Study specifics of the meso-scale circulation under different large-scale conditions for Sofia region

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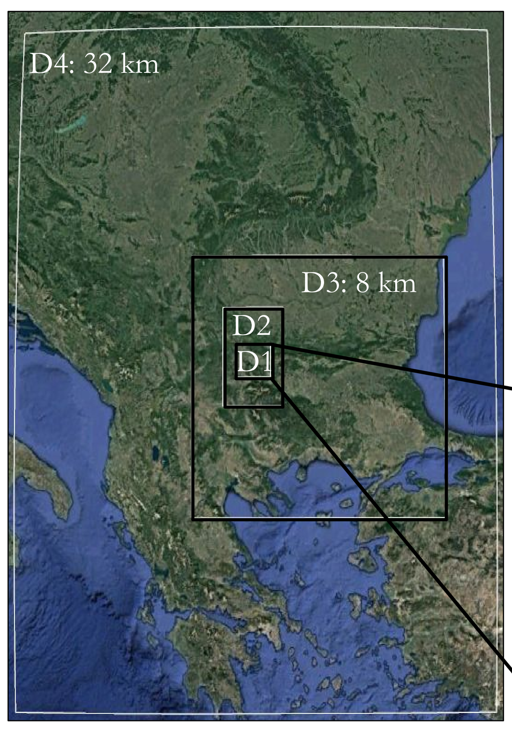
Abstract

Continued development and growth of urban areas leads to intense modifications of the weather conditions compared to rural areas. Sofia is located in very complex terrain and events such as heavy rain and snow, fog, frost, strong winds and foehn are observed. The purpose of this work is to study the specifics of meso-scale circulation under various large-scale (synoptic) conditions for the Sofia city region. Different model options were tested to determine the optimal configuration.

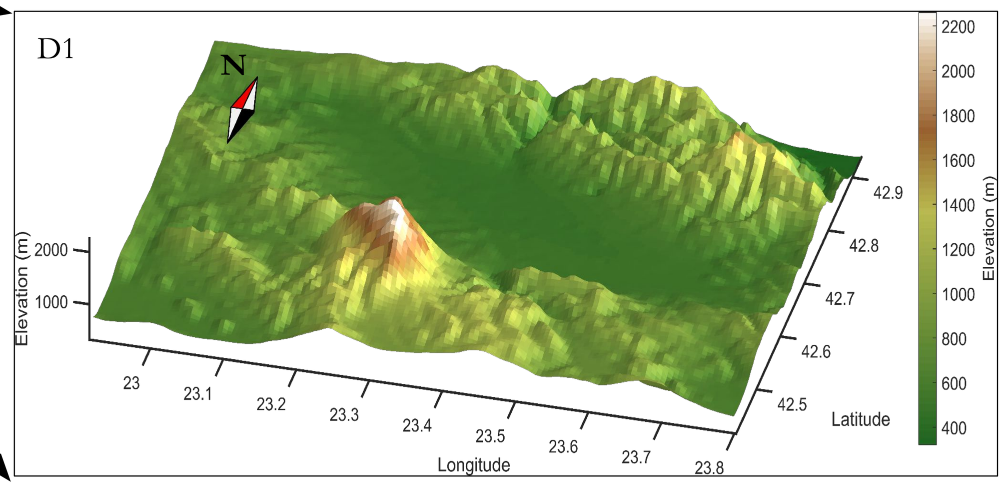
ARW-WRF v.3.8.1 model setup for the Sofia region

Configuration:

- Lambert projection (23.4°E, 42.68°N)
- 4 nested domains with grid sizes of 32, 8, 2 and 0.5 kms
- Resolution of the inner domain: 157x129x51
- High terrain resolution 1 arcsec, https://lta.cr.usgs.gov/SRTM1Arc
- High land-use resolution 3 arcsec: Corine adopted to USGS classes, http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012
- Input data: NCEP Final Analysis 0.25 deg, http://rda.ucar.edu/datasets/ds083.2/



Model parametrization:
Radiation: RRTM and Dudhia schemes
PBL: YSU, ACM2, MYJ, MYNN2.5, MYNN3, QNSE, BouLac, UW;
Moisture: Lin et al., WRF Single-Moment 6, Goddard, Thompson;

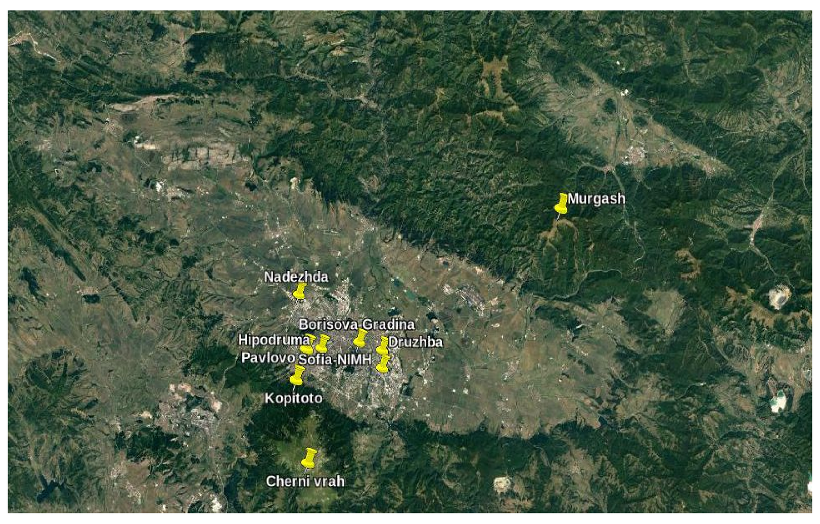


Case study

Cases	Start (MDT)	End (MDT)	Start (UTC)	End (UTC)	Description	Wind speed
Case 1	13/08/2016 22:00	15/08/2016 22:00	14/08/2016 00:00	16/08/2016 00:00	Quiescent	< 5m/s
Case 2	03/01/2016 22:00	04/01/2016 22:00	04/01/2016 00:00	05/01/2016 00:00	Moderate SW wind	5 m/s – 10 m/s
Case 3	05/08/2015 22:00	06/08/2015 22:00	06/08/2015 00:00	07/08/2015 00:00	Moderate NE wind	5 m/s – 10 m/s
Case 4	10/11/2015 22:00	11/11/2015 22:00	11/11/2015 00:00	12/11/2015 00:00	Moderate NW wind	5 m/s – 10 m/s
Case 5	21/10/2015 22:00	22/10/2015 22:00	22/10/2015 00:00	23/10/2015 00:00	Moderate SE wind	5 m/s – 10 m/s
Case 6	24/05/2016 22:00	25/05/2016 22:00	25/05/2016 00:00	26/05/2016 00:00	Strong NW wind	> 10 m/s
Case 7	04/02/2016 22:00	05/02/2016 22:00	05/02/2016 00:00	06/02/2016 00:00	Strong NE wind	> 10 m/s
Case 8	21/11/2015 22:00	22/11/2015 22:00	22/11/2015 00:00	23/11/2015 00:00	Strong SW wind	> 10 m/s
Case 9	26/11/2015 22:00	27/11/2015 22:00	27/11/2015 00:00	28/11/2015 00:00	Strong SE wind	> 10 m/s

Observations

Surface observations (SYNOP): every 3 hours; National Institute of Meteorology and Hydrology (NIMH): Sofia-NIMH (552 m), Cherni Vrah (2286 m) and Murgash (1687 m). **Radiosonde:** at 12h UTC; NIMH aerological observatory. **Automatic stations:** hourly data: Borisova Gradina (577 m), Kopitoto (1321 m), Nadezhda (534 m), Pavlovo (615 m), Hipodruma (581 m), Druzhba (548 m).



Model validation for the Sofia region

Model data and in situ observations comparison

Comparison between model data and observations with 4 different PBL schemes: Table 1 and 2 - moderate and strong winds for 6 stations in Sofia city; Table 3 - for 2 mountain stations (Kopitoto and Murgash).

Table 1

6 Stations + 4 Cases	Mean	St. Dev.	MB	ME	RMSE	IA	r
Temperature – MODERATE WIND 5-10 m/s							
Observation	9.2	2.3					
Model data – QNSE	9.9	2.9	0.2	2.1	2.4	0.75	0.82
Model data – YSU	10.5	2.4	0.7	1.5	1.8	0.81	0.82
Model data – BouLAc	12.9	2.5	1.1	1.9	2.2	0.77	0.76
Model data – ACM2	10.5	2.7	0.7	1.9	2.1	0.79	0.82
Relative Humidity - MODERATE WIND 5-10 m/s							
Observation	71.4	8.1					
Model data – QNSE	72.5	10.1	-1.2	7.9	9.5	0.70	0.71
Model data – YSU	70.2	8.4	-4.3	7.2	8.2	0.77	0.83
Model data – BouLAc	67.4	8.1	-5.2	7.2	8.3	0.78	0.86
Model data – ACM2	70.9	8.7	-3.6	7.1	8.3	0.76	0.78

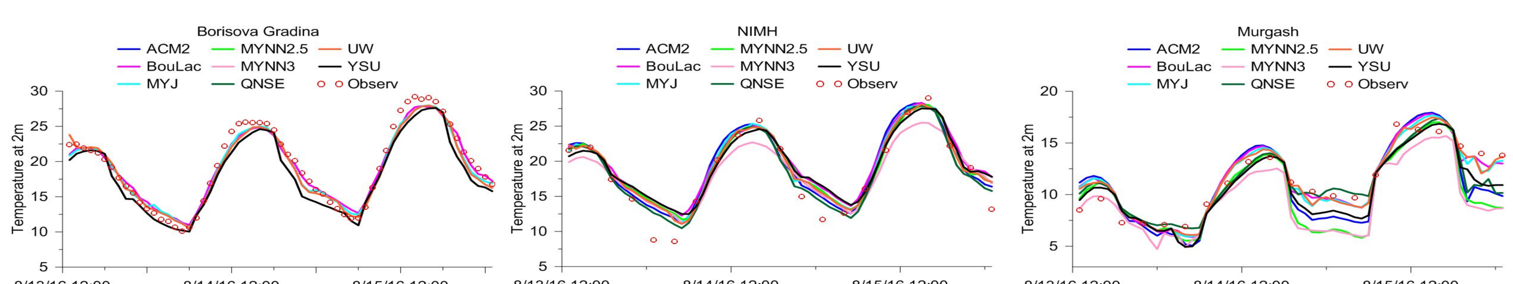
Table 2

6 Stations + 4 Cases	Mean	St. Dev.	MB	ME	RMSE	IA	r
Temperature – STRONG WIND > 10 m/s							
Observation	7.4	1.6					
Model data – QNSE	8.2	1.8	0.3	1.6	1.9	0.74	0.68
Model data – YSU	11.8	2.0	-0.1	1.9	2.2	0.74	0.69
Model data – BouLAc	9.2	1.4	1.2	1.6	1.8	0.71	0.73
Model data – ACM2	8.6	1.7	0.7	1.6	1.8	0.71	0.69
Relative Humidity – STRONG WIND > 10 m/s							
Observation	75.2	9.1					
Model data – QNSE	75.9	9.1	-2.4	10.2	11.9	0.62	0.67
Model data – YSU	71.0	8.5	-3.7	9.2	10.4	0.64	0.71
Model data – BouLAc	70.9	7.6	-7.5	10.3	12.1	0.60	0.69
Model data – ACM2	73.4	9.3	-4.4	10.4	11.7	0.64	0.71

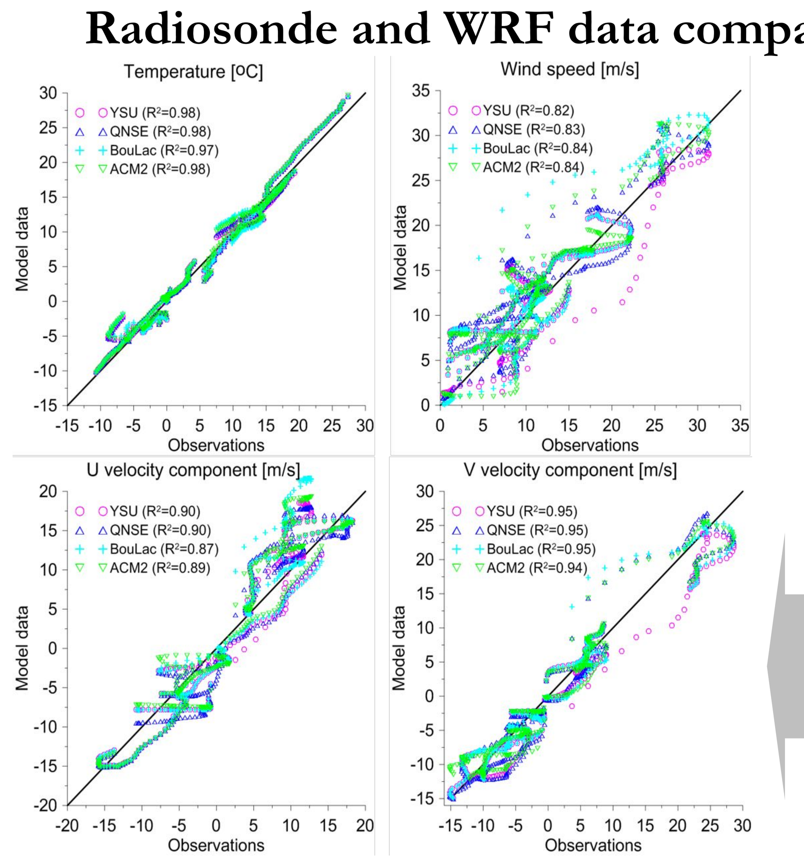
Table 3

2 Stations + 9 Cases	Mean	St. Dev.	MB	ME	RMSE	IA	r
Temperature							
Observation	6.6	1.6					
Model data – QNSE	5.6	1.6	-1.1	1.7	1.9	0.68	0.74
Model data – YSU	5.6	1.7	-1.0	1.6	1.8	0.71	0.76
Model data – BouLAc	5.9	1.7	-0.7	1.6	1.8	0.71	0.78
Model data – ACM2	5.6	1.8	-1.0	1.7	1.9	0.70	0.77
Relative Humidity							
Observation	72.9	7.1					
Model data – QNSE	77.6	6.1	4.7	10.0	11.4	0.49	0.40
Model data – YSU	77.8	5.8	4.9	9.7	10.9	0.51	0.45
Model data – BouLAc	77.2	5.4	4.3	9.7	11.1	0.48	0.40
Model data – ACM2	78.2	6.2	5.3	10.3	11.8	0.49	0.40

Comparison of diurnal temperature evaluation for different PBL schemes, for quiescent conditions.

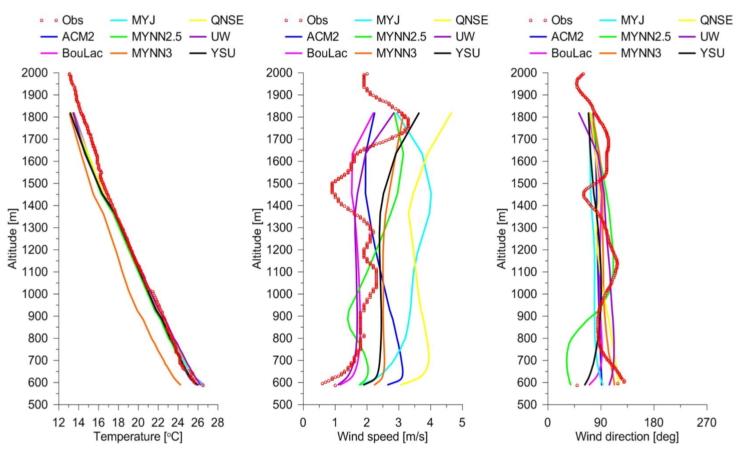


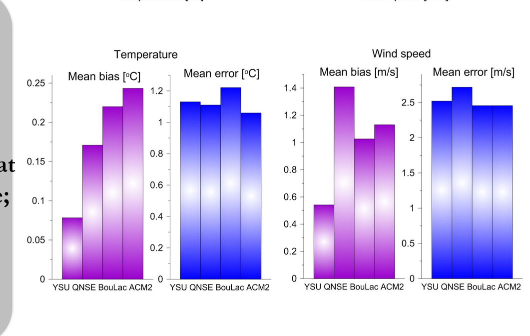
Radiosonde and WRF data comparison



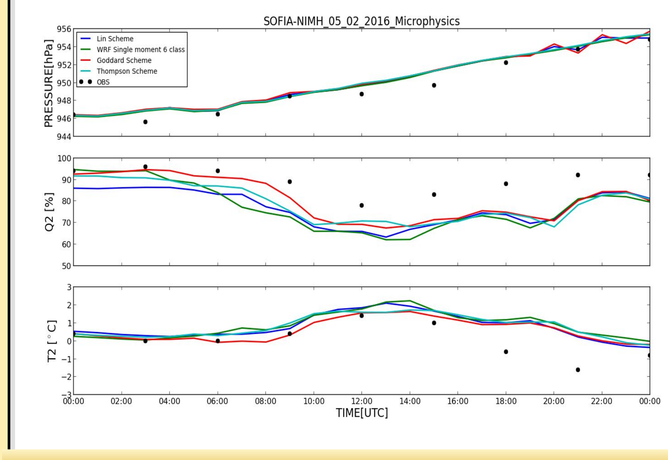
Scatter plots of interpolated observation and model data at the same vertical levels for 4 PBL schemes at 12 UTC, NIMH site; all cases are included.

Comparison of vertical profiles for different PBL schemes, 15.08.2015 at 12 UTC, NIMH site.





Mean bias and error of interpolated observation and model data at the same vertical levels for 4 PBL schemes at 12 UTC, NIMH site; all cases are included

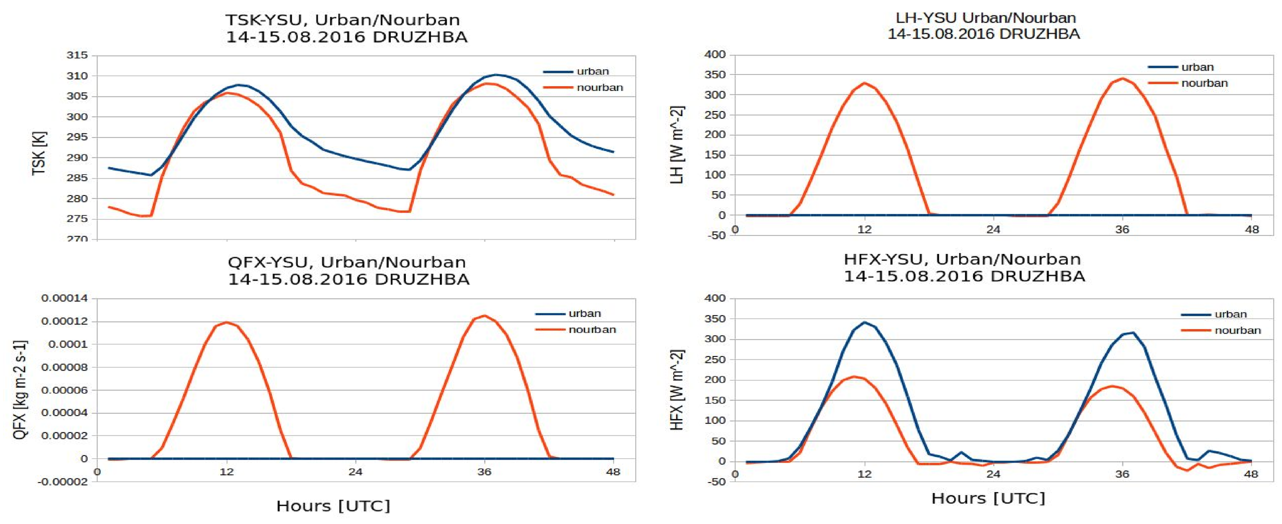


Comparison between model data and observations with 4 different microphysics schemes for Sofia-NIMH station, Case 2

Statistical measures for different microphysics schemes: for Sofia-NIMH station for Case 2

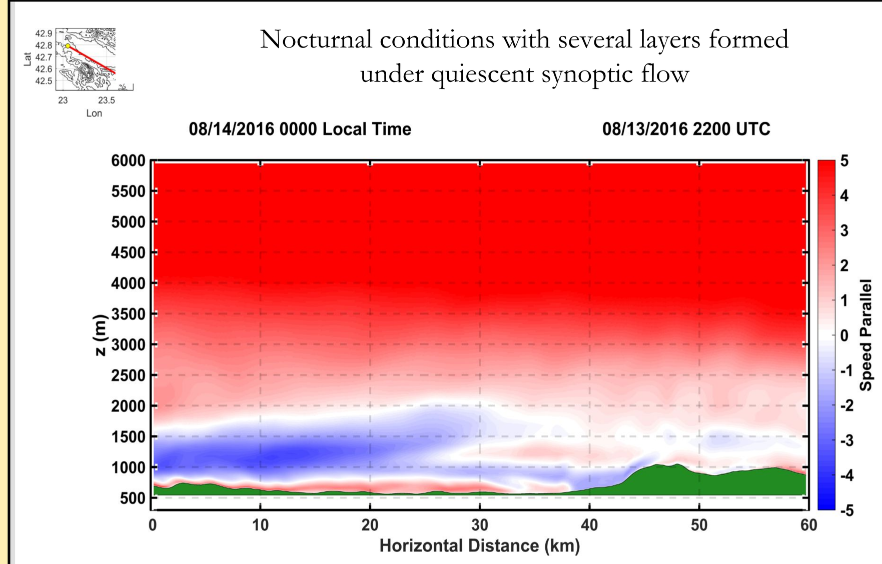
Sofia-NIMH 05.02.2016 (Case 7)	Mean	St. Dev.	MB	ME	RMSE	IA	r
Temperature							
Observation	0.0	0.9					
Model data-Lin Scheme	0.7	0.7	0.7	0.7	0.9	0.73	0.75
Model data – WRF Single Moment 6 class Scheme	0.7	0.6	0.7	0.7	1.0	0.68	0.65
Model data – Goddard Scheme	0.5	0.6	0.5	0.5	0.8	0.71	0.63
Model data – Thompson Scheme	0.8	0.6	0.7	0.8	1.0	0.66	0.60
Relative Humidity							
Observation	89.6	5.5					
Model data-Lin Scheme	77.9	6.9	-11.7	11.7	11.9	0.58	0.97
Model data – WRF Single Moment 6 class Scheme	79.9	7.9	-9.7	9.7	10.5	0.62	0.87
Model data – Goddard Scheme	81.8	8.7	-7.8	7.8	9.0	0.71	0.90
Model data – Thompson Scheme	78.9	10.1	-10.6	10.8	12.1	0.61	0.89
Pressure							
Observation	949.6	3.1					
Model data-Lin Scheme	950.2	3.0	0.6	0.6	0.8	0.98	0.98
Model data – WRF Single Moment 6 class Scheme	950.3	3.2	0.7	0.7	0.9	0.98	0.98
Model data – Goddard Scheme	950.3	3.1	0.7	0.8	1.0	0.98	0.98
Model data – Thompson Scheme	950.2	3.2	0.6	0.7	0.8	0.98	0.99

Effect of urban area on local radiative balance

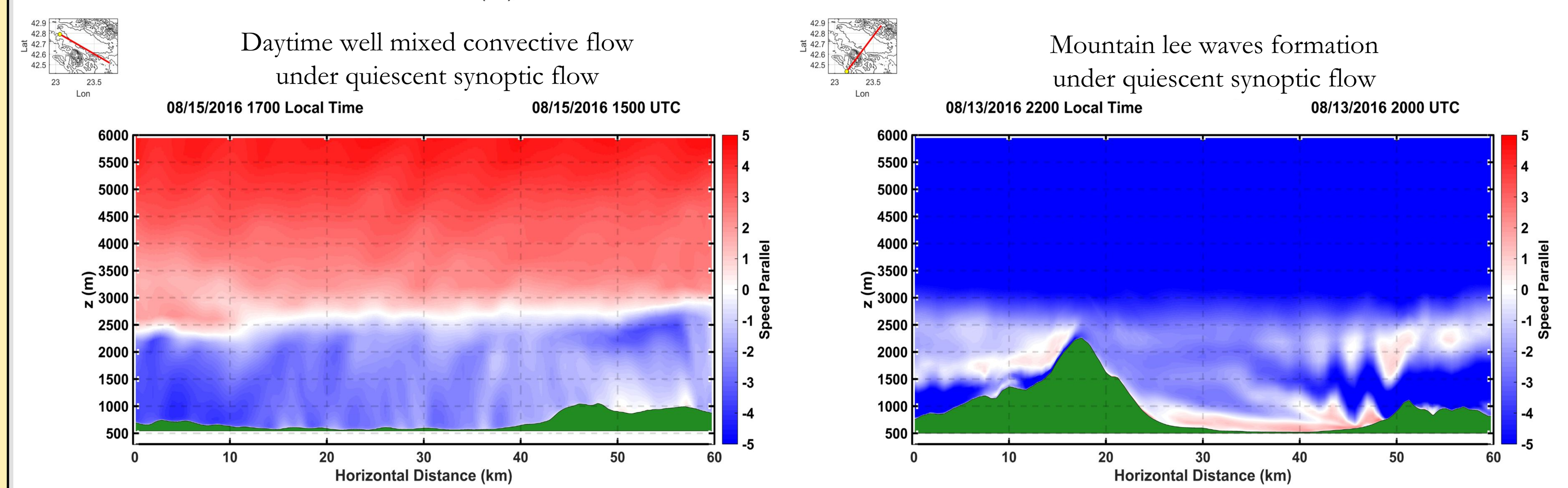


Comparison of skin temperature, heat, moisture and latent fluxes for Case 1. The urban area were replaced with most representative rural land use for nourban case.

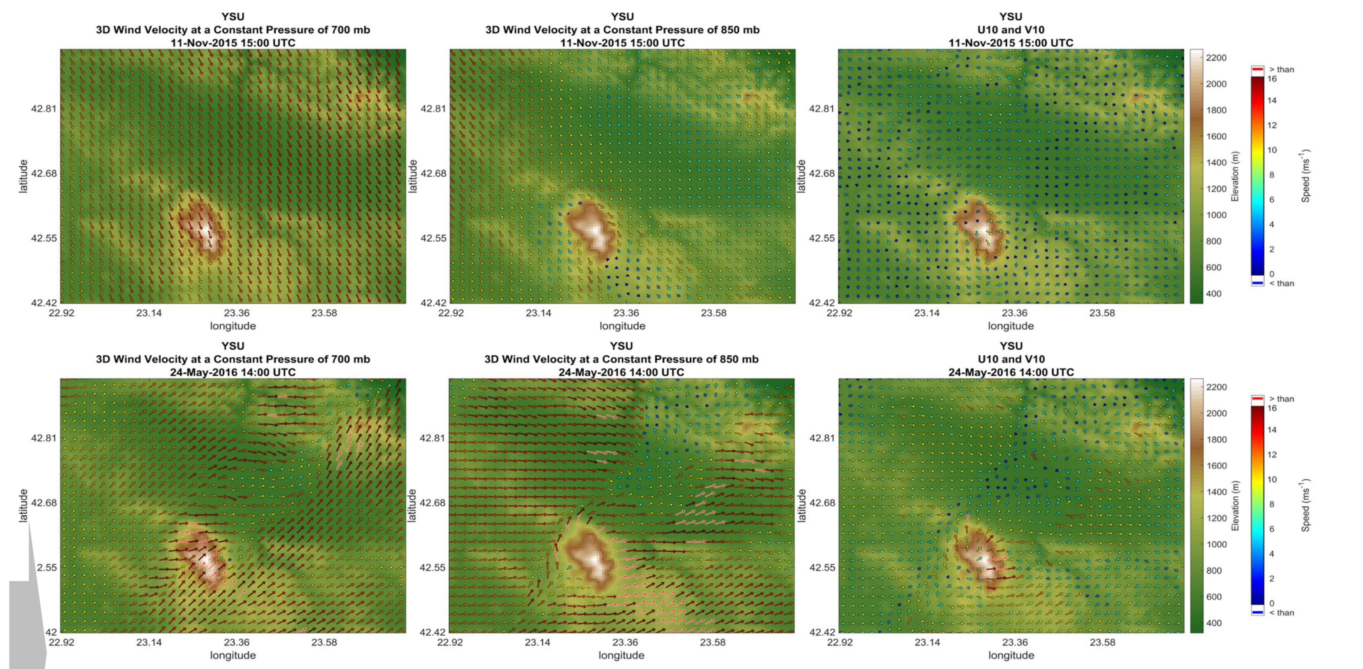
Modification of the synoptic flow



The synoptic flow experience significant modification in complex terrain, leading to formation of mesoscale phenomena as mountain/ valley flow, nocturnal jet, mountain lee waves, vortex shedding, rotors and boundary-layer separation. Such phenomena play significant role of local PBL structure and microclimate. Vertical slides of interpolated wind over the chosen cross-section are shown for YSU PBL scheme for the case with quiescent conditions 13 – 15.08.2015 (Case 1).



Velocity vectors - horizontal cross-sections at different levels: 700 and 850 mbar and 10 m for NW (case 4) and SW (case 6) synoptic flow.



Conclusions

- The comparisons made between WRF data and observations of temperature, relative humidity and wind speed show good agreement for the selected cases for both, 9 in situ stations and available once per day radiosounde observations. YSU PBL scheme describes the best selected parameters at surface and vertical profiles. The model performance is worse for the strong wind cases and mountain stations.
- The comparison for microphysics schemes for one case shows that Lin schemes represents the best temperature, pressure and relative humidity diurnal evolution.
- The urban area modify significantly the skin temperature, heat, moisture and latent fluxes. There is substantial increase of the heat flux (during the day) and skin-surface temperature (during the night), and lack of moisture in the city area.
- The modification of the synoptic flow, due to the complex terrain in Sofia region, is significant. Formation of several layers due to katabatic flows with different density coming from the surrounding mountains and orographic lee waves, can be observed during the night, under stable conditions, in presence of weak synoptic flow. The well mixed convective layer within the valley is typical during the day for quiescent synoptic conditions.
- The synoptic flow modification, due to mesoscale effects, is substantial up to 850 hPa, when the presence of Vitosha Mountain play major role. The flow remains unaffected at 700 hPa.

Acknowledgements

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