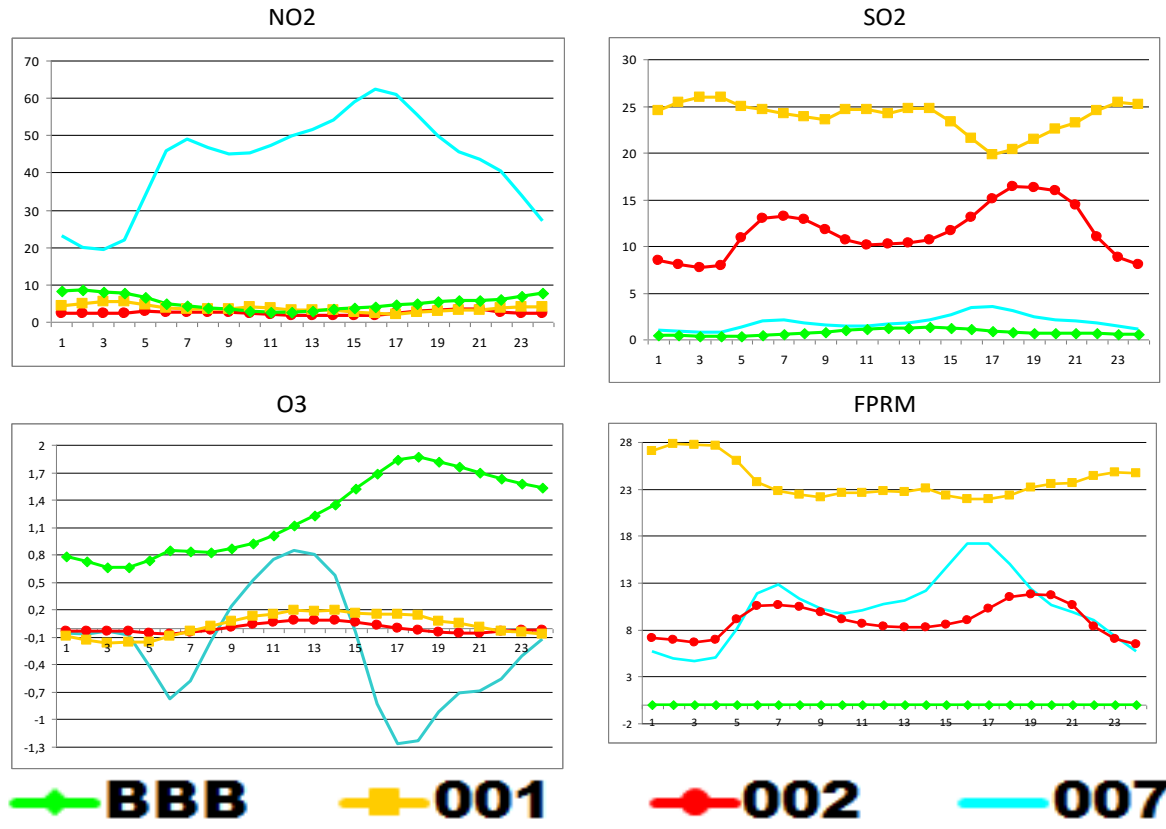


◆ BBB **■ 001** **● 002** **— 007**

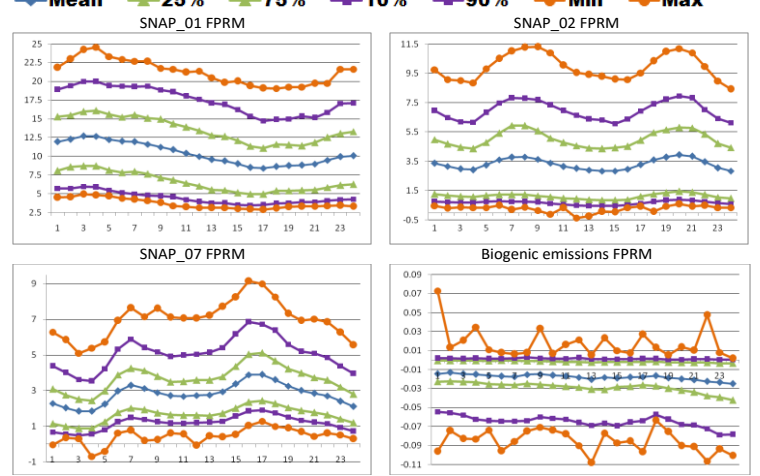
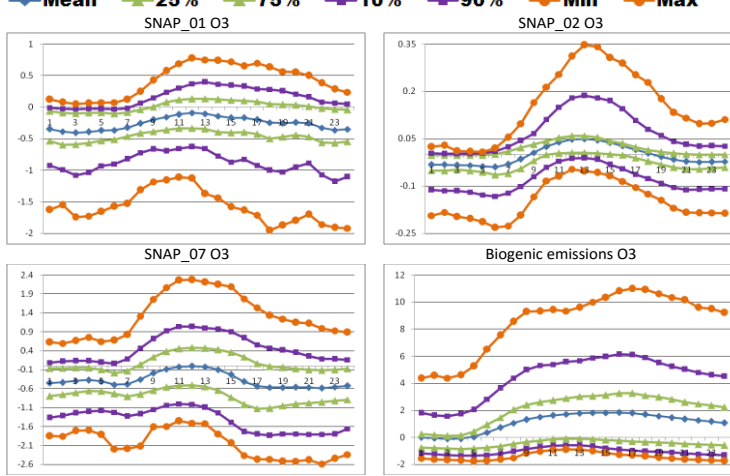
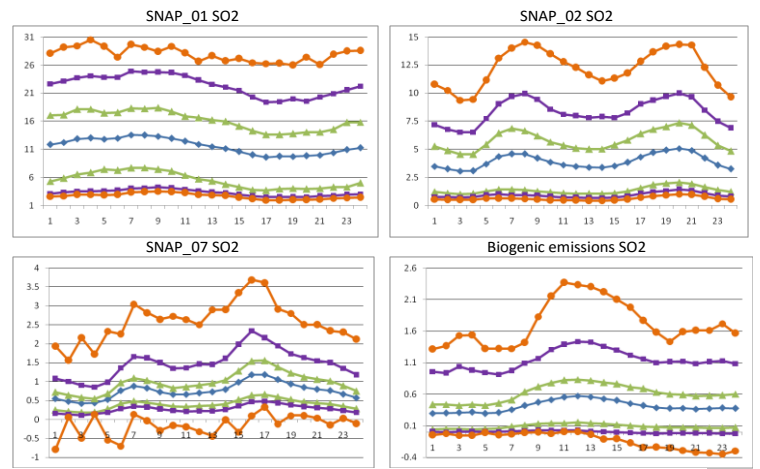
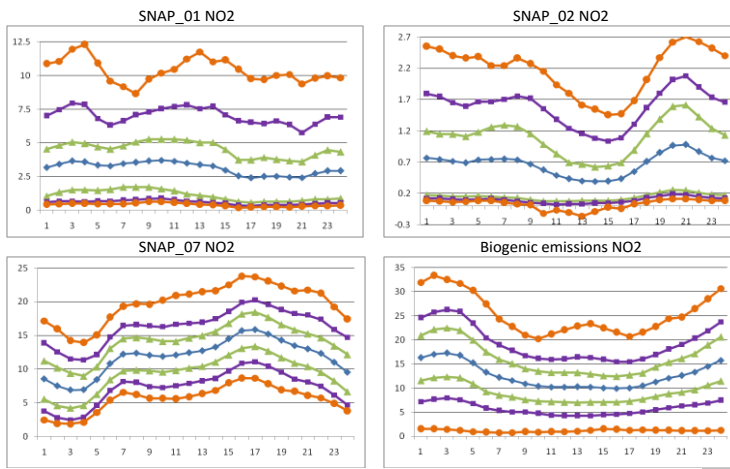
Numerical Study of the Atmospheric Composition in Bulgaria : annual SNAP contributions for Rojen



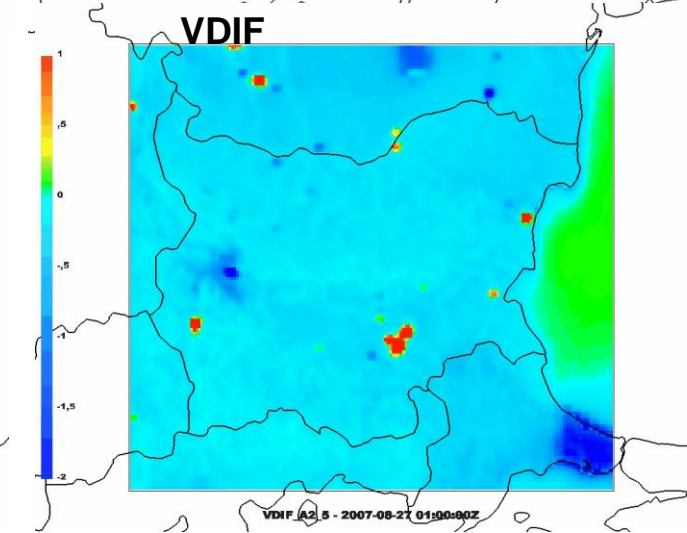
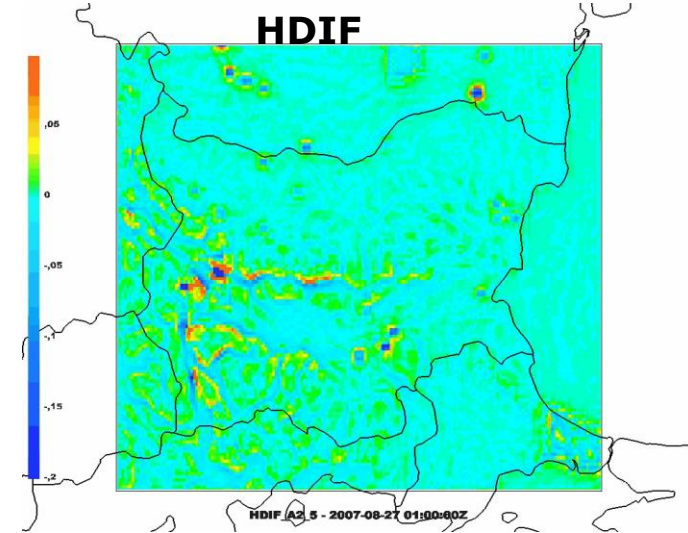
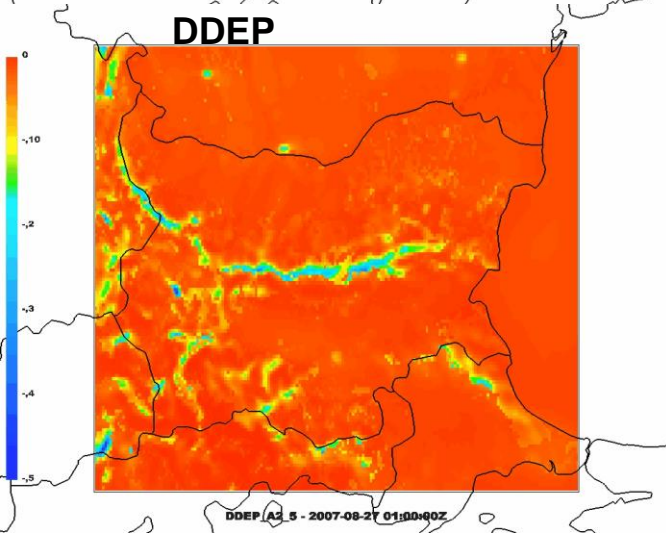
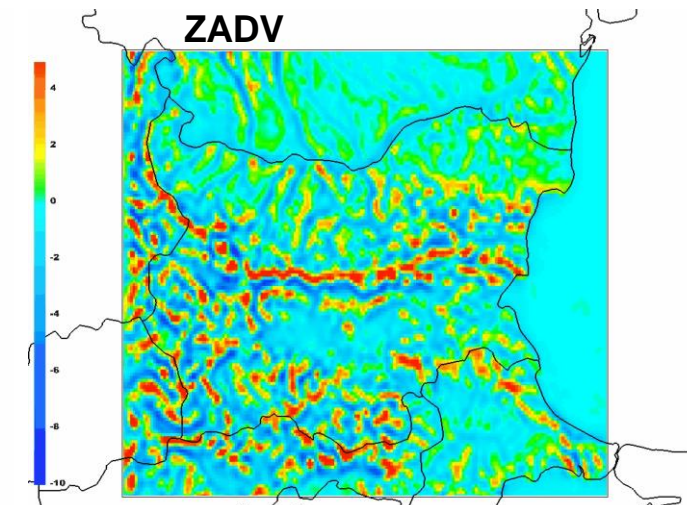
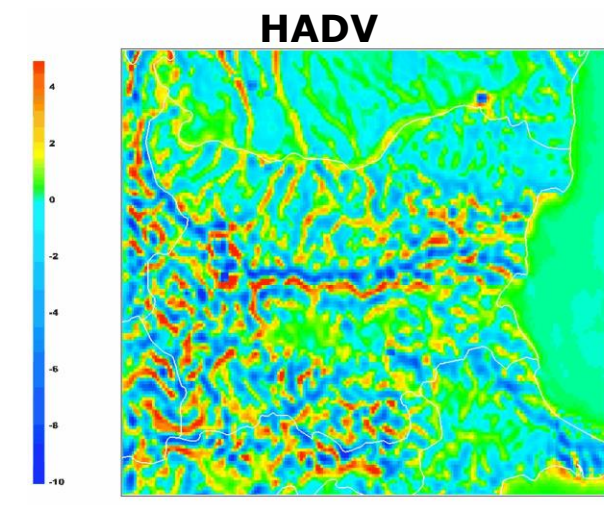
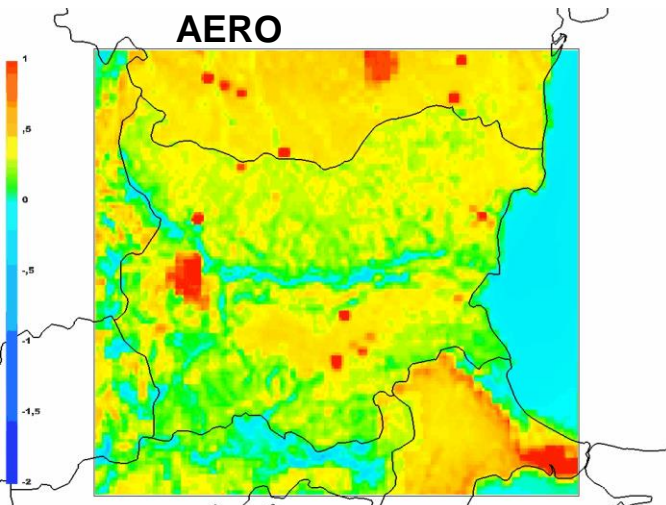
Rojen



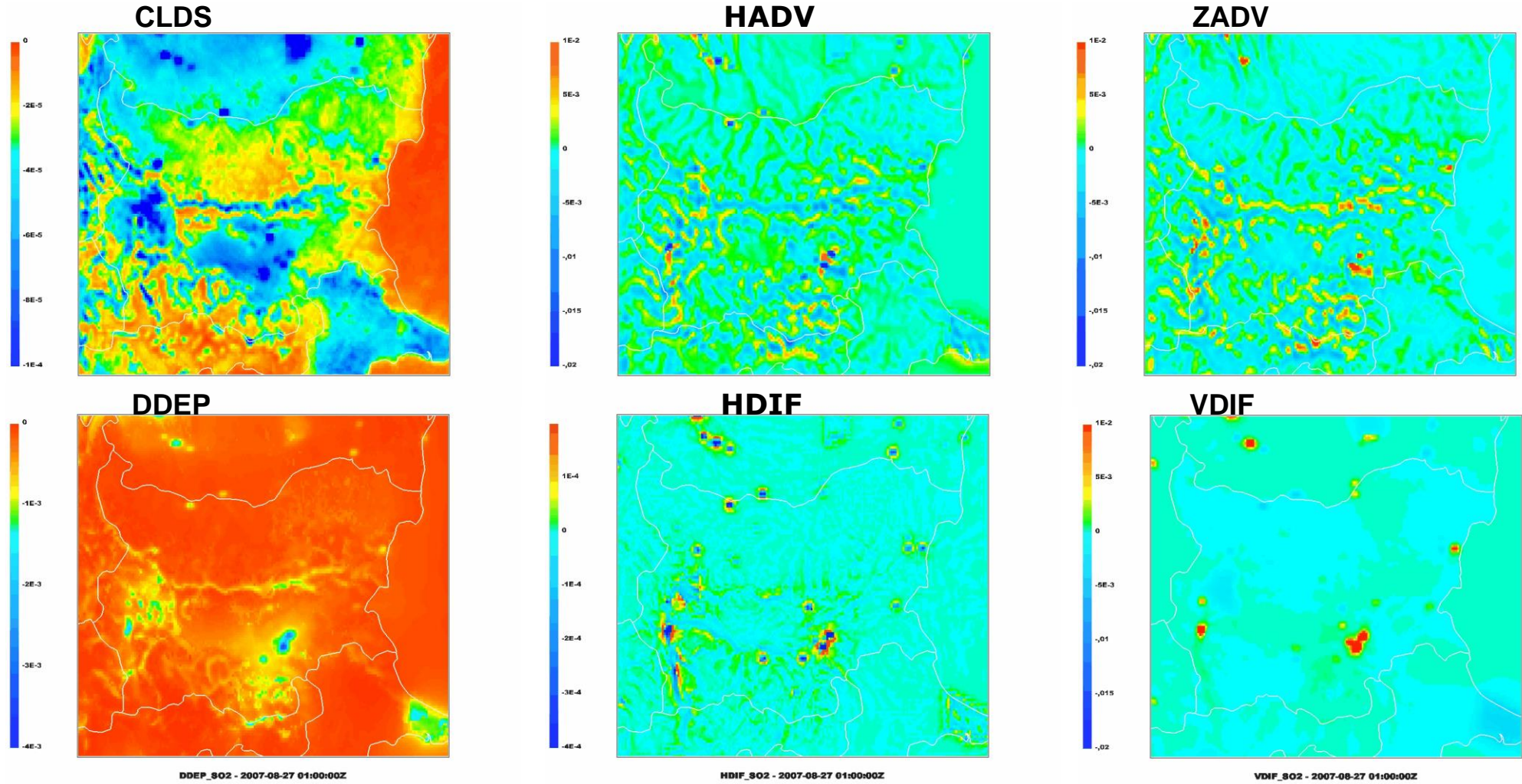
Numerical Study of the Atmospheric Composition in Bulgaria : annual SNAP contributions averaged for Bulgaria



Numerical Study of the Atmospheric Composition in Bulgaria : process contribution to hourly change of PM2.5



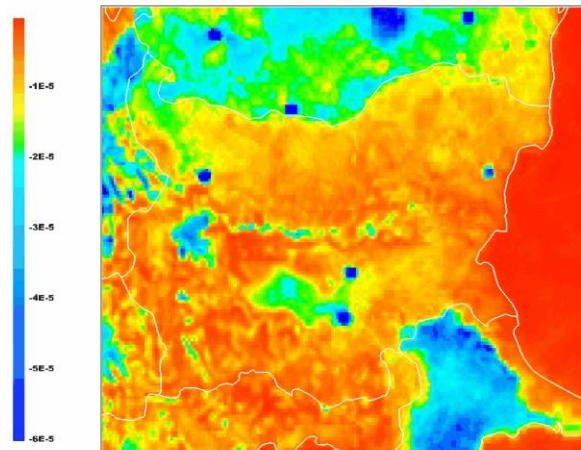
Numerical Study of the Atmospheric Composition in Bulgaria : process contribution to hourly change of SO₂



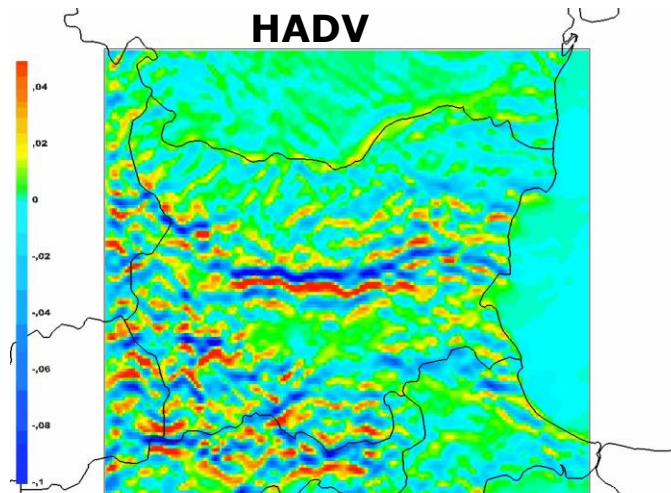
Numerical Study of the Atmospheric Composition in Bulgaria : process contribution to hourly change of O3



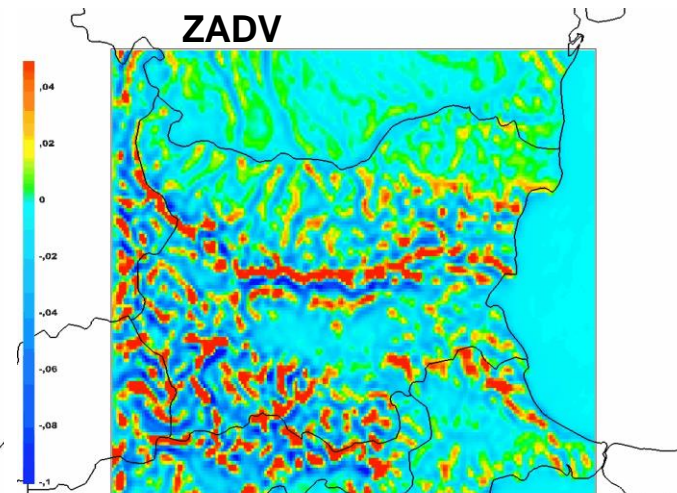
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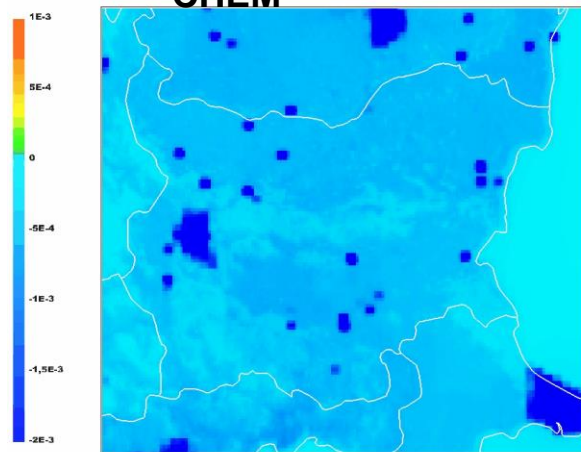
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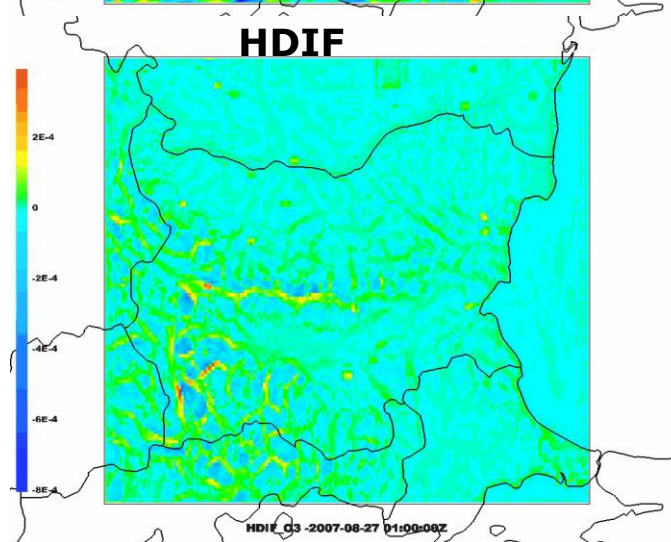
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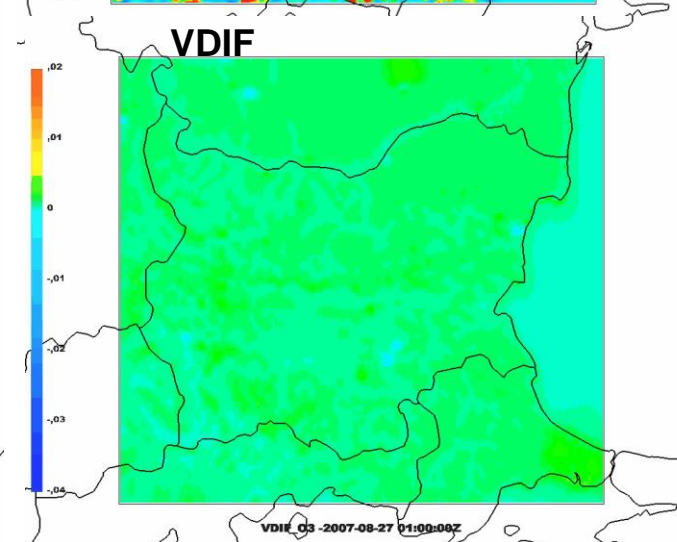
CHEM



HDIF



VDIF



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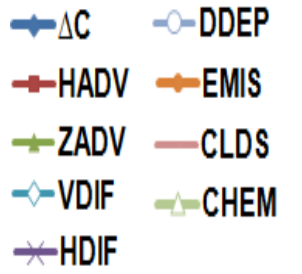
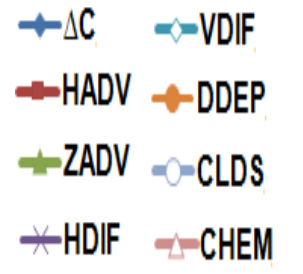
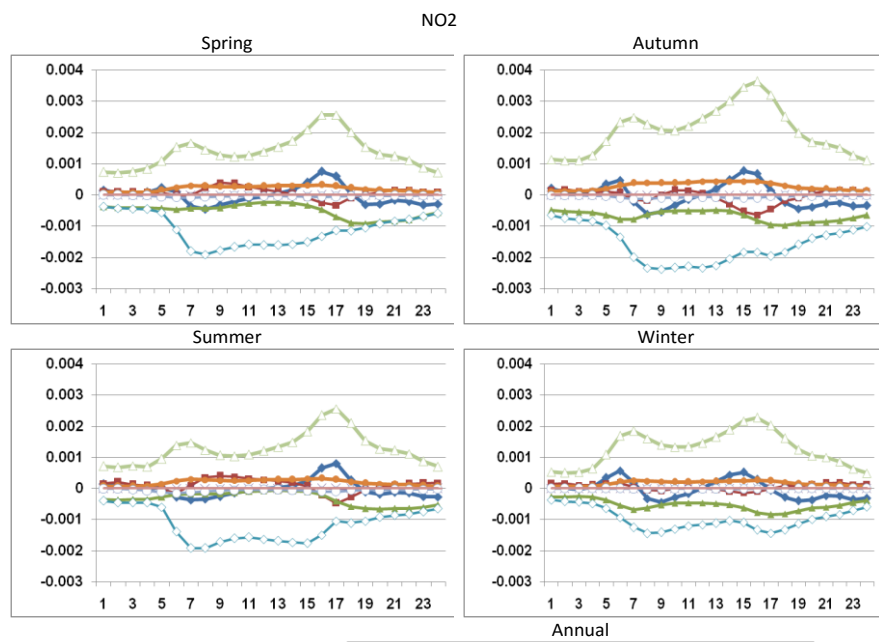
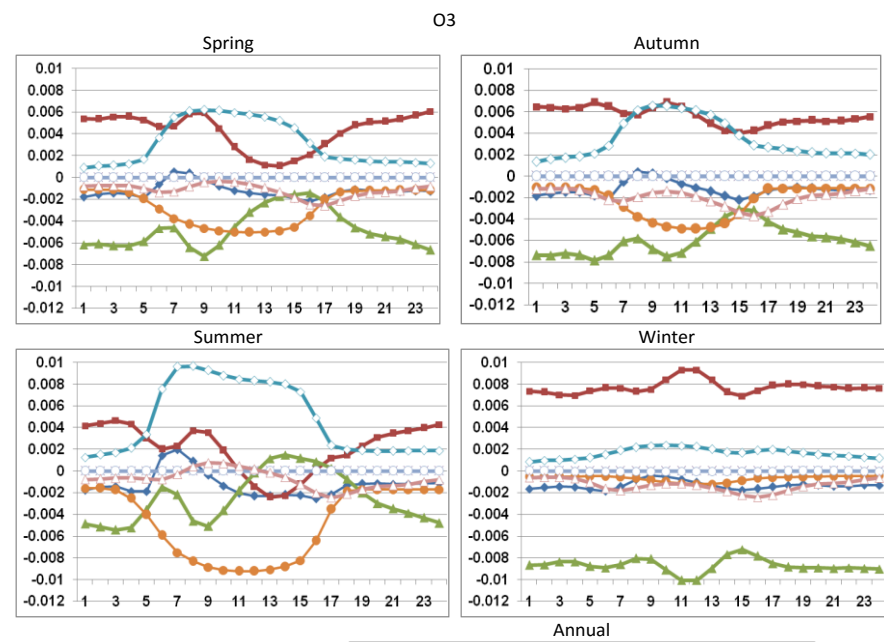
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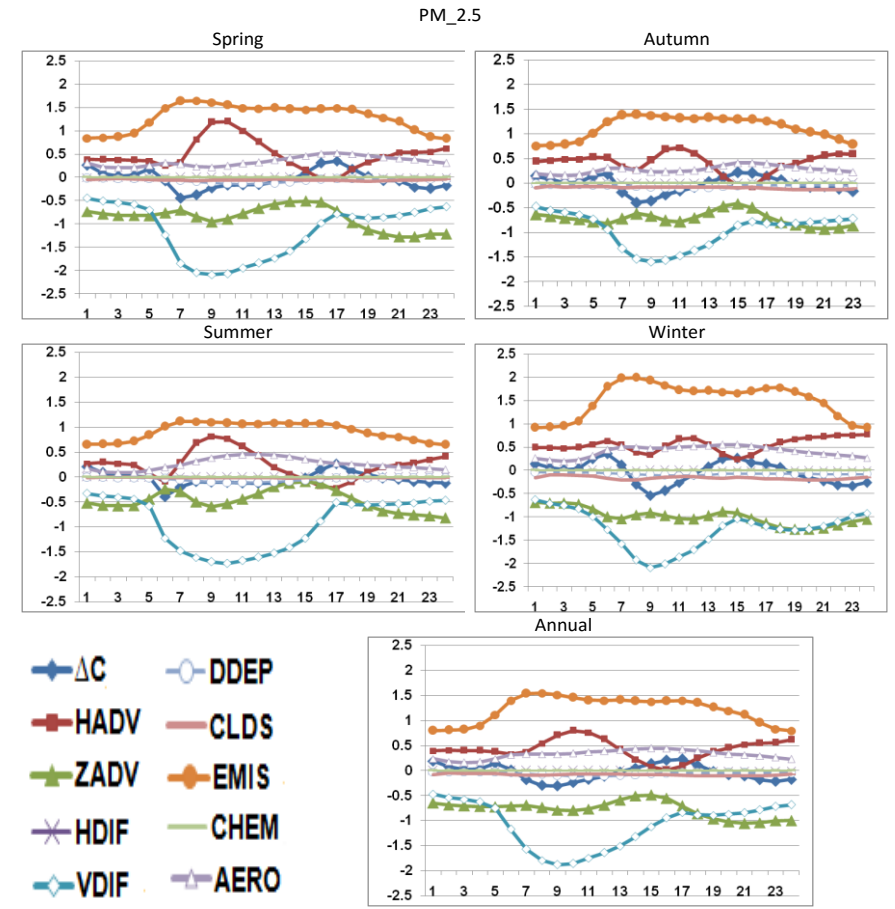
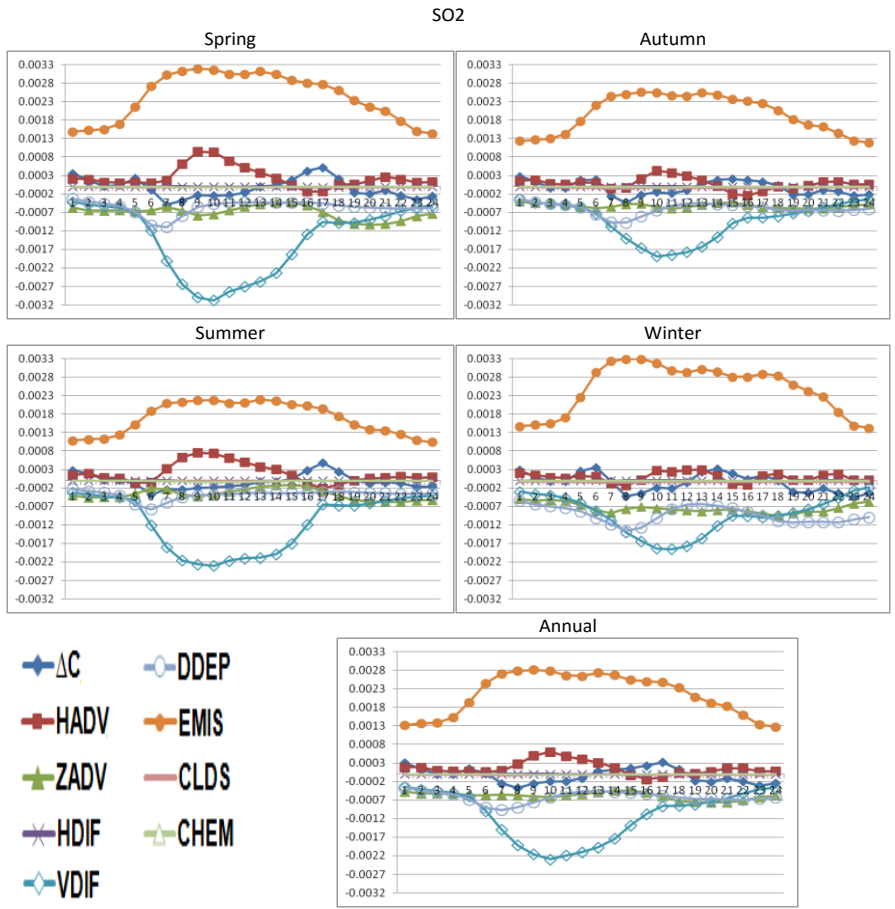


EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Numerical Study of the Atmospheric Composition in Bulgaria : seasonal variations of process contribution

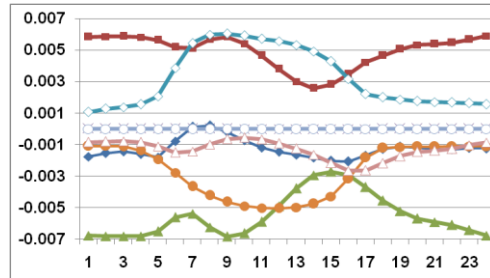
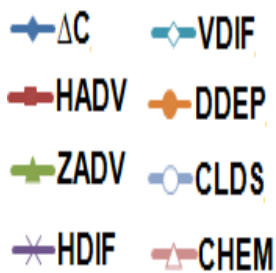
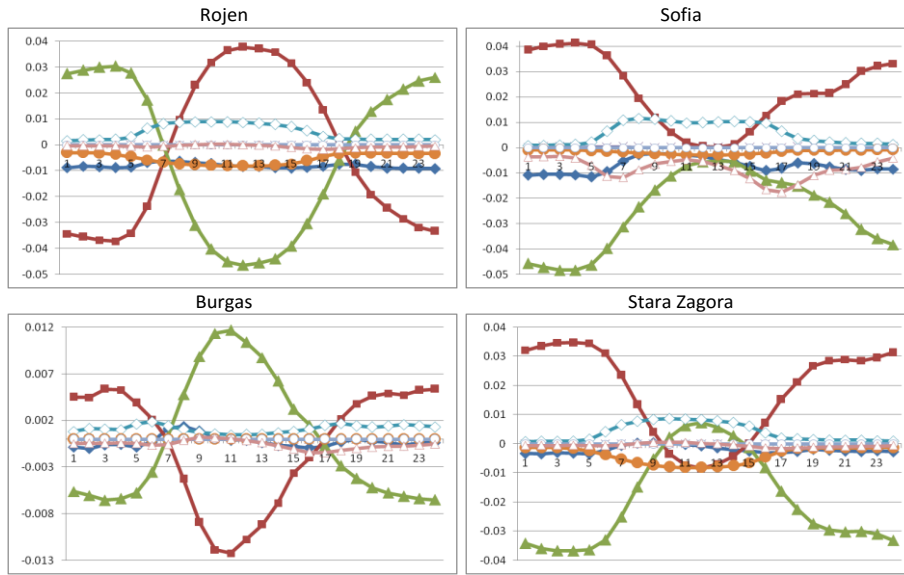


Numerical Study of the Atmospheric Composition in Bulgaria : seasonal variations of process contribution

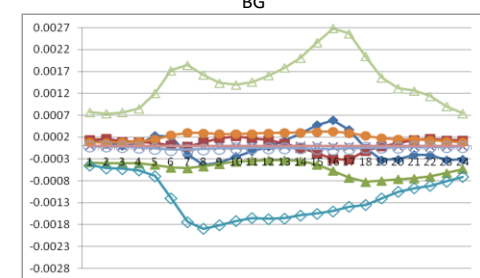
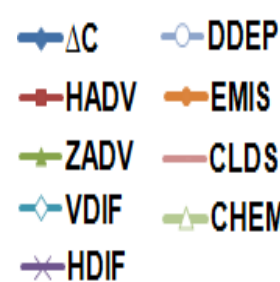
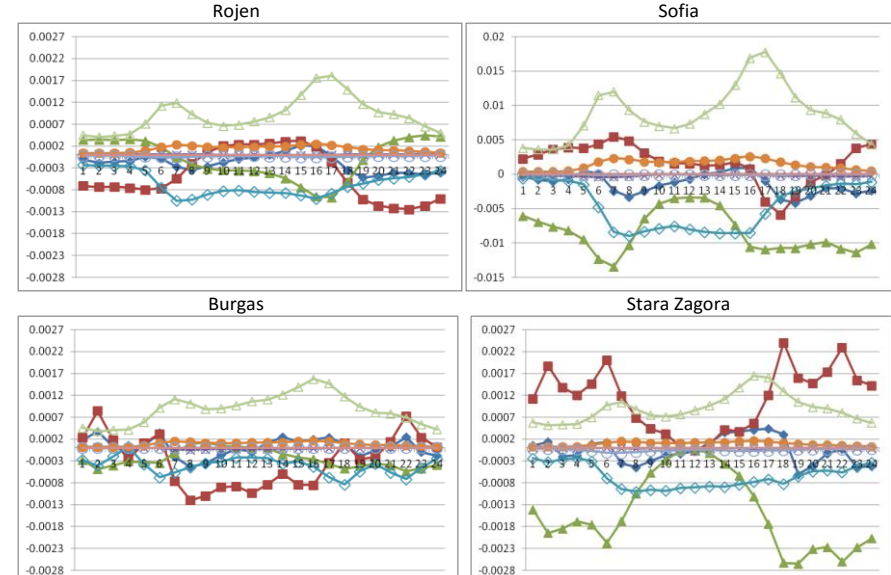


Numerical Study of the Atmospheric Composition in Bulgaria : geographical variations of process contribution

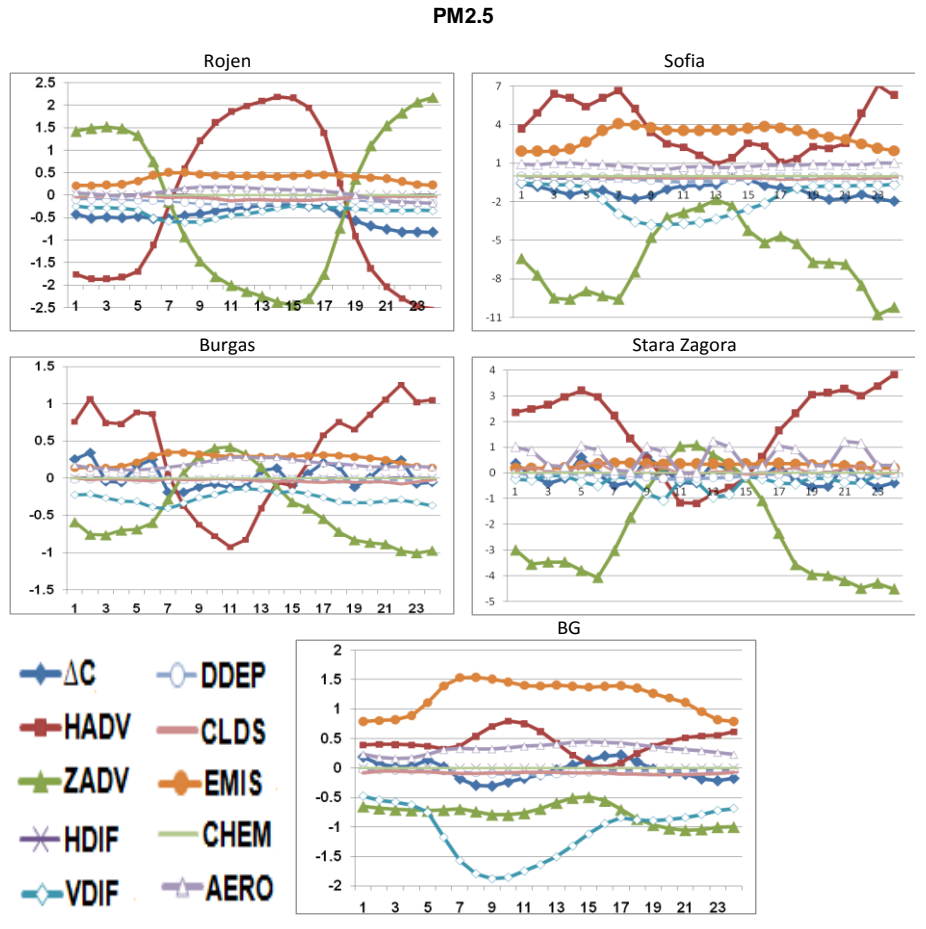
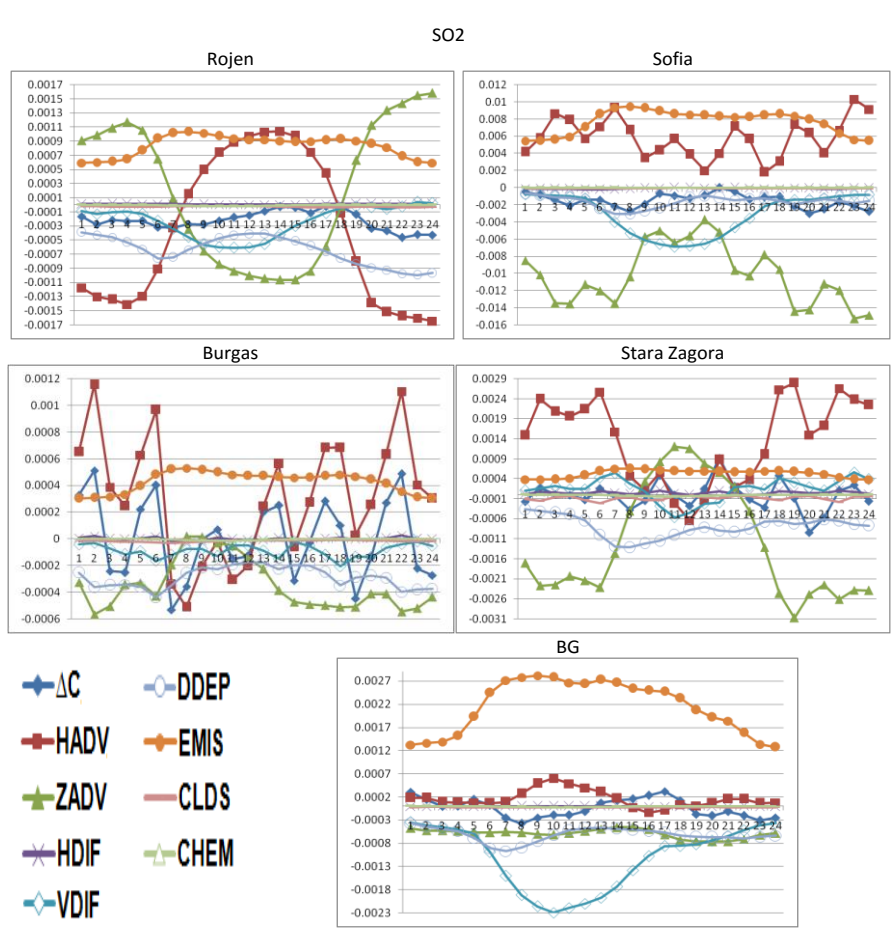
O3



NO2



Numerical Study of the Atmospheric Composition in Bulgaria : geographical variations of process contribution



Numerical Study of the Atmospheric Composition in Bulgaria : Air Quality Index (AQI)

The AQI, calculated in the frame of Bulgarian Chemical Weather Forecast System follows the UK Air Quality Index.

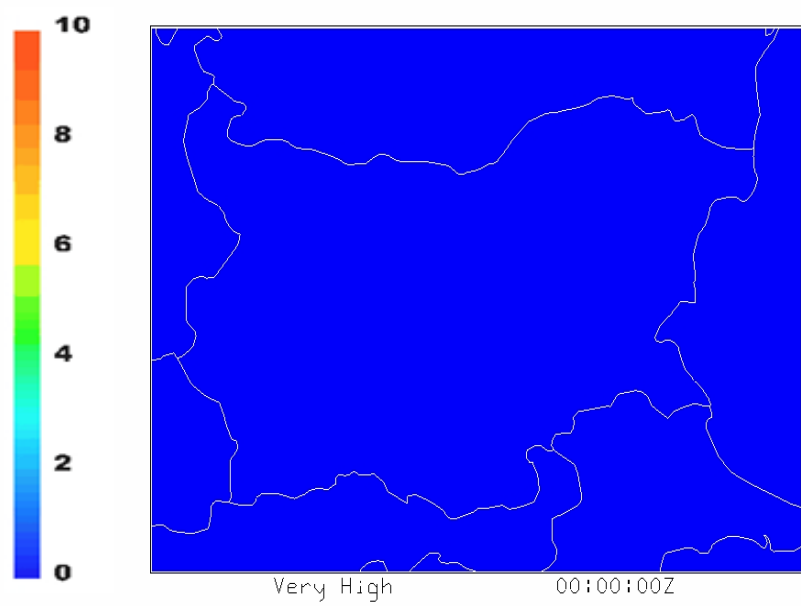
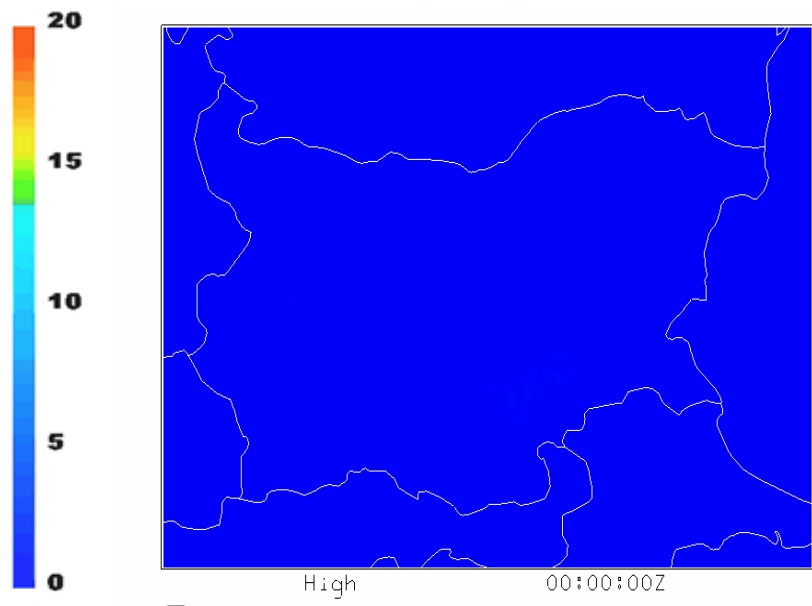
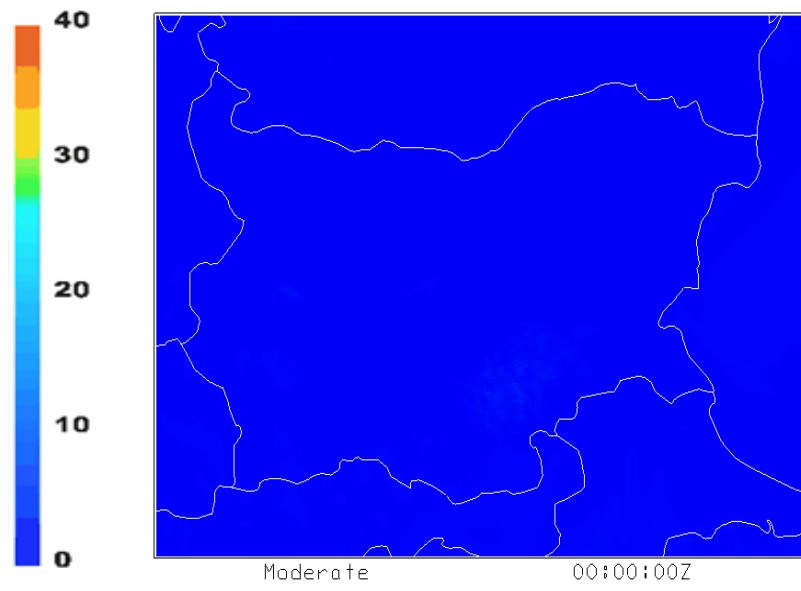
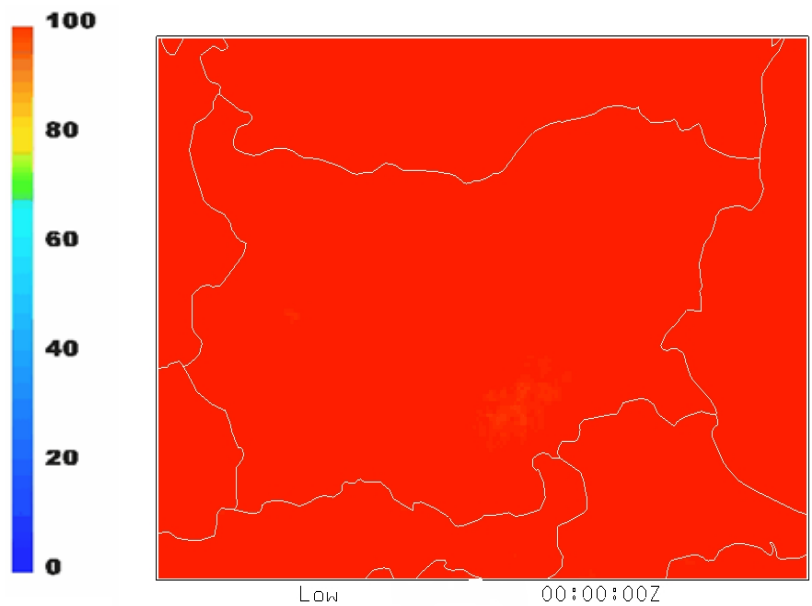
Index	O ₃ Running 8 hourly mean (µg/m ³)	NO ₂ Hourly mean (µg/m ³)	SO ₂ 15 minute mean (µg/m ³)	PM10 Particles, 24 hour mean (µg/m ³)	PM2.5 Particles, 24 hour mean (µg/m ³)
1 (Low)	0-33	0-66	0-88	0-11	0-16
2 (Low)	34-65	67-133	89-176	12-23	17-33
3 (Low)	66-99	134-199	177-265	24-34	34-49
4 (Moderate)	100-120	200-267	266-354	35-41	50-58
5 (Moderate)	121-140	268-334	355-442	42-46	59-66
6 (Moderate)	141-159	335-399	443-531	47-52	67-74
7 (High)	160-187	400-467	530-708	53-58	75-83
8 (High)	188-213	468-534	709-886	59-64	84-91
9 (High)	214-239	535-599	887-1063	65-69	92-99
10 (Very High)	≥ 240	≥ 600	≥ 1064	≥ 70	≥ 100

Air Pollution Bandings and Index and the Impact on the Health of People who are Sensitive to Air Pollution

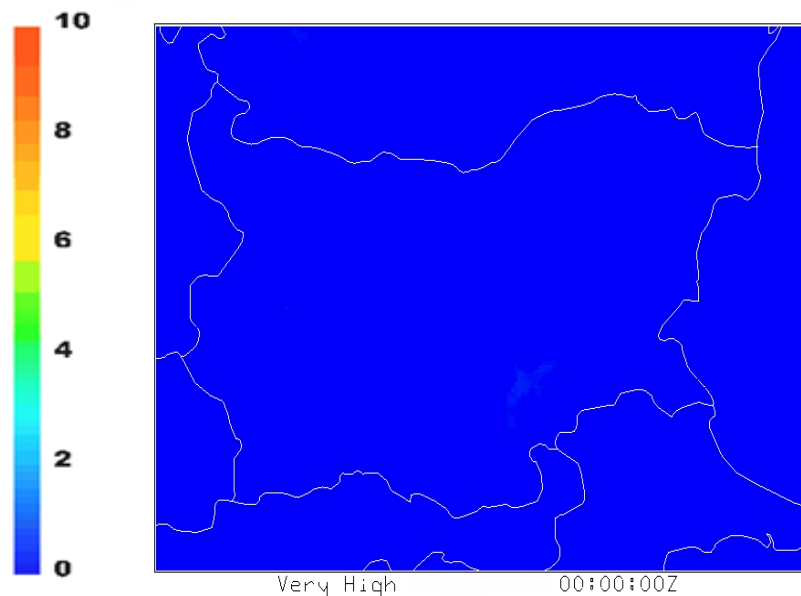
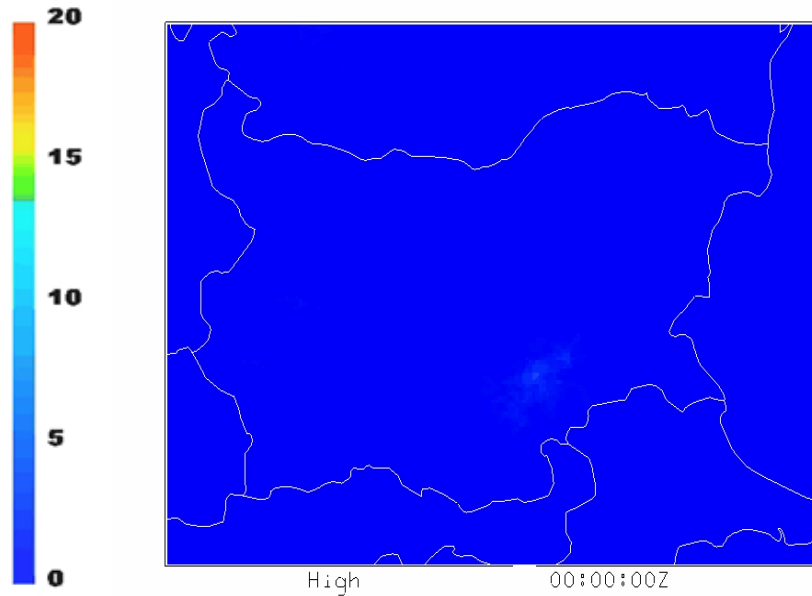
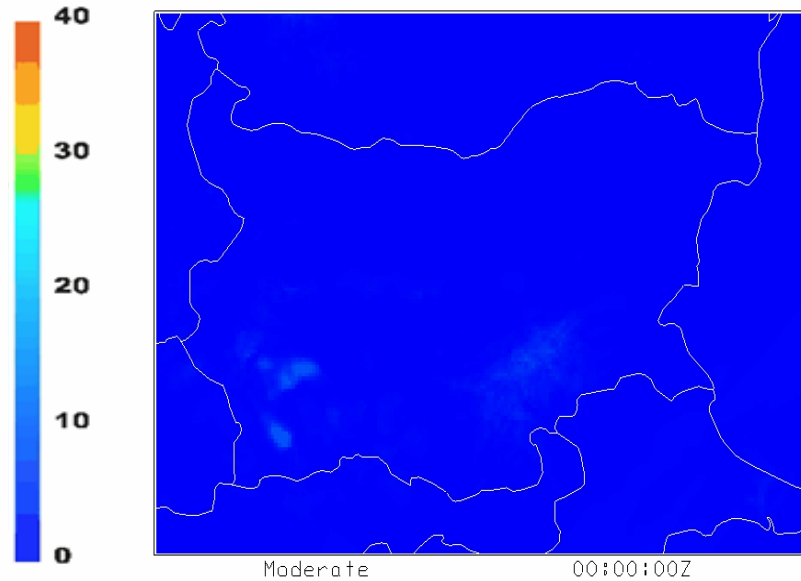
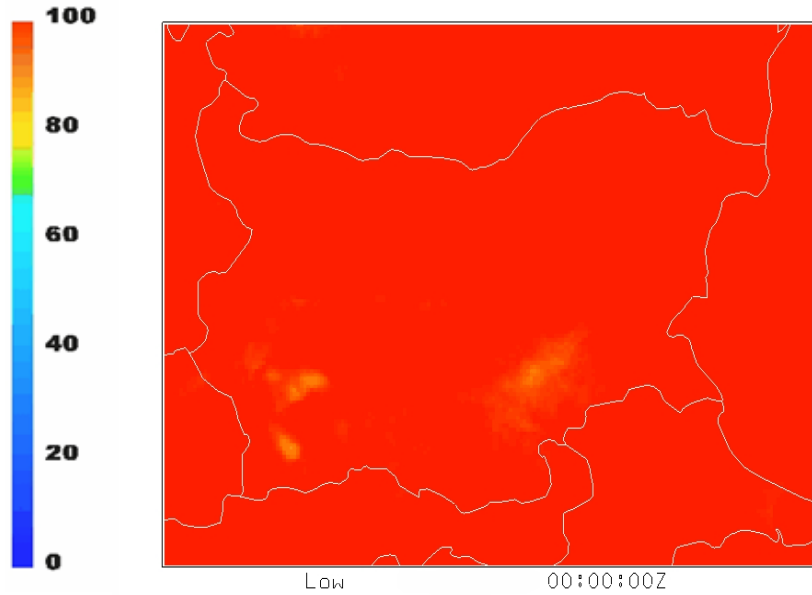
Banding	Value	Health Descriptor
Low	1-3	Effects are unlikely to be noticed even by individuals who know they are sensitive to air pollutants
Moderate	4-6	Mild effects, unlikely to require action, may be noticed amongst sensitive individuals.
High	7-9	Significant effects may be noticed by sensitive individuals and action to avoid or reduce these effects may be needed (e.g. reducing exposure by spending less time in polluted areas outdoors). Asthmatics will find that their 'reliever' inhaler is likely to reverse the effects on the lung.
Very High	10	The effects on sensitive individuals described for 'High' levels of pollution may worsen.

The reference levels used in the conversion are based on health-protection related limit, target values set by the EU or by the WHO.

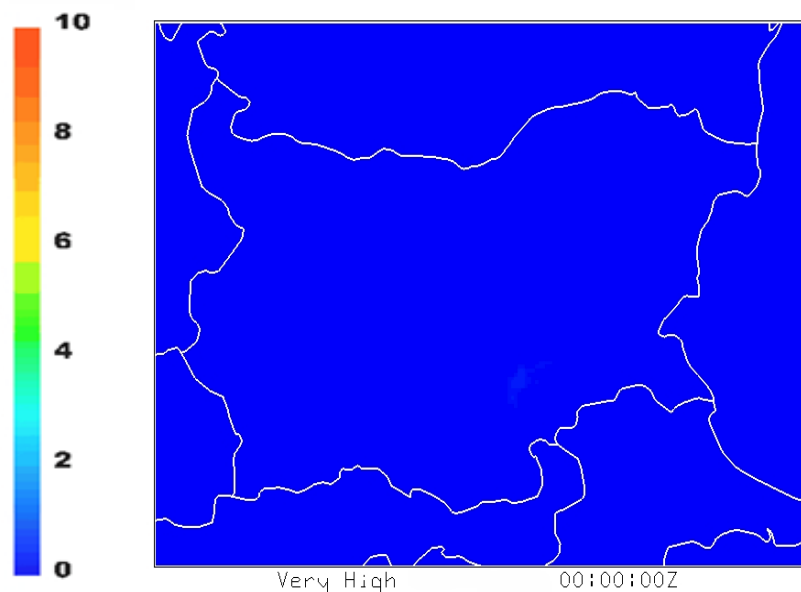
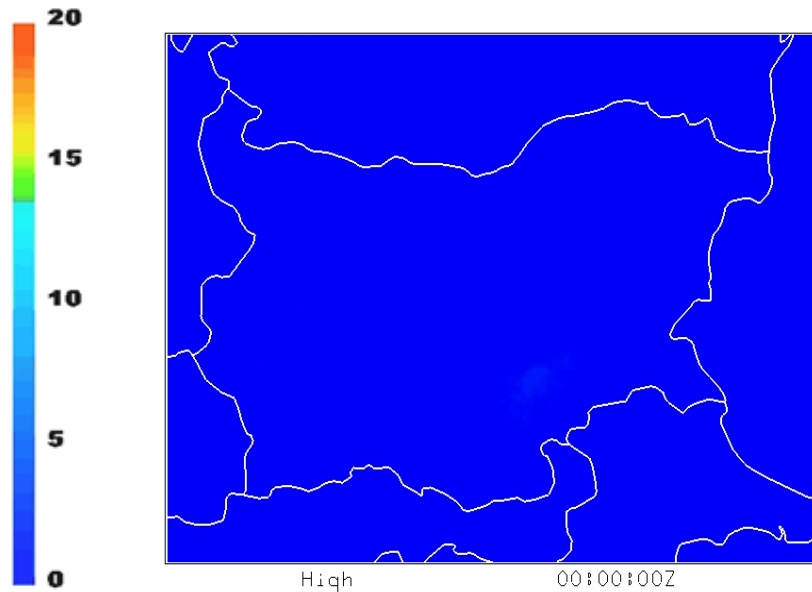
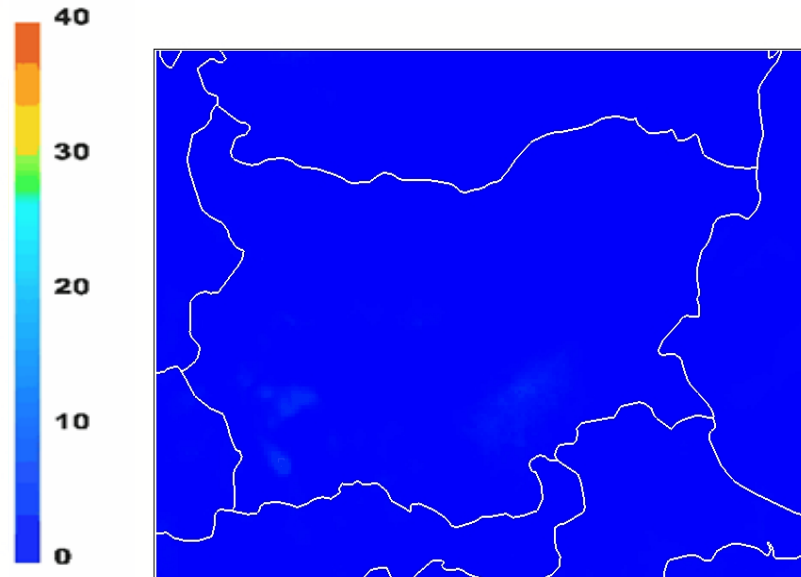
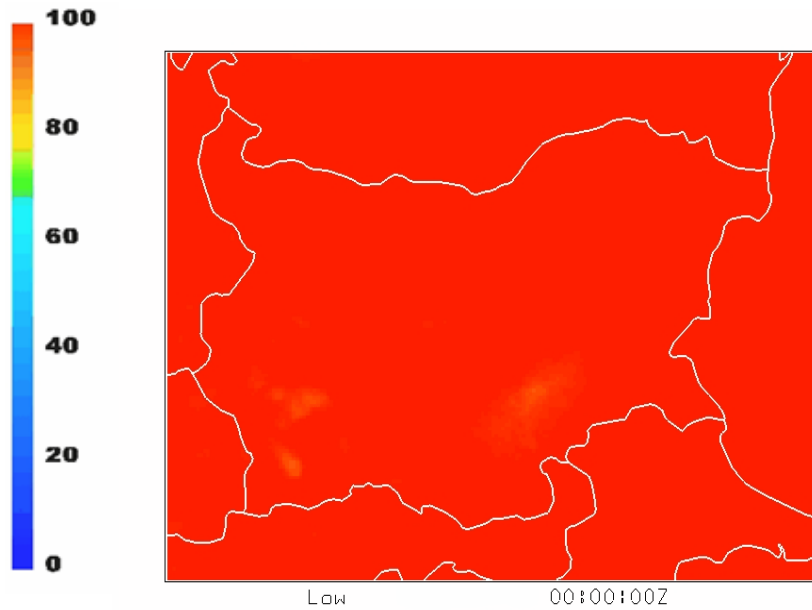
Numerical Study of the Atmospheric Composition in Bulgaria : Summer recurrence [%] of the 4 AQI bands



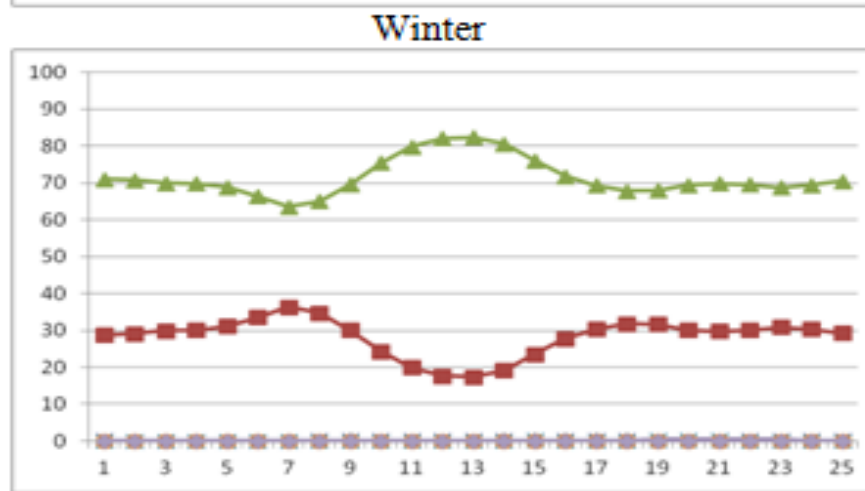
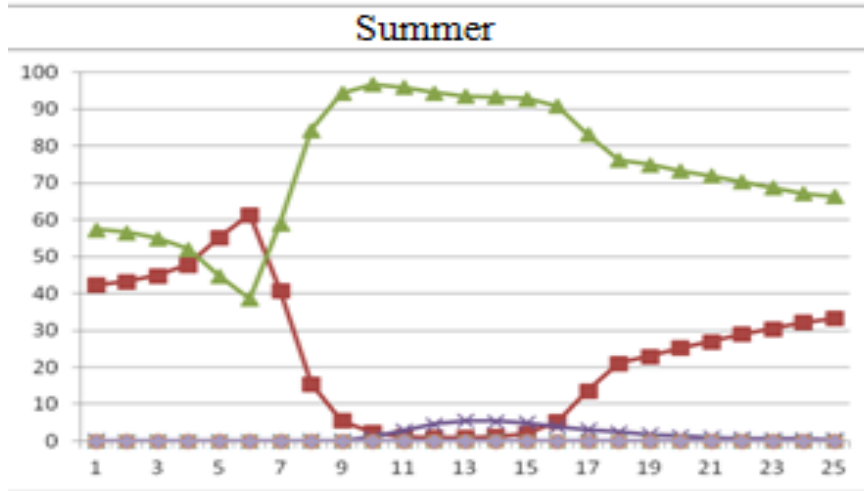
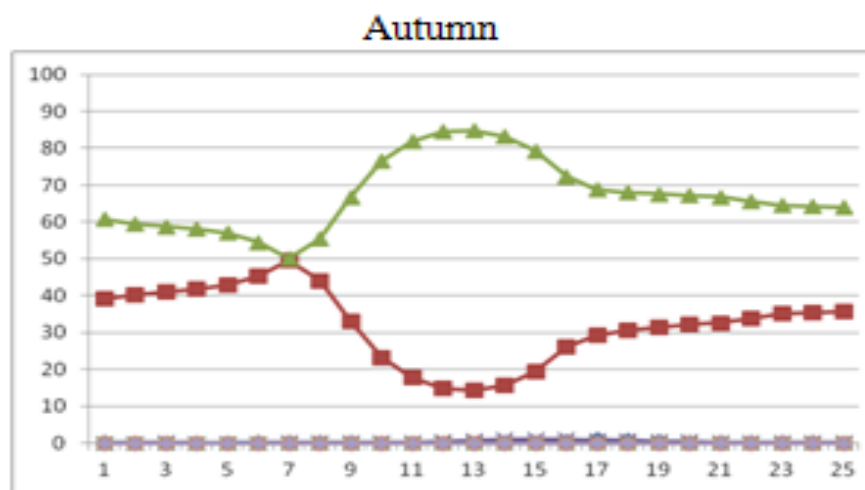
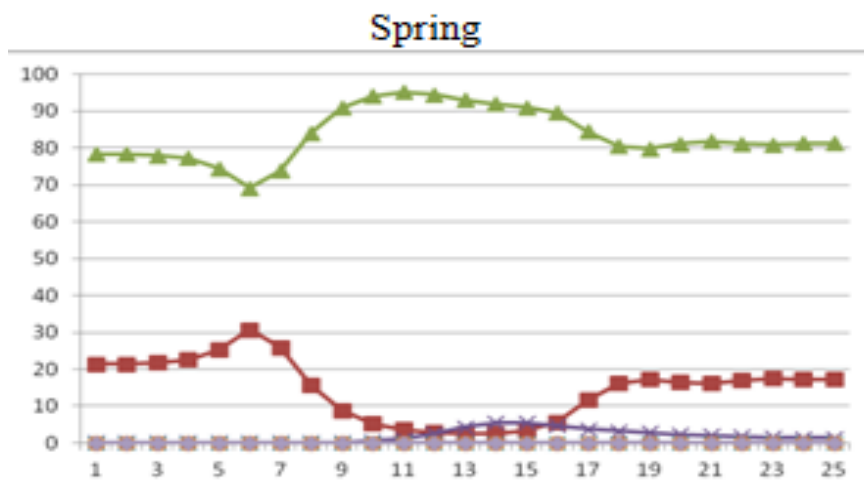
Numerical Study of the Atmospheric Composition in Bulgaria : Winter recurrence [%] of the 4 AQI bands



Numerical Study of the Atmospheric Composition in Bulgaria : Winter recurrence [%] of the 4 AQI bands



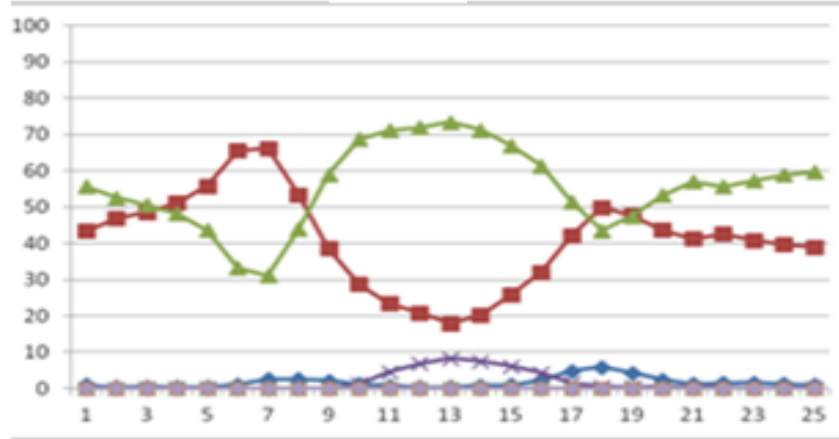
Numerical Study of the Atmospheric Composition in Bulgaria : Diurnal and seasonal variations of the averaged recurrence [%] of the different AQI over Bulgaria.



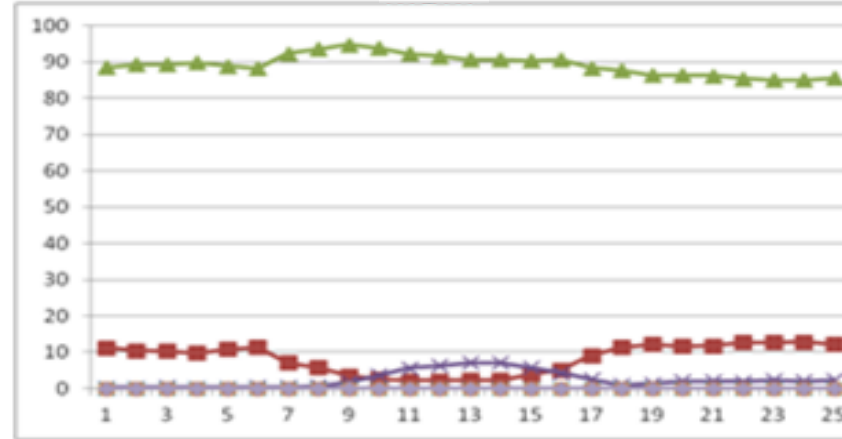
- ◆ AQI_1
- AQI_2
- ▲ AQI_3
- ✱ AQI_4
- ✱ AQI_5
- ◆ AQI_6
- ◆ AQI_7
- AQI_8
- ▲ AQI_9
- ✱ AQI_10

Numerical Study of the Atmospheric Composition in Bulgaria : Diurnal and seasonal variations of the recurrence [%] of the different AQI for different points

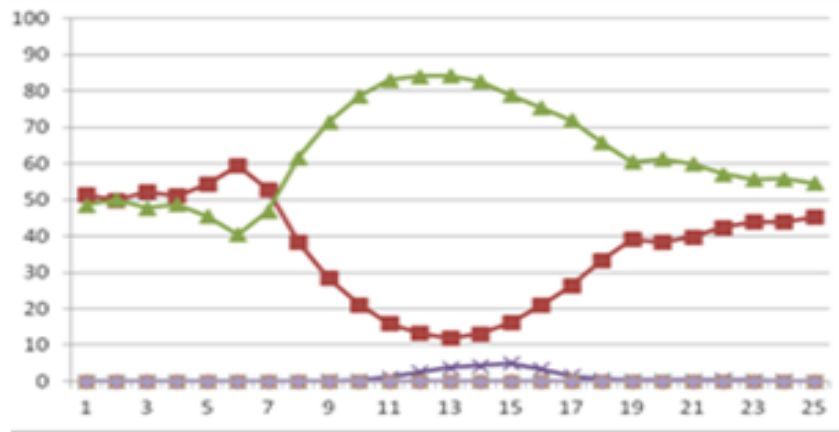
Sofia



Rojen



Stara Zagora



Varna



◆ AQI_1
 ■ AQI_2
 ▲ AQI_3
 ✖ AQI_4
 ✱ AQI_5
 ✚ AQI_6
 ◆ AQI_7
 ■ AQI_8
 ▲ AQI_9
 ✖ AQI_10

Numerical Study of the Atmospheric Composition in Bulgaria : Conclusions

- the behavior of the surface concentrations, averaged over the ensemble annually, or for the four seasons and over the territory of the country is reasonable and demonstrates effects which for most of the compounds can be explained from a point of view of the generally accepted schemes of dynamic influences (in particular the role of turbulent transport and its dependence on atmospheric stability) and/or chemical transformations;
- the SNAP 1 contribution to the surface SO₂ concentrations is smaller than one should expect, having in mind that the “Maritza” power plants are among the biggest sulfur sources in Europe. Probably, a significant amount of SO₂ from these sources becomes a subject of larger scale transport and so is moved outside the country;
- the contribution of biogenic emissions to surface ozone in the country is relatively small. This indicates that local O₃ production rate is limited by the availability of NO_x concentration, a regime which is called NO_x-limited. Obviously from a point of view of atmospheric composition climate the Balkan Peninsula and Bulgaria are predominantly “rural” environment which explains the ozone photochemistry specifics in the region;
- the contribution of the emission from categories 1 and 7, which are the major sources of the other ozone precursor – nitrogen oxides, is also small. This, once again is an indirect indicator, that the surface ozone in Bulgaria is to a small extent due to domestic sources, but is mostly imported;
- the results produced by the CMAQ “Integrated Process Rate Analysis” demonstrate the very complex behavior and interaction of the different processes. The analysis of the behavior of different processes does not give simple answer of the question how the air pollution in a given point or region is formed.

Numerical Study of the Atmospheric Composition in Bulgaria : Acknowledgements

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Deep gratitude is due to US EPA, US NCEP and EMEP for providing free-of-charge data and software. Special thanks to the Netherlands Organization for Applied Scientific research (TNO) for providing us with the high-resolution European anthropogenic emission inventory.