Numerical simulations of fog formations over the Zagreb area

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Motivation & Aim

- According to the climatological data, haze and fog occur frequently over the Zagreb-Airport (Fig.1) area and cause severely low visibility that can last for several days.
- Comparison of the number of days with fog at airport is more than double compared with the urban station Zagreb-Grič.
- During the fog events, the most common wind direction is in the range of 230°–260° (Koračin, 1978). As wind speed increases, the winds are more often from N – NE directions.
- Although Zagreb stations show a reduction in the number of days with reduced visibility in the last 40 years, it is the smallest at Zagreb-Airport (~15% on an annual basis) without changes in the winter months (Brzoja, 2012).
- Considering this reduction, the anthropogenic (urban) impact and effects of the nearby topography and the Sava river are still unclear.

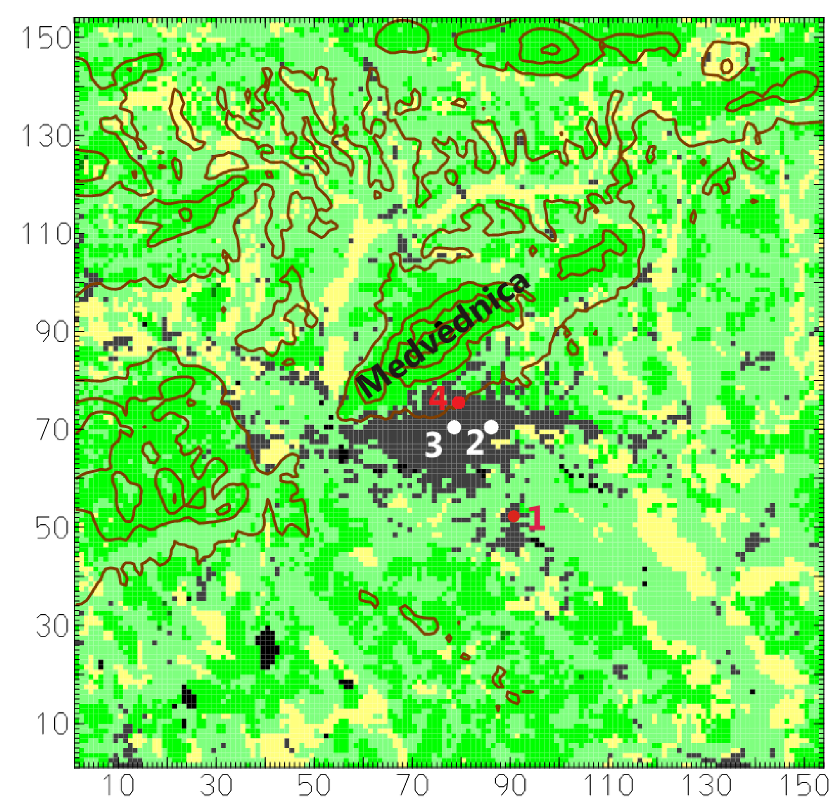

Fig. 1: The area of interest (wider Zagreb area) and measuring sites as circles: Zagreb-airport (1), Zagreb-Maksimir-radiosounding site (2) and urban site Zagreb-Grič (3) and Zagreb-GO (4). Zagreb airport is located in a flat terrain south of Zagreb near the Sava river at a height of 108 m above sea level (asl). To the north, the city of Zagreb (~120 m asl) is a main source of urban pollution including condensation nuclei. There are heavy traffic roads around the airport which also generate pollutants. North of Zagreb, the Medvednica mountain rises up to 1000 m asl in a relatively short distance of about 10 km, with a very well defined downslope forest area.

Model WRF-ARW, V3

- 3.5-day period: 5-9/November/2013
- initial and boundary conditions (every 6 h)
- ECMWF analysis;
- vegetation and land-use: USGS & CORINE databases;
- 4 domains (dx=13.5 km, 4.5 km, 1.5 km, 0.5 km) & 2-way nesting on a Lambert conformal projection;
- top of the atmosphere = 70 hPa & 97 sigma levels with 25 levels in the first 1 km.

Table 1: Two options of parametrization schemes

Parametrizations:	WRF1	WRF2
SW & LW radiation	*Dudhia & RRTM*	*Dudhia & RRTM*
Cumulus par. in 2 outer domains	*Betts-Miller-Janjić*	*Betts-Miller-Janjić*
Microphysics	*Morrison 2-Moment*	*Lin*
Thermal diffusion scheme for the soil temperature	*5-layer*	*5-layer*
PBL scheme	*MYNN**	*MYJ*
Urban surface scheme	*single-layer UCM*	*single-layer UCM*
Height of vertical mid-levels in first 1 km, z (m)	5, 16, 28, 41, 54, 67, 81, 95, 110, 125, 142, 159, 177, 195, 215, 235, 256, 278, 302, 328, 369, 433, 525, 663, 838, 1025...	

Fog detection

- Detection of fog from measurements visibility < 1000 m & satellite MSG data
- Detection of fog from model: cloud water content (LWC), relative humidity and algorithms:

$$h\ (km) = 60 * e^{-2.5 * \frac{rh-15}{80}} \quad (1)$$

$$h\ (km) = \frac{1}{1.6} * 6000 * \frac{T - Td}{rh^{1.75}} * 1.60953 \quad (2)$$

(1) Adopted from Rapid Update Cycle (RUC) method
(2) Developed by NOAA/Forecast systems Laboratory (FSL) method

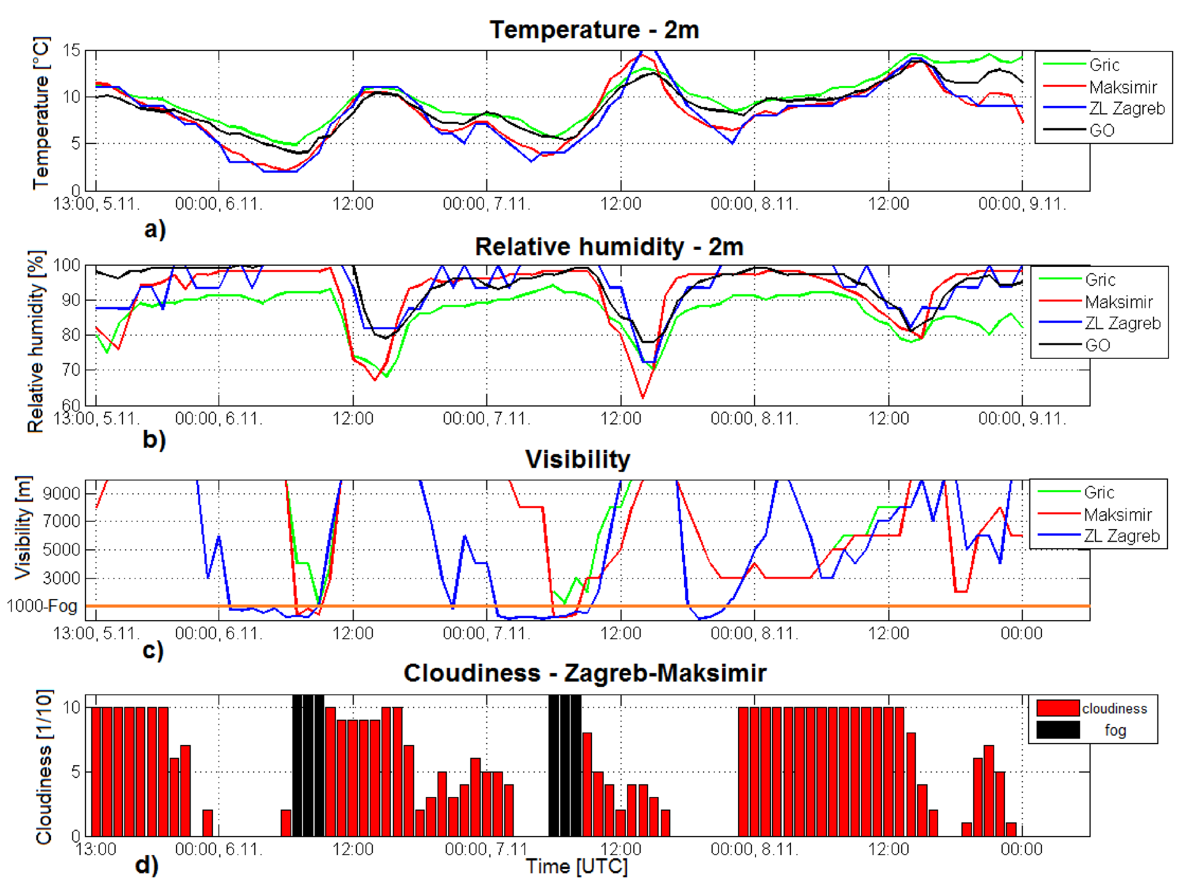

Fig 2: Measured time-series of temperature (a), relative humidity (b), visibility (c) on four measuring sites: Zagreb-airport (blue), Zagreb-Maksimir (red), Zagreb-Grič (green) and Zagreb-GO (black). Cloudiness is shown only for Zagreb-Maksimir (d). Fog is observed 3 times at Zagreb-Airport and 2 times at Zagreb-Maksimir mostly in cloudless periods when relative humidity was above 95%. At Zagreb-airport three episodes of fog were detected within the analyzed period of 8 h, 9 h and 3 h, respectively.

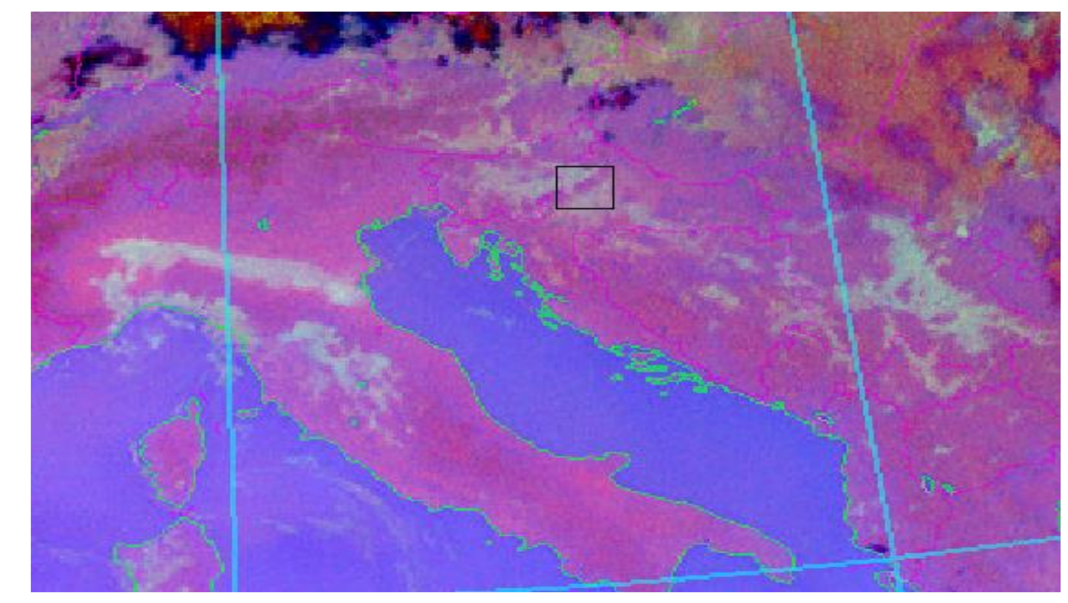

Fig. 3: MSG satellite images on 7 Nov 2013, at 05 UTC the combined NM-RGB channel. Fog is in greenish color on the RGB products covering wider Zagreb area. Black square represents domain of interest shown in Fig. 1

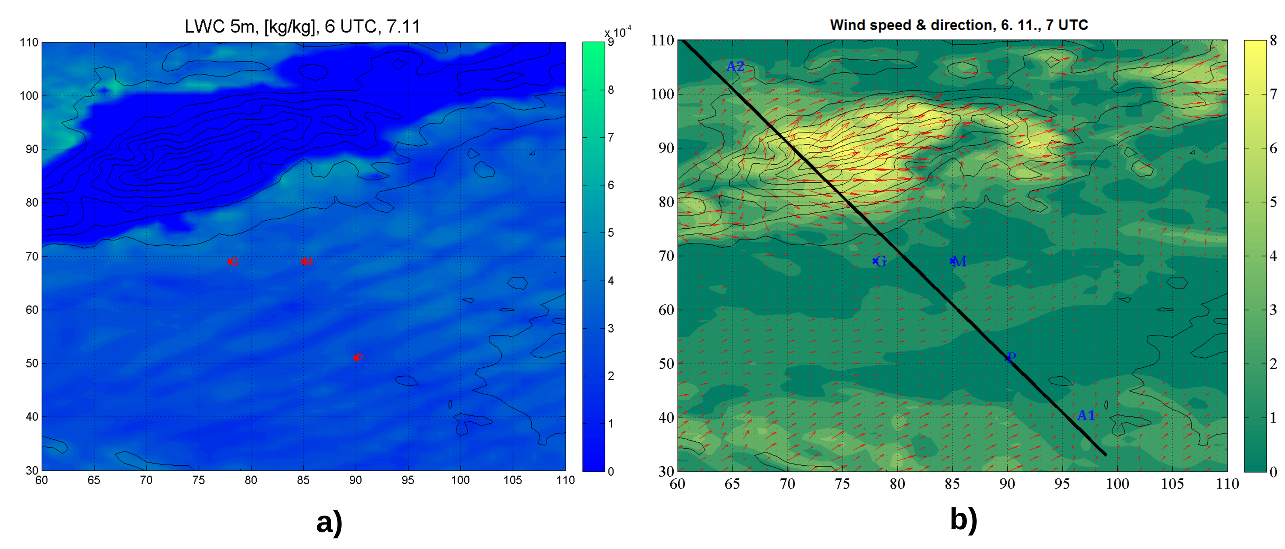

Fig 4: Simulated horizontal values of LWC (a) and wind (b) on 7 Nov 2013, at 06 UTC. High values of LWC suggest occurrence of fog over most of domain. Fog has developed over the night when wind speed was below 3 m/s. Similar situation is in other two cases of low visibility. Vertical cross-section used to observe vertical structure of PBL is shown with black line (b).

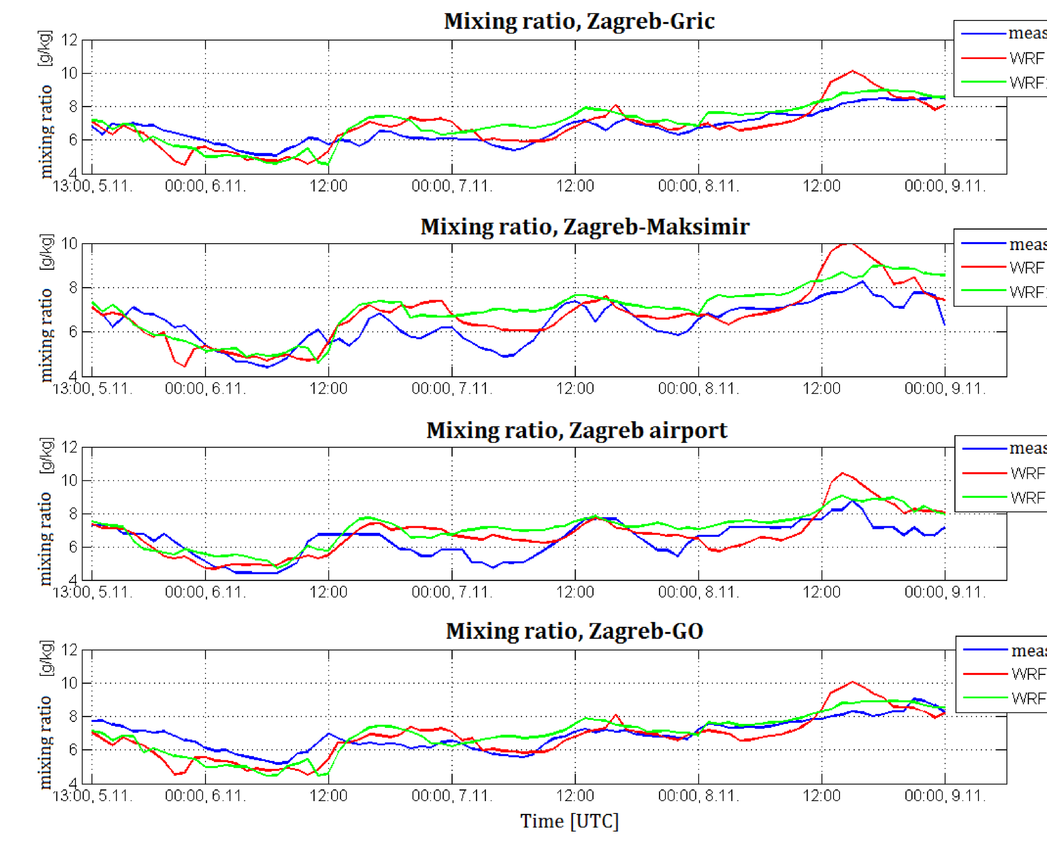

Fig 5: Comparison of mixing ratio [g/kg] between near surface measurements (blue) and two model setups (tab. 1; WRF 1 – red, WRF 2 - green) for all four stations during 84h period from 05 Nov in 13 UTC to 09 Nov in 00 UTC. WRF 2 setup has shown as more relevant during statistical analyisis and because of that case study is analysed with WRF 2 setup output.

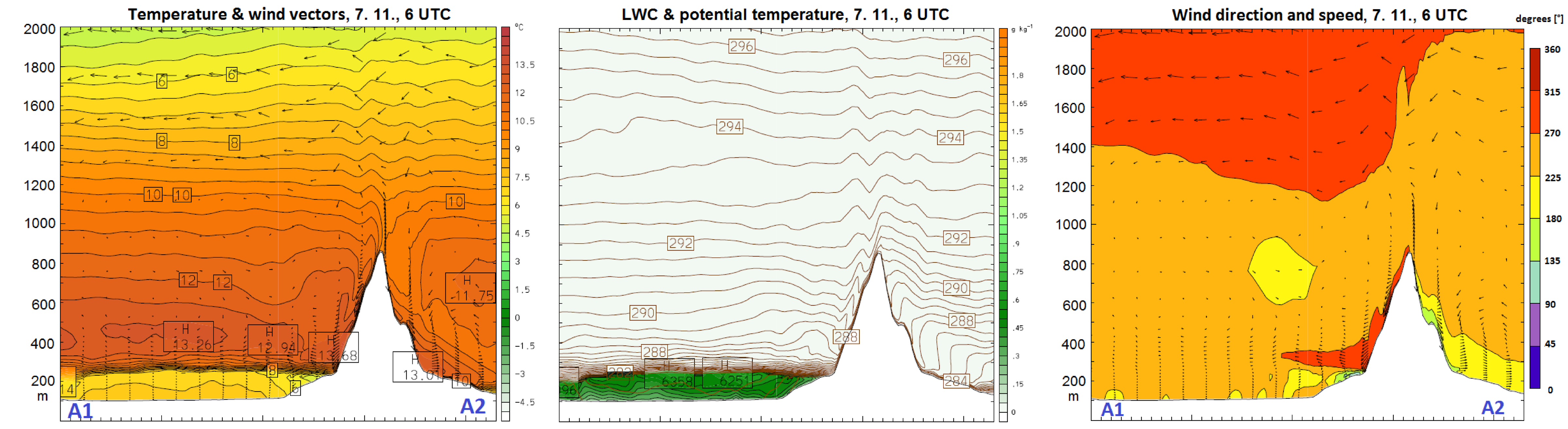

Fig 6: Vertical structure of temperature and wind vectors (a), *LWC* and potential temperature (b) and wind direction (c). Temperature inversion develops during the night and reaches its maximum at 7 Nov in 6 UTC (7 CET). During this time temperature inversion occurs between 200 and 350 m over the urban area of Zagreb (a). LWC is also dependent on temperature inversion (b) in a way that higher values are also in first 350 m above surface. Wind direction (c) suggests surface downslope wind formed on south Medvednica slope and its flow over the thermal inversion. Its speed is decreasing towards the urban area.

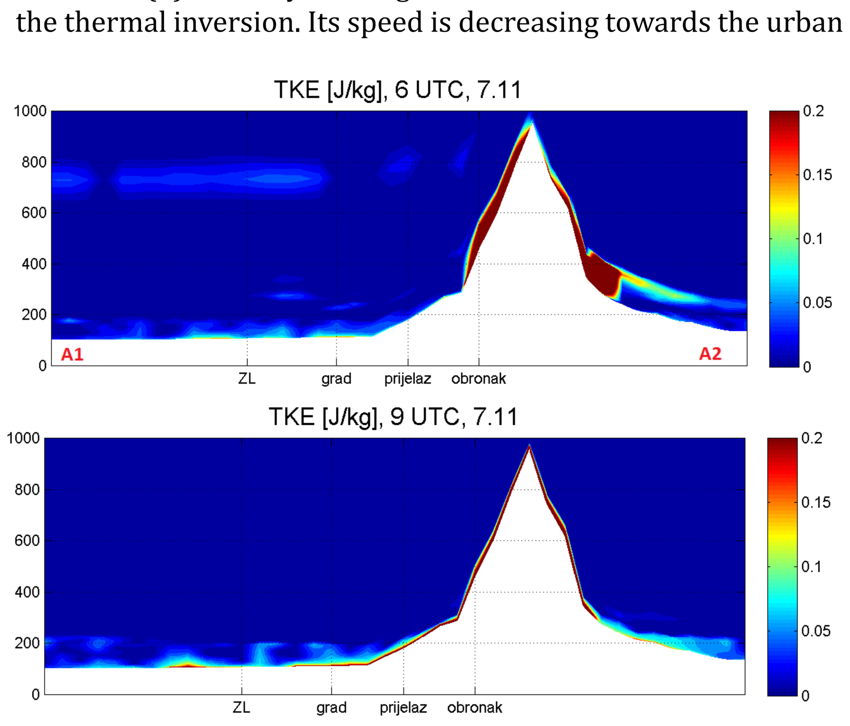

Fig 7: Vertical structure of TKE [J/kg]. Downslope wind (Fig 6c) doesn't have enough strength to form turbulence on top of the fog (a). Fog dissipates after surface turbulence is formed (b) but it is too weak for breaking thermal inversion.

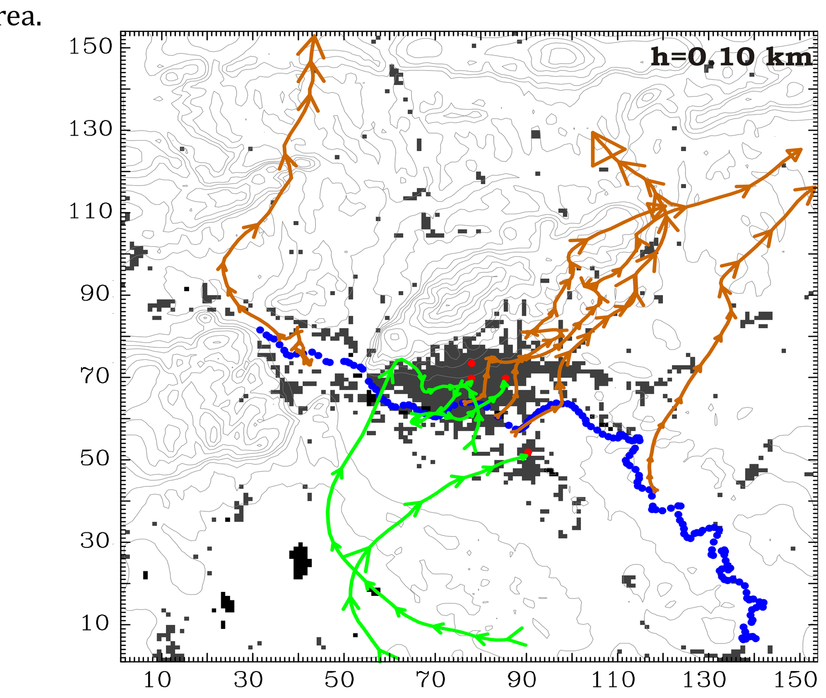

Fig 8: 13-h 3D forward (tan) and backward (green) trajectories. Forward trajectories start at the 5 points along the Sava river at 00 UTC on 7 Nov 2013. Backward ones arrive in 3 stations at 00 UTC (7 Nov 2013). The trajectories were calculated at 0.5 km horizontal resolution within the smallest model domain at 100 m level and arrows represent parcel positions for every 1/2 h.

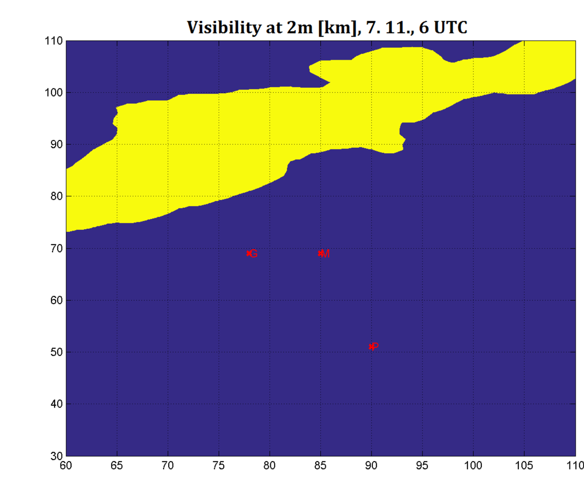

Fig 9: Visibility at height od 2m estimated from model output variables with algorithm (2).

Summary

- Influence of downslope wind on forming and dissipation of fog over the urban Zagreb area is limited.
- Downslope cannot cause enough large turbulence on top of fog layer because of its low speed
- Trajectories are showing that particles are arriving in urban area from south-west so influence of Sava river must be thoroughly examined
- Visibility algorithm (2) is good for estimating low visibility but is very rough

References

- Koračin D (1978): Glavni uzroci magle na zagrebačkom aerodromu Pleso. Diplomski rad. PMF Zagreb, str. 69.
- Brzoja D (2012): Analiza pojave magle na širem području Zagreba. Diplomski rad. PMF Zagreb, str. 74.