Nighttime cold air drainage from patchy slope-forests in Tokyo

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Abstract

Tokyo Metropolitan area consists of western diluvial upland and eastern alluvial plain. In upland area, there are many dissected valleys arborescently, and some slope-forests remain along those valleys in patches even though in central Tokyo. It is difficult to lay out a new large park within built-up area, so such slope-forests are precious plots as a natural resource of cold air production. In this paper, results are shown from micro-climatological observations performed in and around several slope-forests. The obvious shift of wind direction appeared at the beginning of flow-down with a sharp temperature fall of 1 or 2 degrees. In slope-forest, cold air drainage occurs earlier than plane green space because of topographical effects.

1. Introduction

In Japan, cooling effect of green space is especially important in hot and humid summer. We have investigated cold air seeping phenomena and “Park breeze” from large green space, for example the Shinjuku Gyoen Park (57*ha*) [1], the Imperial Park (230*ha*) [2] and the Institute of Natural Study (20*ha*) [3] (see Figure 1). Different from daytime advection by prevailing wind, turbulent mixing is very weak in nighttime seeping phenomena because of stable atmospheric condition. Therefore, the cooling effect for ambient air, that is negative sensible heat flux, was very small, but the flow-out air was kept cool as far as the seeping front. That is the reason we focus to nighttime seeping phenomena as an important method available to city planning. And cold air tends to flow down gravitationally along a geographical slope, so in case of slope-forests, it is expected to accelerate and start earlier than plane green space.

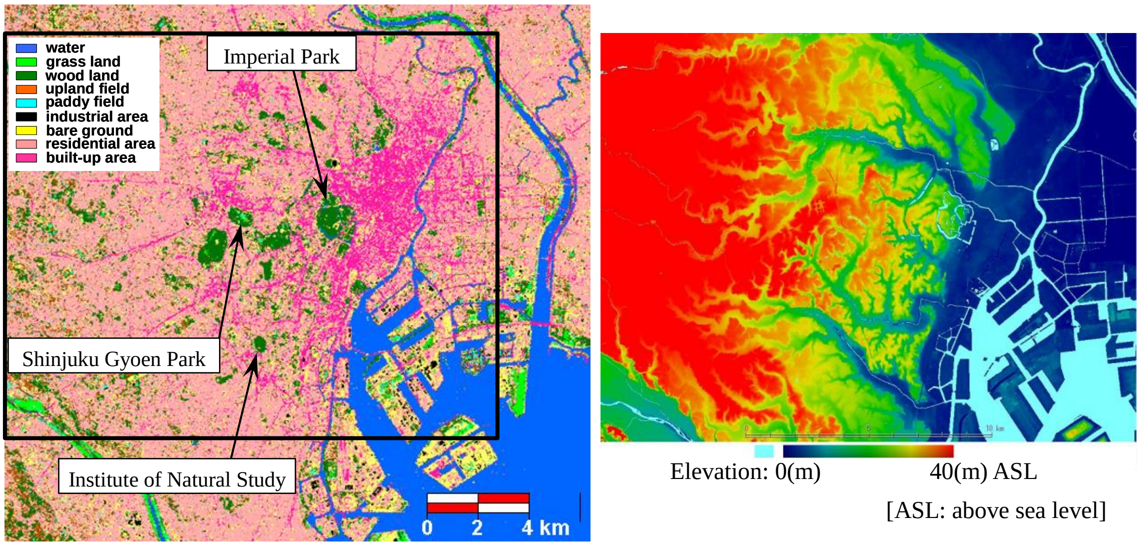

Fig. 1: Land classification by satellite (left) and elevation map (right) in central Tokyo

2. Outline of observations

Observations were performed during summer from 2011 to 2013. Location of observation sites are shown in Figure 3. We selected totally 12 slope-forests, which have different sizes, slope directions, types of vegetation and surrounding building conditions. Basically, thermistor thermometers (T&D RTR-52) mounted original natural ventilation shelters were set along the section of slope forests. And in order to catch the cold air flow-out in calm conditions, 2-dimensional sonic anemometers (GILL PGW-100) was set lower boundary of the slope-forest. In some case, it was also set another side of forest to check compensation flow of cold air drainage (Figure 4). These instruments were set upped using light-poles at the height of 3m (Figure 2). Sampling intervals are 1-minute for air temperature and 1-second for wind speed and direction.

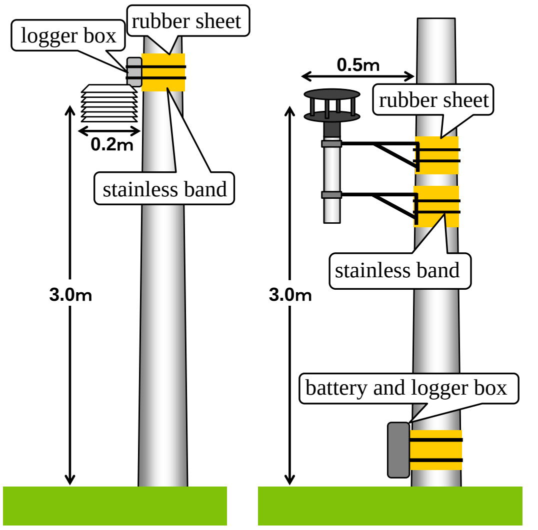

Fig. 2: Setup of instruments for light-pole

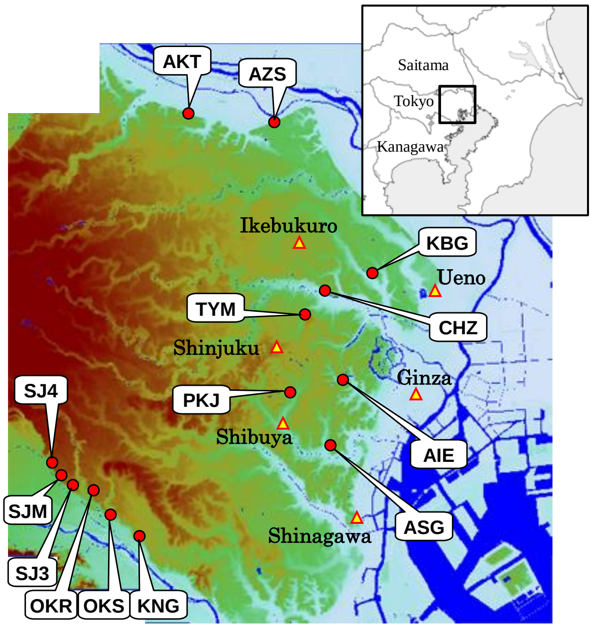

Fig.3: Location of observation sites

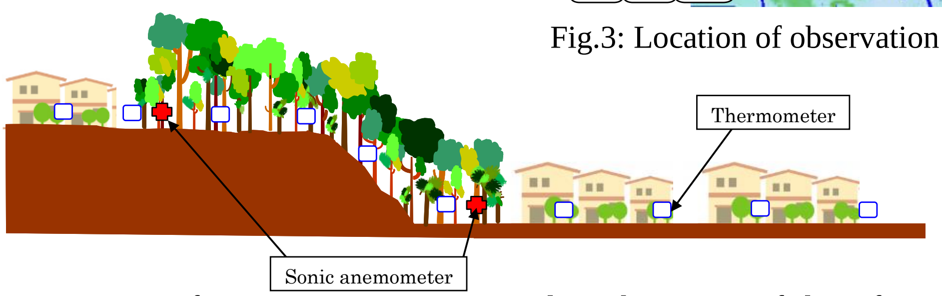

Fig.4: Image of instruments arrangement along the section of slope-forest

3. Results

3.1 Discovery of cold air drainage in patchy slope-forest

In 2007 summer, we have performed micro-climate observations to investigate thermal effect of a small river throughout built-up area. At that time, we happen to find a conspicuous air temperature drop during nighttime at the point close to a slope-forest (CHZ in Figure 3). Elevation gap of the slope is 21 m and the length of inclined direction is about 250 m. Figure 5 shows the results of typical night. Around 23:20, westerly wind suddenly stopped and steep air temperature drop was appeared with wind direction change to north-east which is down slope direction. After this event, wind became very week, about 0.2 m/s, and turbulence was almost disappeared. Such sharp temperature drop about 2 degrees was discernible only the foot area of slope-forest. In comparison with the large parks, which we have reported cold air seeping-out phenomena, size of this slope-forest is small, but magnitude of temperature drop is correspond to that of large parks. According to weekly data (Figure 6), these nighttime cold air drainage appeared without exception in clear and calm condition. In this case, however, the cold air flowed into the river channel directly, so the grasp of drainage front and availability for the improvement of residential thermal environment were remained as a future consideration.

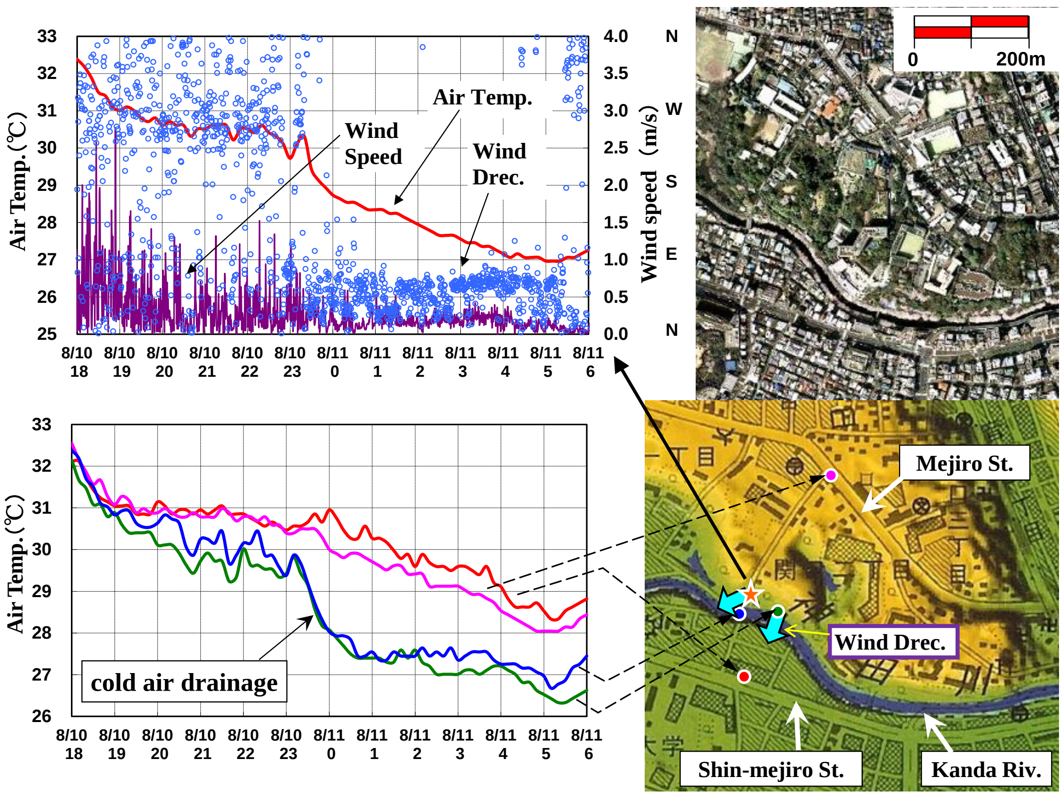

Fig.5: Finding of cold air drainage from patchy slope-forest around “*chinzan-so*” (CHZ)

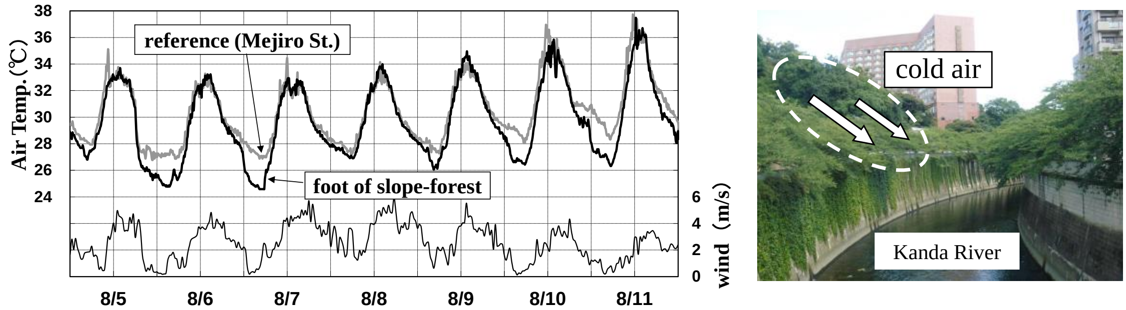

Fig.6: Weekly change of air temperature at the foot of slope-forest and upper wind speed

3.2 Case study in *Koishikawa* Botanical Garden

One of observation site in 2011 summer was around the *Koishikawa* Botanical Garden (KBG, in Figure 3). Shape of the garden is almost rectangular, and consists of forest and grass-land with some small ponds. Its area is 16.1*ha*, and includes slope-forest (elevation gap is 23 m). The length of inclined direction is 250m and width along the slope is about 750 m. Figure 7 shows comparison of air temperature during a clear night between points along *Senkawa* St. parallel to the slope. This street is away 50～100 m from near boundary of the garden, but remarkable temperature drop about 2 degrees can be seen at some observation points adjacent the garden. In consequence, cold air extended for at least 100 m toward the downslope built-up area.

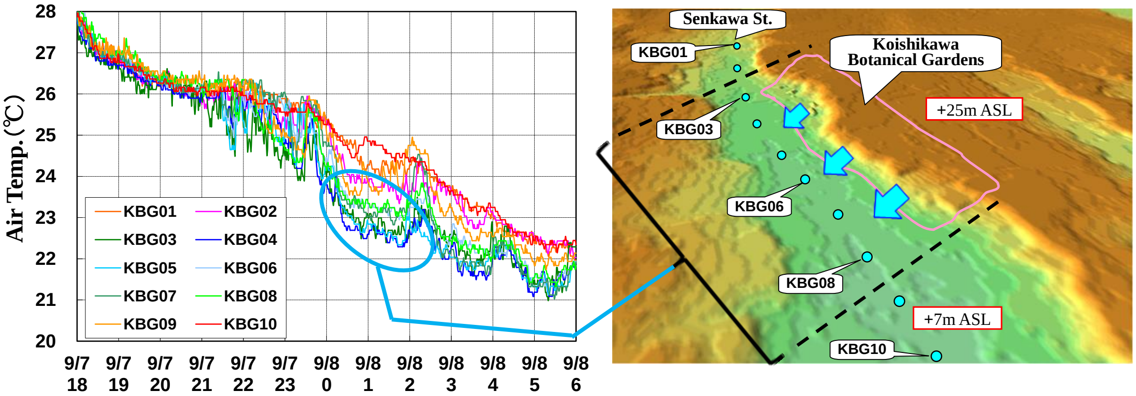

Fig.7: Topography image around *Koishikawa* Botanical Garden (KBG) and air temperature distribution along the main street adjacent the garden

3.3 Comparison between slope-forest and plane green space

Another observation site in 2011 is around *Akatsuka* Park (AKT) located in northern part of Tokyo. Here, north-facing straight slope-forest (elevation gap is 21 m) extends for 1.7 km. And plane almost square-shape park (9.2 *ha*) is existing close to the slope-forest. Therefore, we can compare the thermal effect between slope-forest and plane green space. Though there is a highway between the slope forest and residential area, cold air from slope-forest was expected to reach the housing complex area (Figure 8). So, in this area, totally 52 thermometers were set all over the area, and 6 sonic sensors were distributed along the slope and park boundary. Twin bubble-graphs show air temperature difference from reference point on the hill and wind direction of each sonic point (Figure 9). In early nighttime, around 21:00, foot area of the slop-forest was colder than the plane green space. The wind direction of foot area was flow-down slope and to the adjacent residential area, but cold air did not reach to the residential area beyond the highway. On the contrary, early morning, around 3:00, the plane park was colder than foot area of the slope. Consequently, in slope-forest, cold air drainage begins earlier than plane green space because of topographical effects. However, because the accumulation of cold air is difficult in slope-forest, finally plane green space becomes colder than slope-forest in early morning. Attention to the wind direction at upper boundary of the slope-forest, it is another direction of slope-drainage, that is, cold air also flow out another side adjacent area.

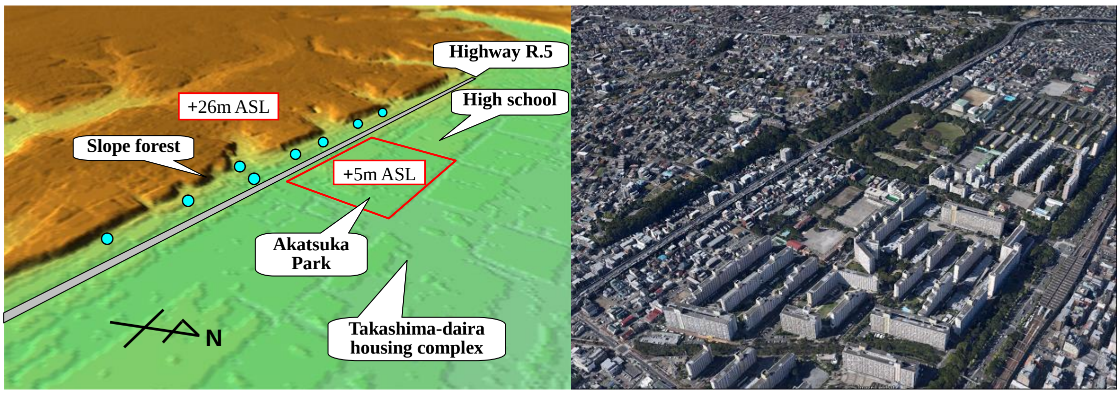

Fig.8: Topography image and bird’s-eye view around *Akatsuka* Park (AKT)

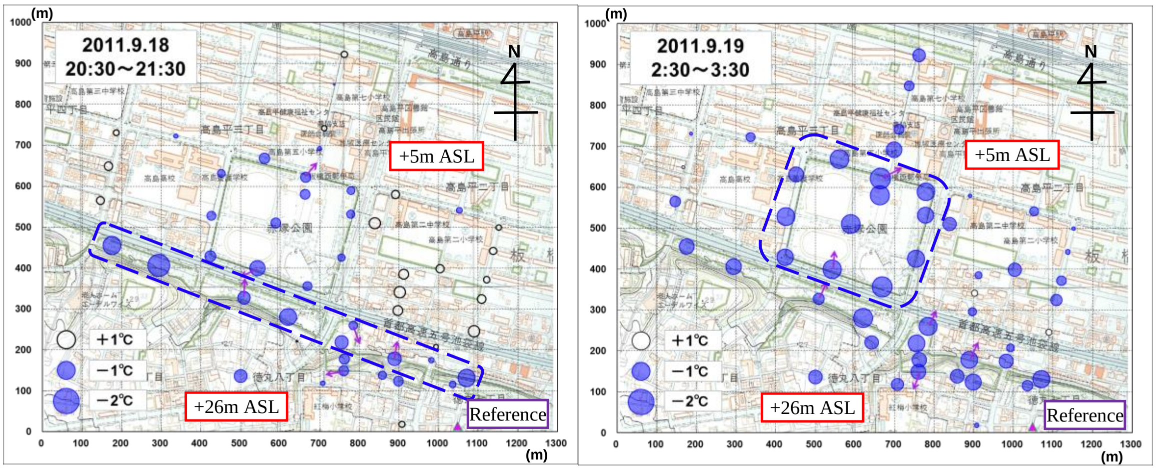

Fig.9: Distribution of temperature difference from reference point and wind direction around *Akatsuka* Park (AKT)

3.4 Effect of topography on cold air drainage in urban area

In case of *Akasaka* Imperial Estate (AIE), the feature of topography is somewhat different from other observation sites. There are several dissected valleys due to former river channel system in the area (Figure 10). Here, adding to topographical effects, air temperature difference exceeds 3 degrees (Figure 11).

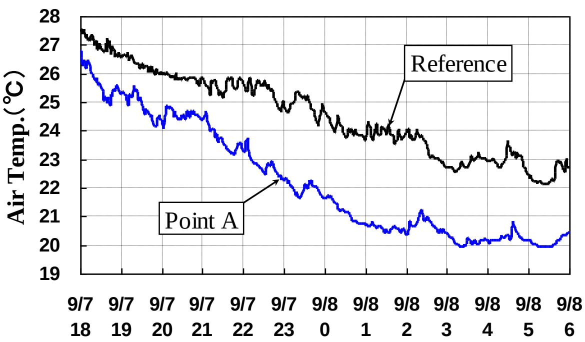

Figure 11: Topographical cold air drainage

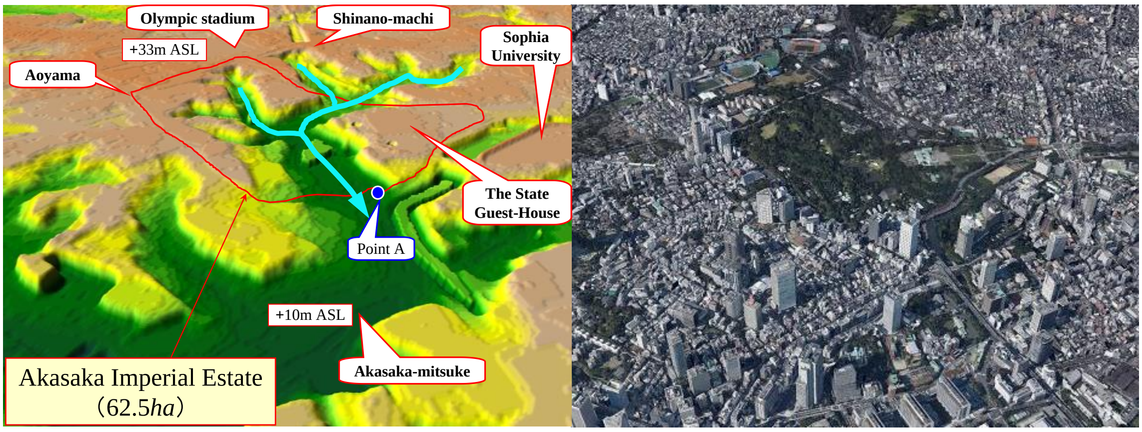

Figure 10: Topography image and bird's-eye view around *Akasaka* Imperial Estate (AIE)

Unfortunately, because the point A located near a main intersection in one of CBD, heavy traffic and many high-rise buildings obscure this large cooling potential.

3.5 Effect of forest sizes on cooling potential

All results are summarized in Table 1. We can safely say that the forest dimension of 200 m is threshold to occur cold air drainage constantly toward the adjacent built-up area. Considering detailed air temperature distribution, slope length (dimension of inclined direction) of forest is noticeable factor for cooling potential resulting from nighttime cold air drainage. About the vegetation type, its effect on cooling potential is limited in slight extent within these observations.

Table 1: Dimensions of vegetated area and frequency of cold air drainage

	symbol in Fig.3	slope width (m)	slope length (m)	area (ha)	elevation gap (m)	frequency of appearance
Akasaka Imperial Estate	AIE	*1000	*650	62.5	23	◎
Toyama Park	TYM	*500	*400	18.7	25	○
Koisgikawa Botanical Garden	KBG	750	250	16.1	18	◎
Chinzan-so	CHZ	390	250	8.0	21	◎
Arisugawa Memorial Park	ASG	300	250	4.4	16	○
Azusawa Park	AZS	300	30～230	4.2	17	○
Seijyo Mitsuike	SJM	340	70～140	2.8	21	○
Seijyo 3-chome Park	SJ3	330	60～130	2.5	22	○
Okamoto-seigado Park	OKS	450	125	5.9	19	○
Kaminoge Natural Park	KNG	125	90	1.1	19	○
Seijyo 4-chome Park	SJ4	120	60～90	1.0	20	○
Okura Park	OKR	600	40～170	3.2	14	○
Akatsuka	AKT	1700	30～60	8.0	21	○
Park Court Jingu-mae	PKJ	50	140	0.5	8	△

*: not the slope dimensions but whole green space dimensions

4. Conclusions

Even though rather small slope-forest surrounded built-up area, it has cooling potential available for the improvement of urban thermal environment. In slope-forest, according to the topographical effect, cold air drainage occurs earlier than plane green space. It is important advantage to mitigate uncomfortable sleepless night of inhabitants.

References

[1] K. Narita, et al., *Observation about cool-island phenomena in urban park,* in AMS 4th Symposium on the Urban Environment, Norfolk, VN, USA, 86-87 (2002)

[2] K. Narita, et al., *Cold air seeping from an urban green space, Imperial Palace, in central Tokyo,* in ICUC-7, Yokohama, Japan (2009)

[3] H. Sugawara, et al., *How much dose urban green cool town?* , in 7th Japanese-German Meeting on Urban Climatology, Hannover, Germany (2014)

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