Technical University of Denmark
Sustainability Division
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Per Skougaard Kaspersen, researcher

A combined remote-sensing and flood-modelling approach for assessing the impacts of urban development and climate change on exposing European cities to pluvial flooding.

Contributors: Martin Drews (DTU), Karsten Arnbjerg-Nielsen (DTU), Rasmus Fensholt (KU), Henrik Madsen (DHI), Nanna Høegh Ravn (LNH).

Research objective

Compare quantitatively the impacts of **urban development** and **climate change** in exposing cities to pluvial flooding

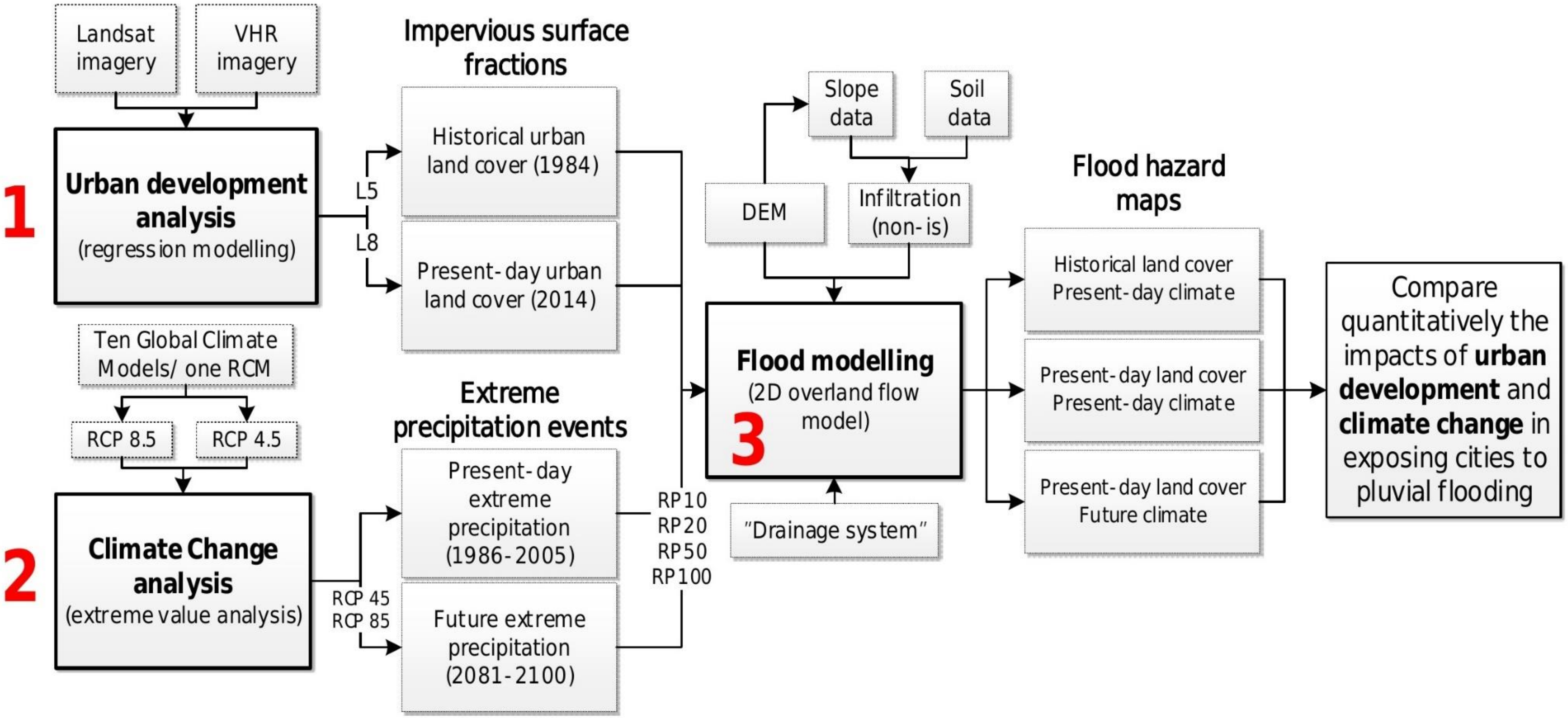
Urban development

Changes in urban land cover, measured as changes in imperviousness during the period 1984-2014 using Landsat 5 and 8 imagery.

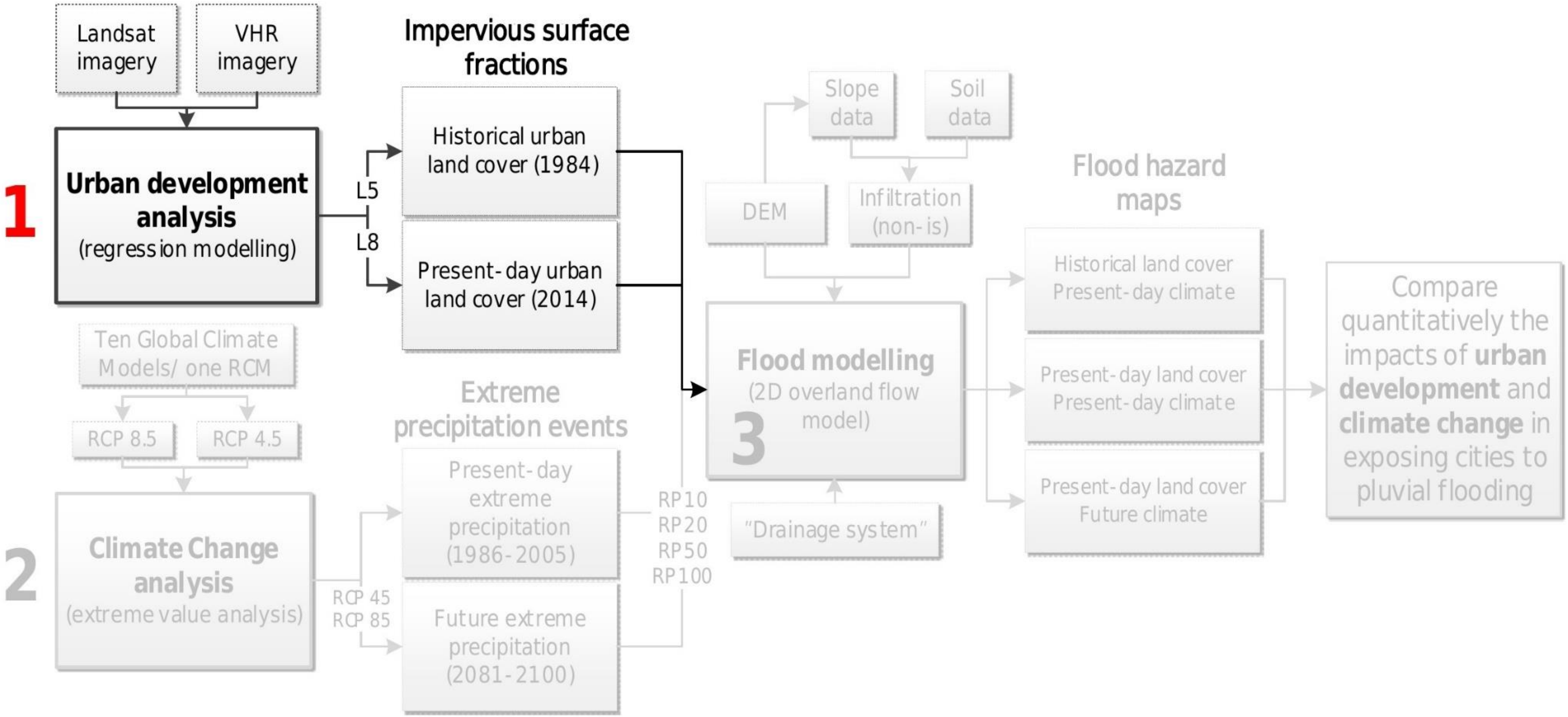
Climate change

Changes in the intensity of extreme precipitation between 1986-2005 (present-day) and 2081-2100 (future) projected for two climate scenarios; RCP4.5 and RCP8.5 using ten different GCMs.

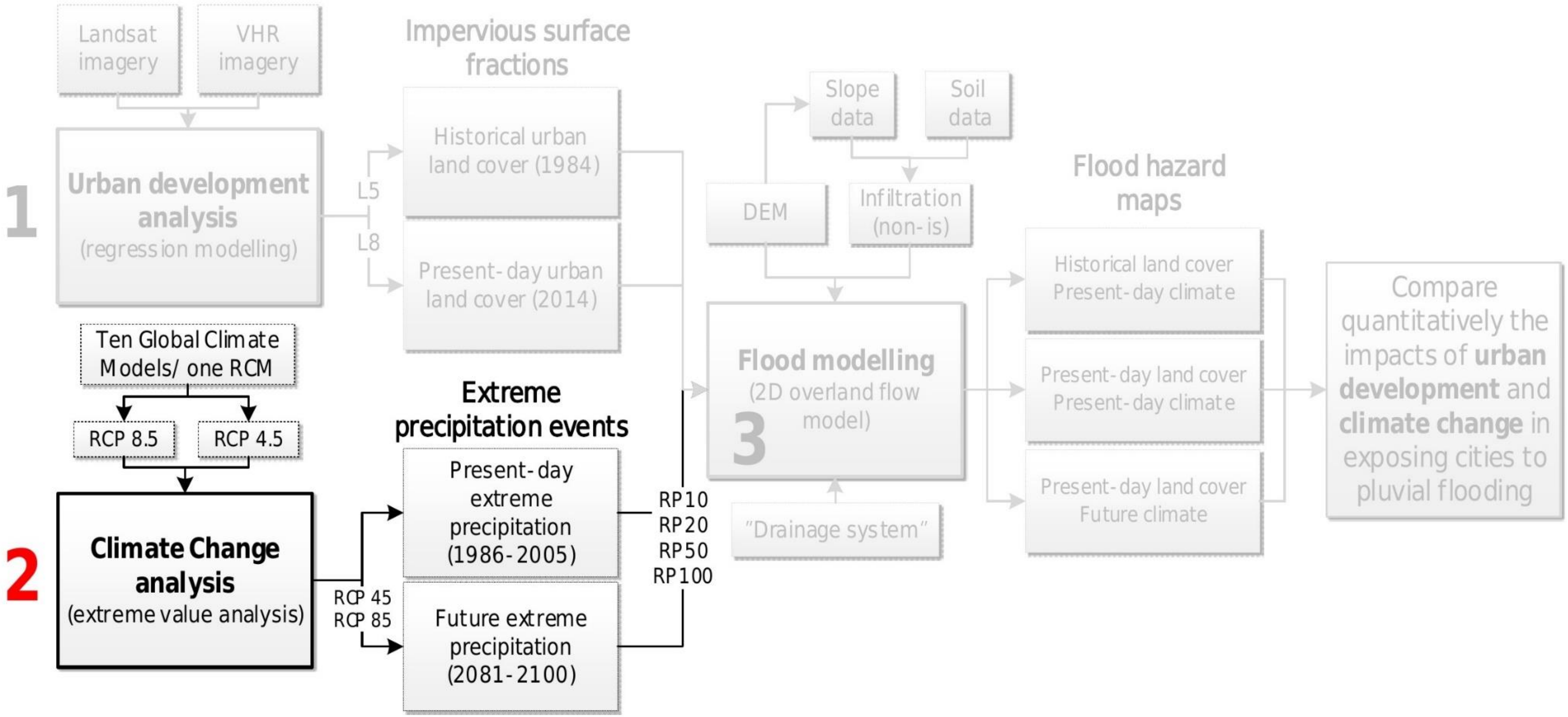
Methodology



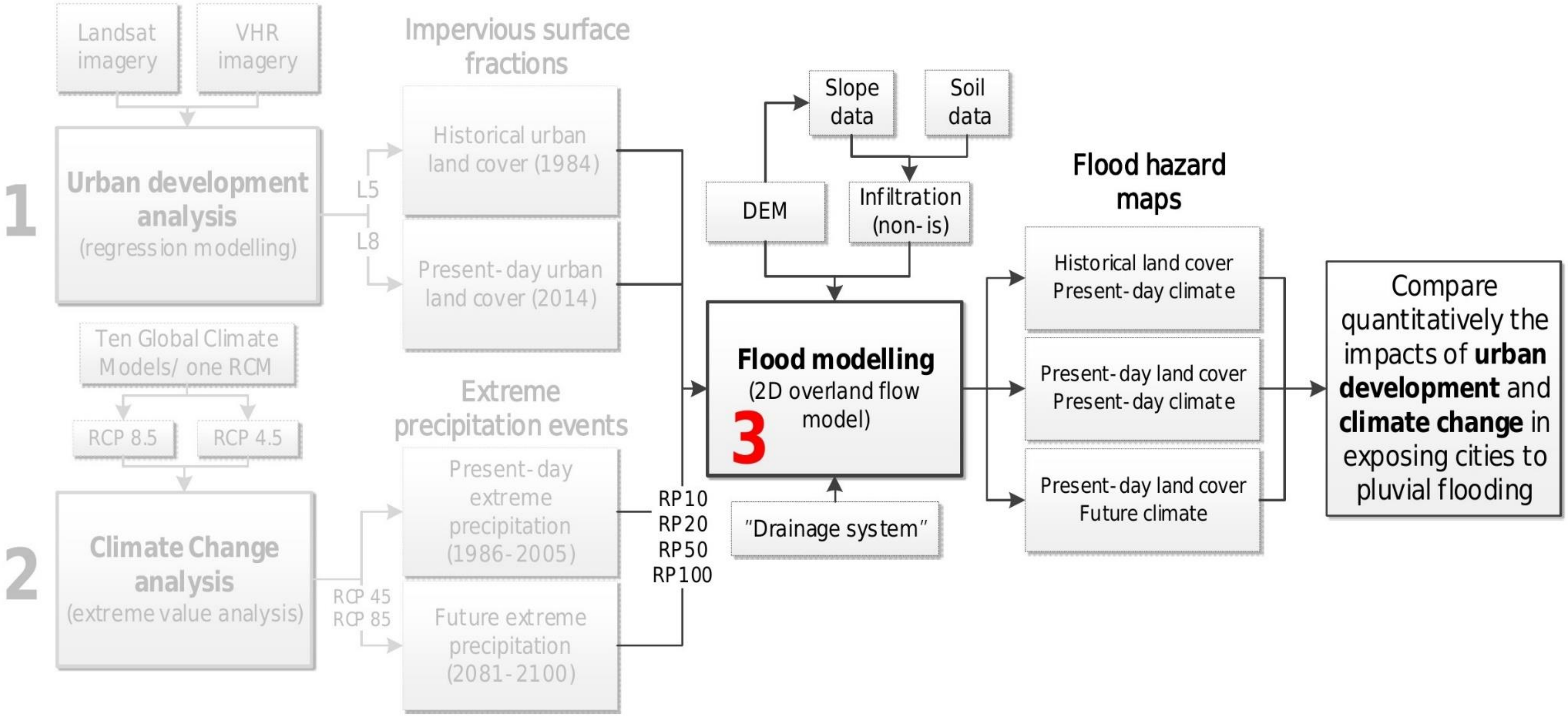
Methodology



Methodology



Methodology

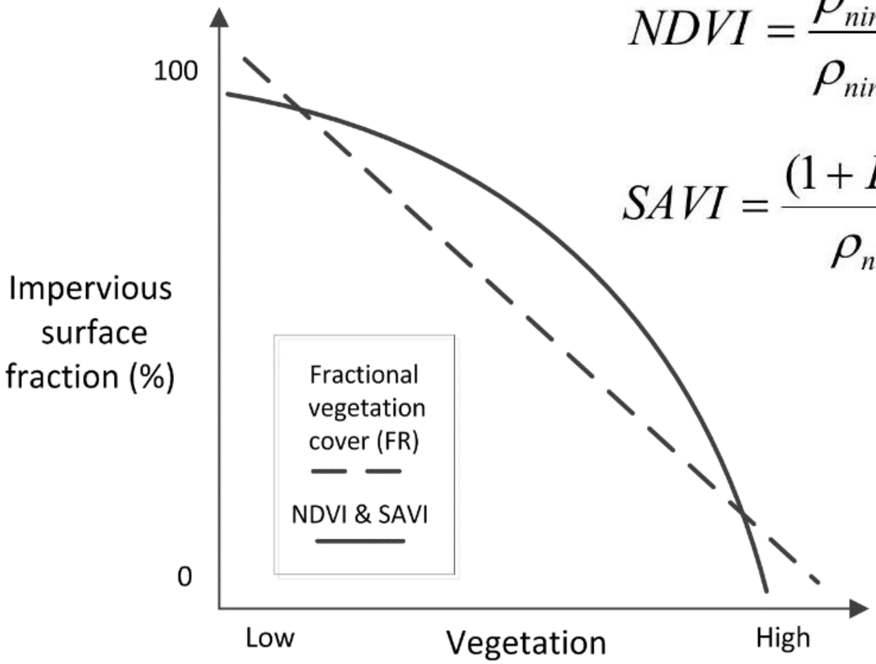


Urban development analysis

Regression modelling

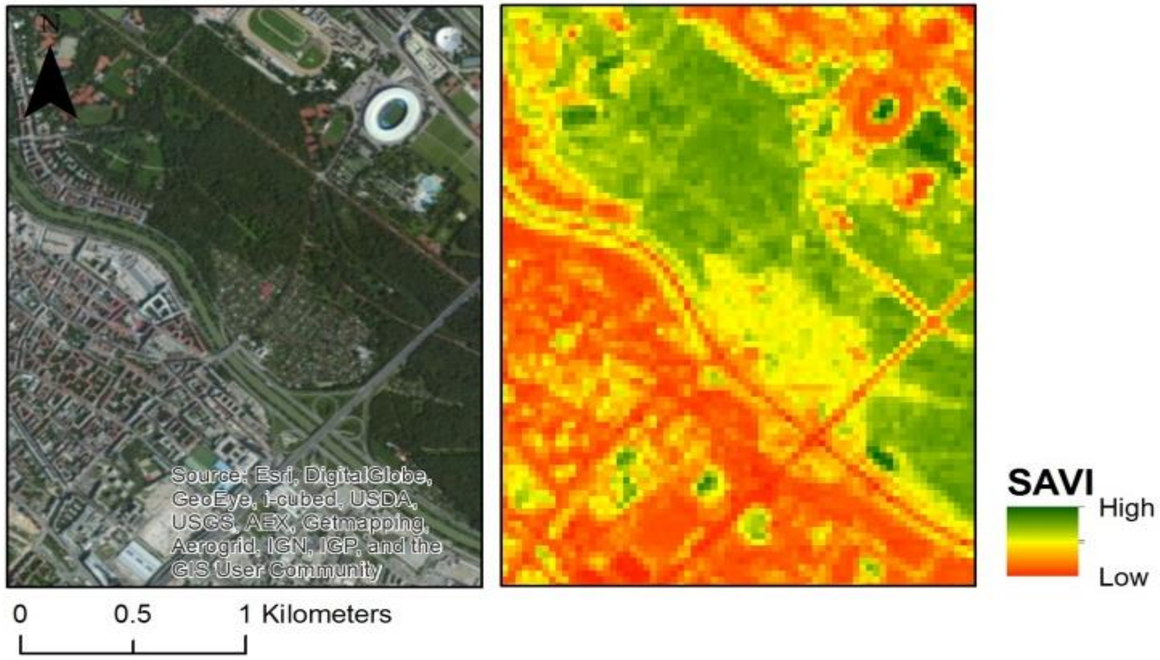
The accuracy of two widely used vegetation indices (NDVI, SAVI) from Landsat in quantifying impervious surface fractions for eight cities at in Europe.

Assumption: Urban areas are comprised of a combination of impervious surfaces and vegetation only



$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

$$SAVI = \frac{(1+L) \times \rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red} + L}$$

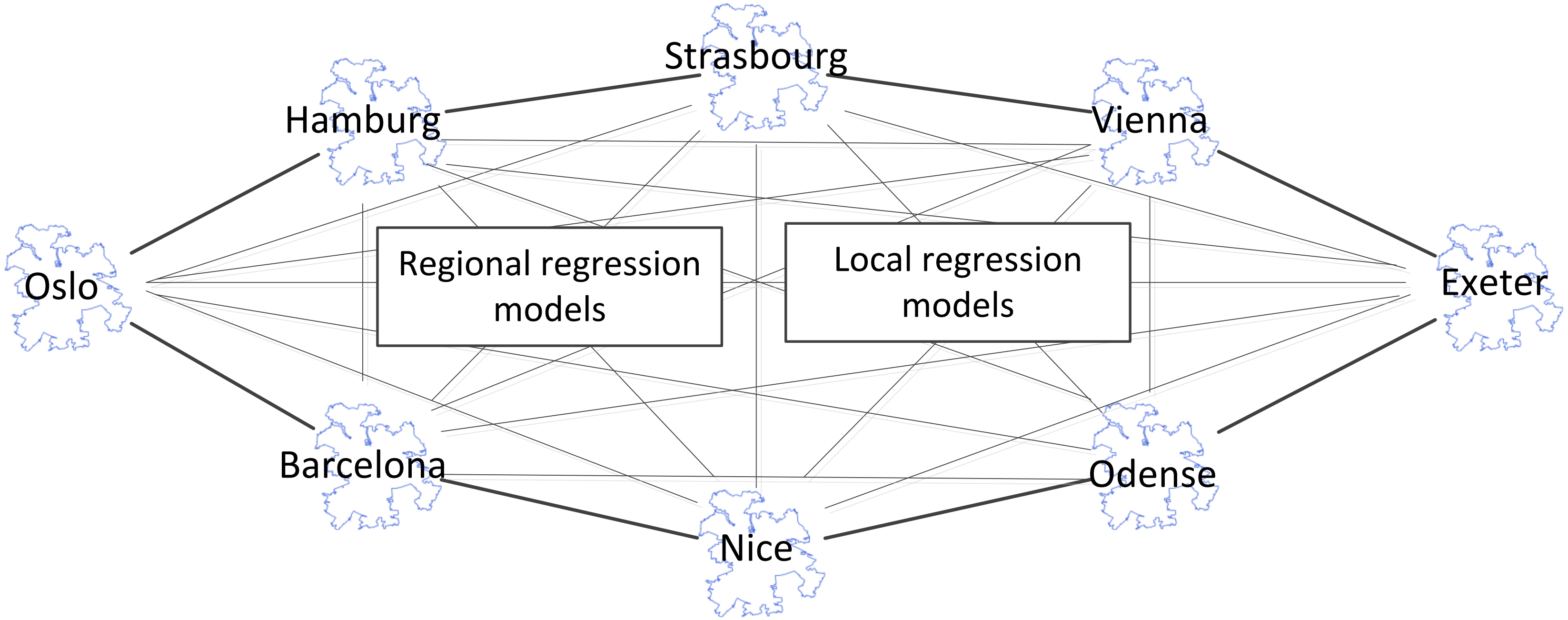


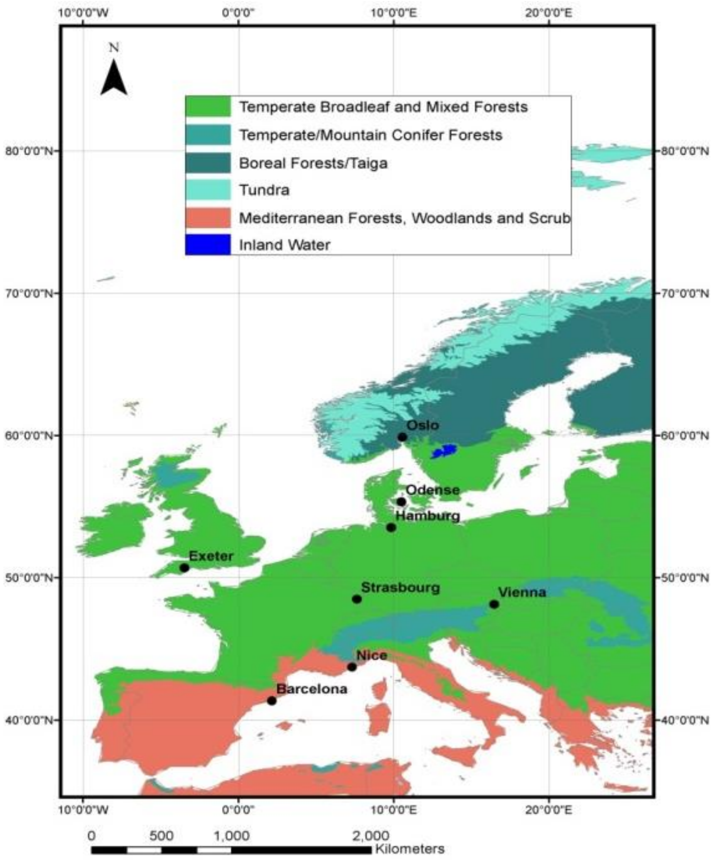
Urban development analysis

Regression modelling – Is it possible to develop one universal model for all urban areas?

-Local/regional regression models

-Spatial transferability



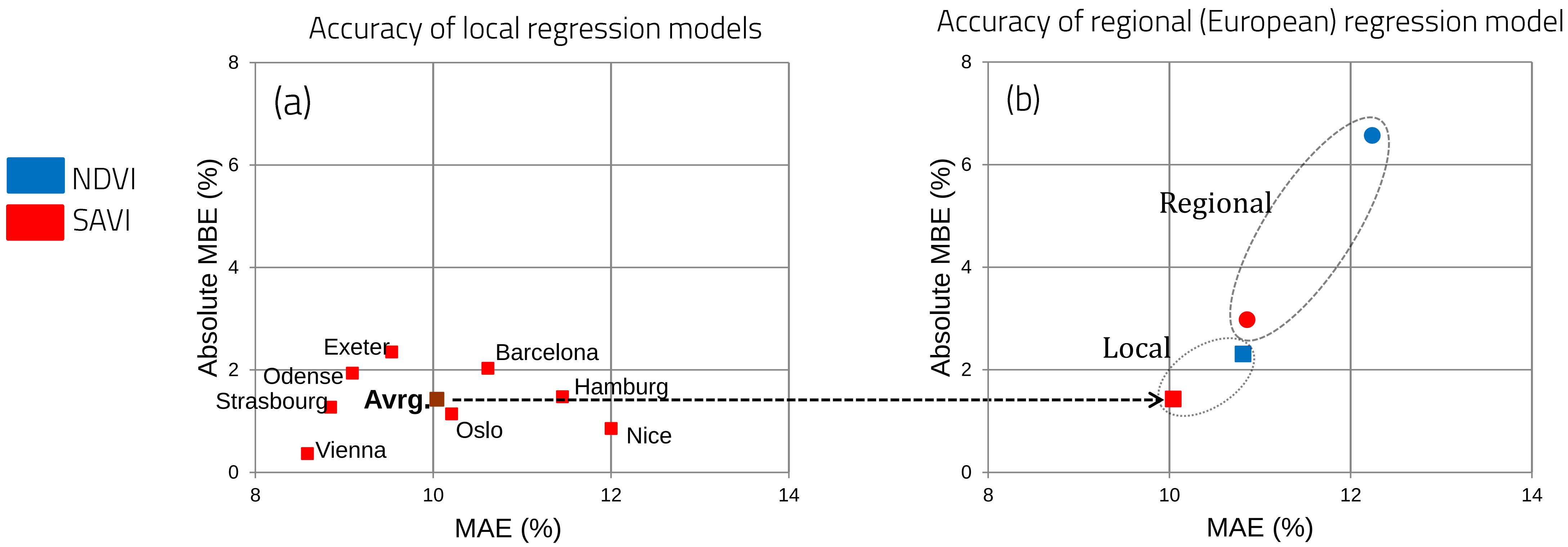


Urban development analysis

Accuracy assessment of Landsat estimates of IS

(a) Low variability in accuracies across geographical locations, suggests that vegetation cover, as measured from Landsat imagery, can be used to provide (fairly) accurate estimates of IS fractions for a major proportion of urban areas in Europe and globally.

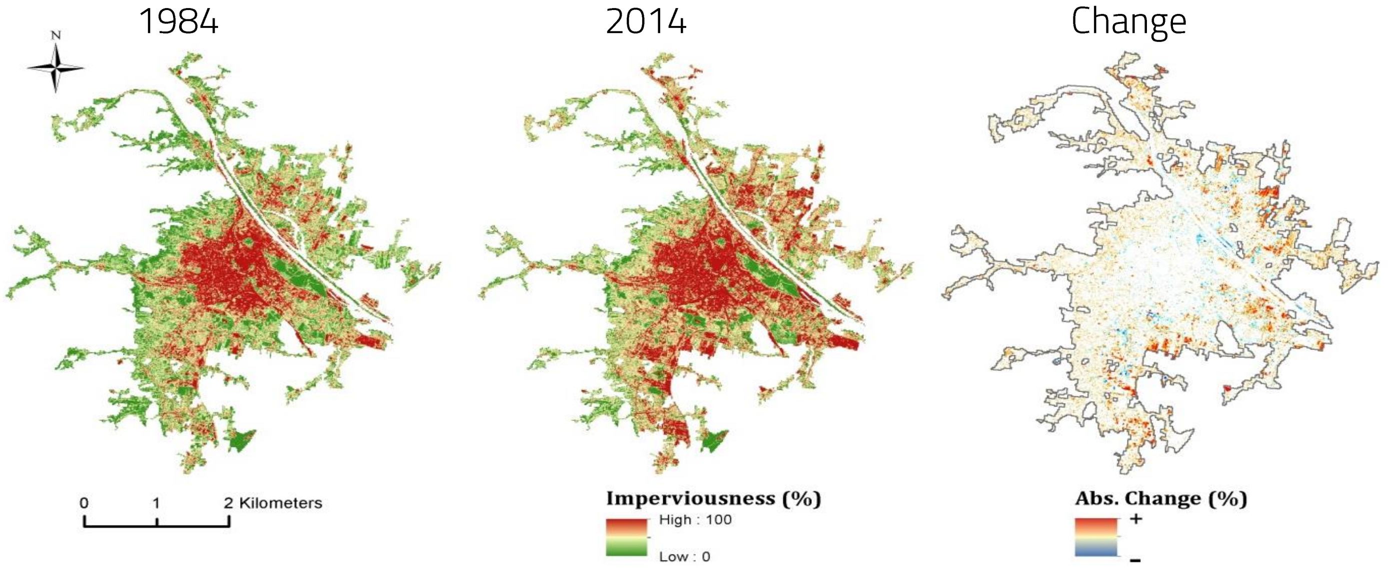
(b) Minor loss in accuracy when applying a regional regression model based on SAVI as compared to local models



Urban development analysis

The full methodology was applied to four out of the eight cities

Urban development analysis for Vienna



Growth and **densification** both occurred during the period 1984-2014

	France	Austria	Denmark	France
	Strasbourg	**Vienna**	**Odense**	**Nice**
1984	41.4 %	42.2 %	29.1 %	38.1 %
2014	53.0 %	53.5 %	36.6 %	44.7 %
Change	11.6 %	11.3 %	7.5 %	6.6 %

Climate change analysis

Climate change impacts on extreme precipitation

Table 2. Change factors for hourly precipitation for the period 2081–2100 (control period: 1986–2005) for RCP 4.5 and RCP 8.5 for Strasbourg, Vienna, Odense and Nice. Results are based on regional climate projections using the RCA4 regional climate model, downscaling 10 different GCMs: CANESM2, CSIRO, CERFACS, ICHEC, IPSL, MIROC, MOHC, MPI, NCC and NOAA (ESGF, 2016).

		France Strasbourg		Austria Vienna		Denmark Odense		France Nice	
Parameter	Return period	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
90th percentile	RP 10	1.22	1.33	1.25	1.37	1.18	1.28	1.30	1.37
	RP 20	1.24	1.38	1.29	1.39	1.20	1.32	1.39	1.42
	RP 50	1.32	[illegible]	1.40	1.43	[illegible]	1.39	1.53	1.51
	RP 100	1.39	[illegible]	1.51	1.46	[illegible]	1.45	1.63	1.59
Average	RP 10	1.13	1.26	1.12	1.25	1.07	1.17	1.18	1.19
	RP 20	1.15	1.28	1.13	1.27	1.08	1.17	1.22	1.21
	RP 50	1.17	1.32	1.15	1.30	1.10	1.18	1.27	1.25
	RP 100	1.20	1.35	1.18	1.33	1.12	1.20	1.32	1.29
10th percentile	RP 10	1.06	1.14	1.01	1.17	1.01	1.09	1.06	1.02
	RP 20	1.04	1.12	1.00	1.14	0.98	1.08	1.03	1.00
	RP 50	1.02	1.09	0.98	1.12	0.97	1.04	1.05	1.00
	RP 100	1.00	1.08	0.96	1.13	0.96	1.00	1.07	1.01

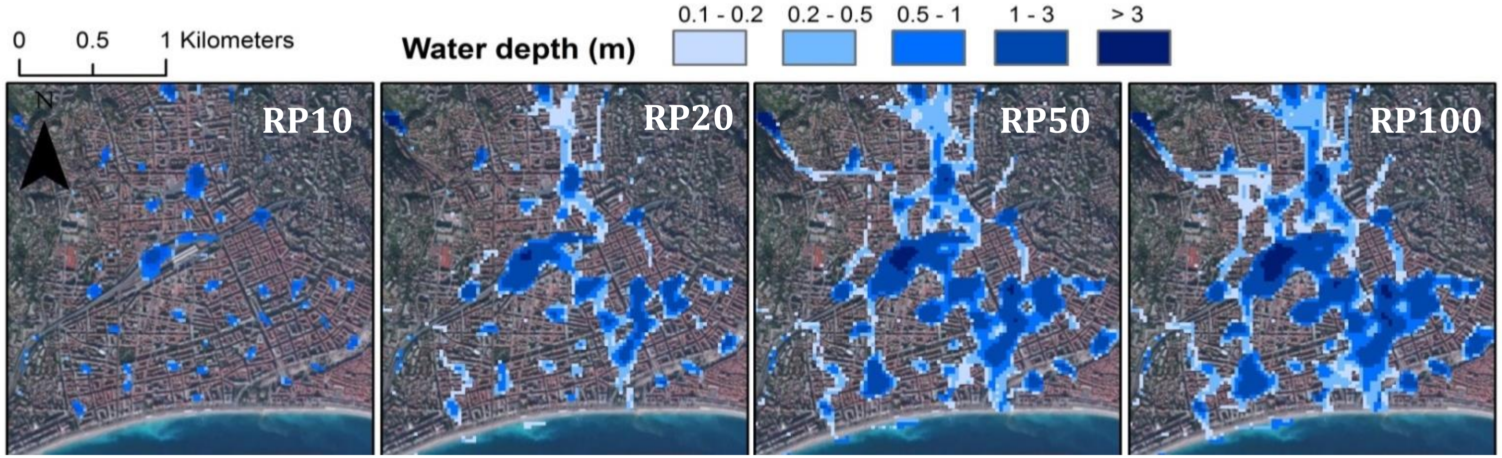
Increase of 12-18 %

Increase of 25-33 %

Flood modelling

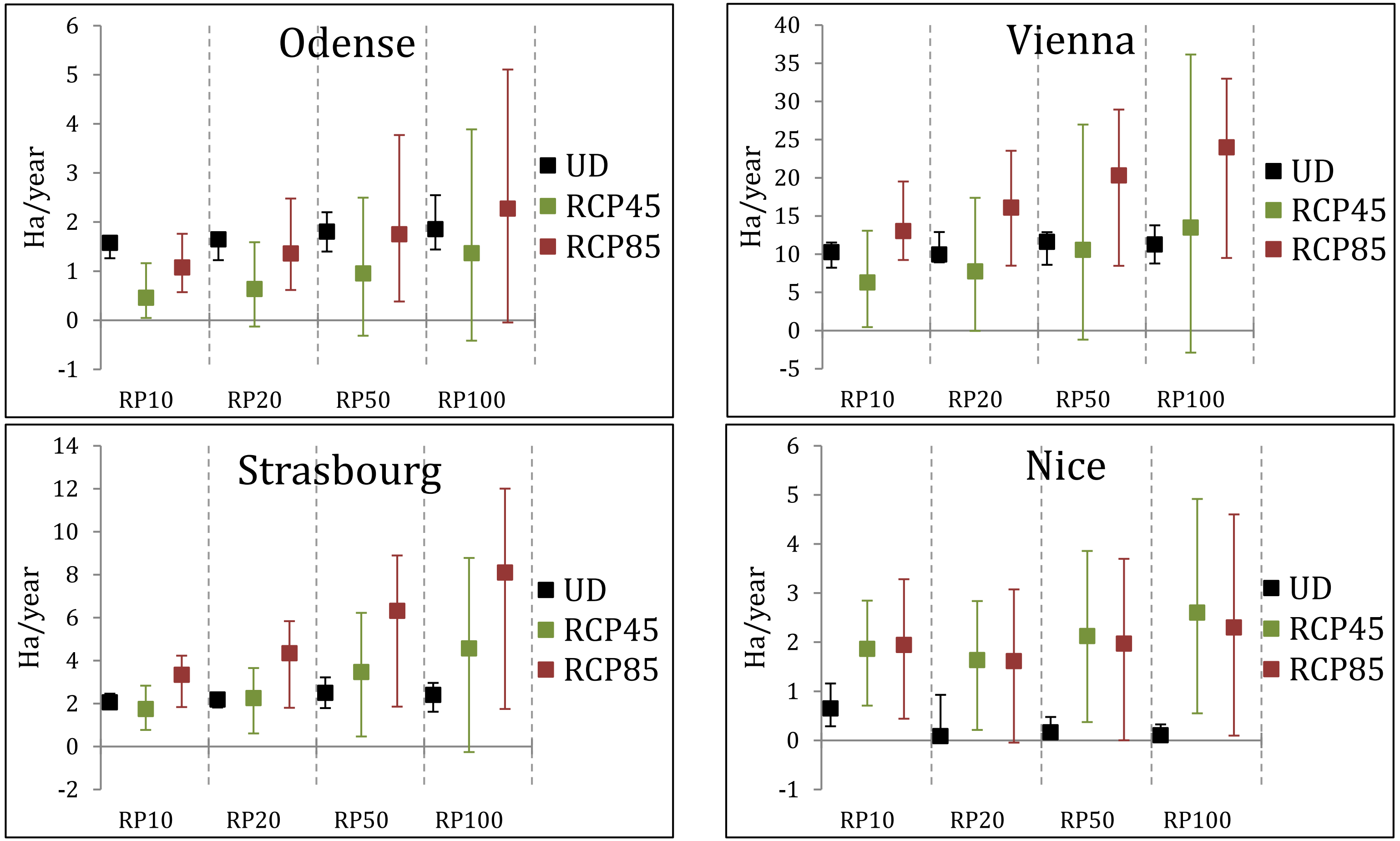
- Overland flow model (MIKE 21 – DHI)
- Precipitation input: Times series of design extreme precipitation with a duration of 6h for RP10, RP20, RP50, RP100 for present-day (1986-2005) and future (2081-2100)
- Digital Elevation Model: EU DEM (DTM -25m resolution)
- Soil infiltration/run-off: Landsat impervious surfaces, Soil texture, slopes (calculated from EU DEM)
- Drainage system assumptions: RP5 removed (for impervious surfaces only) by drainage system

Flood hazard maps for Nice

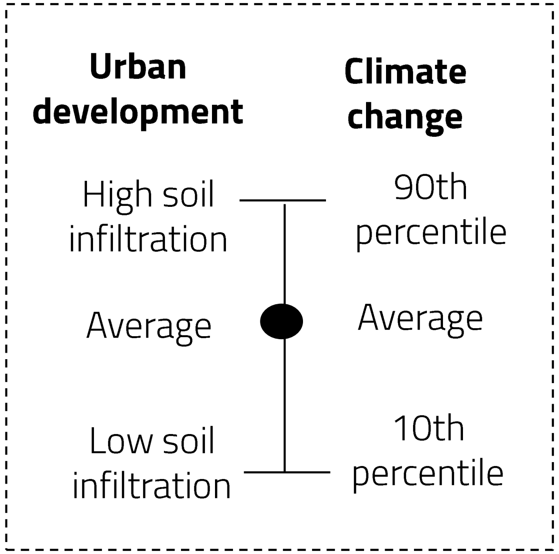


The impacts of urban development and climate change

Averaged annual change in the total flooded area (greater than 10cm water depth) due to the impacts of urban development (UD) and climate change (RCP 4.5 and RCP 8.5) on extreme precipitation for different return periods (RP 10–RP 100).

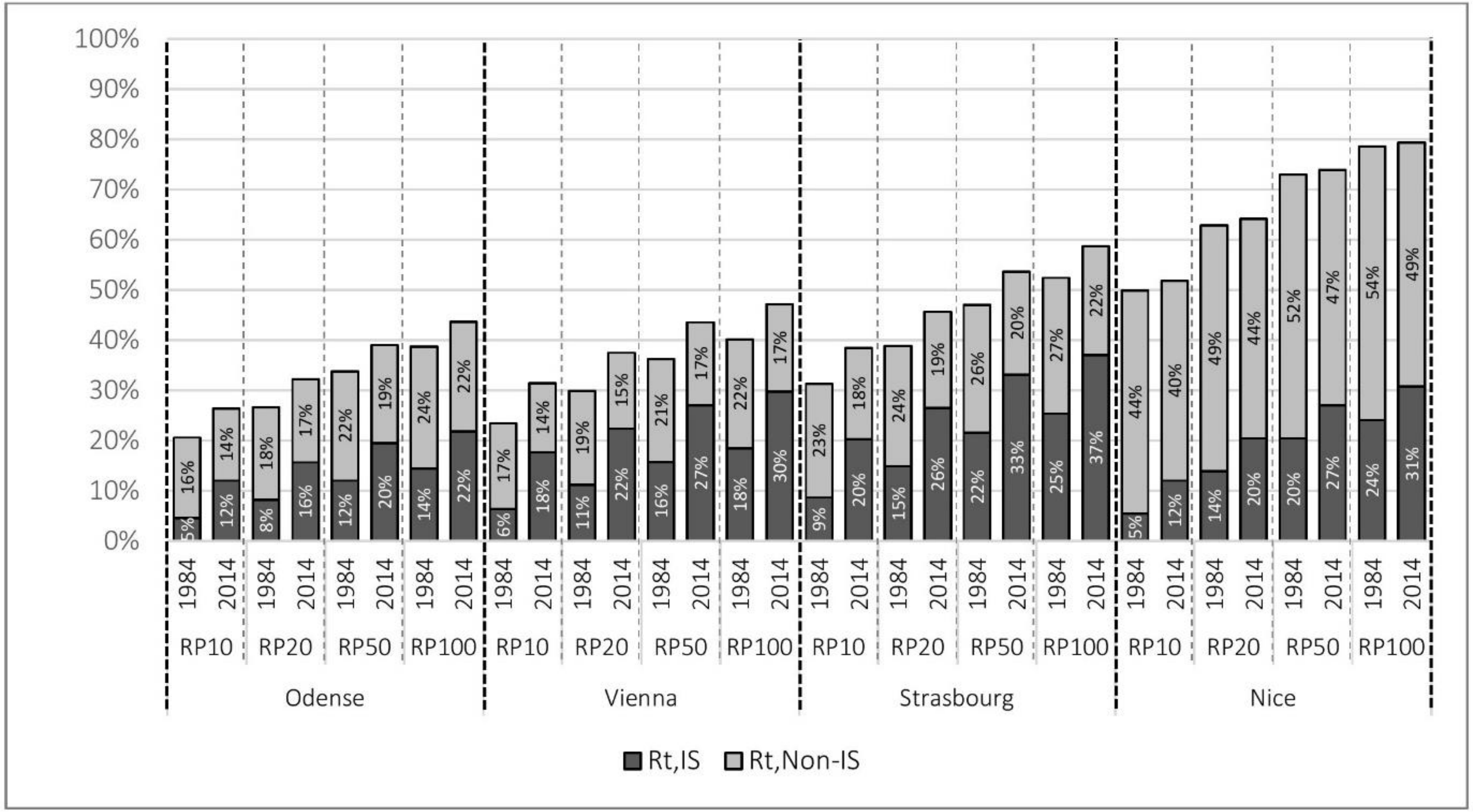


Error bars



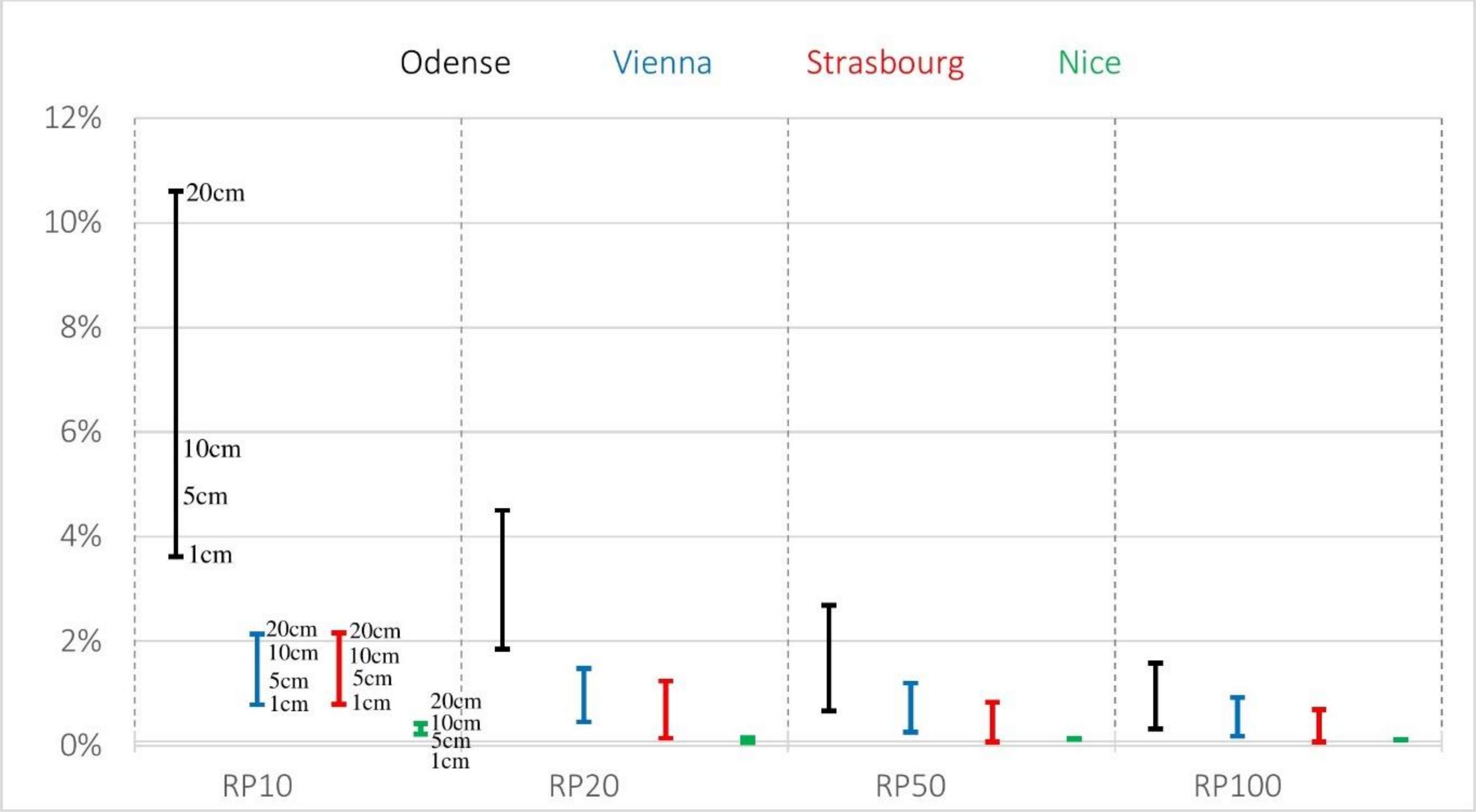
The impacts of urban development

Run-off from impervious (dark grey) and green (light grey) urban areas



The impacts of urban development

Change in flooded area for different water depths per 1 % absolute increase in imperviousness



Conclusions

- Regression models based on Landsat VIs can be applied to accurately estimate impervious surface fractions (and temporal/spatial changes herein) for multiple cities in Europe for use in pluvial flood models.
  - The method is most accurate where areas of bare soil is only marginally present and thus the method should be used with caution for cities in, e.g., developing countries
- The impacts of urban development and climate change are comparable, although with large geographical differences.
- Flooding increases by 0–10% for every increase in absolute imperviousness of 1%.
  - The results show a clear trend towards increased relative impact of soil sealing (urban development) for the least severe events, while only marginally affecting flooding during precipitation with long return periods.
- Climate change is found to increase precipitation intensities for all cities (≈ +0-50%). However, these estimates are surrounded by large (model) uncertainties.
  - There is a trend towards larger increases for RCP 8.5 and for the most extreme events (RP100 as compared to RP10).

Thank you for your attention

For more information

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Article

Using Landsat Vegetation Indices to Estimate Impervious Surface Fractions for European Cities

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Abstract: Impervious surfaces (IS) are a key indicator of environmental quality, and mapping of urban IS is important for a wide range of applications including hydrological modelling, water management, urban and environmental planning and urban climate studies. This paper addresses the accuracy and applicability of vegetation indices (VI), from Landsat imagery, to estimate IS fractions for European cities. The accuracy of three different measures of vegetation cover is examined for eight urban areas at different locations in Europe. The Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI) are converted to IS fractions using a regression modelling approach. Also, NDVI is used to estimate fractional vegetation cover (FR), and consequently IS fractions. All three indices provide fairly accurate estimates (MAEs ≈ 10%, MBE's < 2%) of sub-pixel imperviousness, and are found to be applicable for cities with dissimilar climatic and vegetative conditions. The VI/IS relationship across cities is examined by quantifying the MAEs and MBEs between all combinations of models and urban areas. Also, regional regression models are developed by compiling data from multiple cities to examine the potential for developing and applying a single regression model to estimate IS fractions for numerous urban areas without reducing the accuracy considerably. Our findings indicate that the models can be applied broadly for multiple urban areas, and that the accuracy is reduced

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Comparison of the impacts of urban development and climate change on exposing European cities to pluvial flooding

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Abstract. The economic and human consequences of extreme precipitation and the related flooding of urban areas have increased rapidly over the past decades. Some of the key factors that affect the risks to urban areas include climate change, the densification of assets within cities and the general expansion of urban areas. In this paper, we examine and compare quantitatively the impact of climate change and recent urban development patterns on the exposure of four European cities to pluvial flooding. In particular, we investigate the degree to which pluvial floods of varying severity and in different geographical locations are influenced to the same extent by changes in urban land cover and climate change. We have selected the European cities of Odense, Vienna, Strasbourg and Nice for analyses to represent different climatic conditions, trends in urban development and topographical characteristics. We develop and apply a combined remote-sensing and flood-modelling approach to simulate the extent of pluvial flooding for a range of extreme precipitation events for historical (1984) and present-day (2014) urban land cover and for two climate-change scenarios (i.e. representative concentration pathways, RCP 4.5 and RCP 8.5). Changes in urban land cover are estimated using Landsat satellite imagery for the period 1984–2014. We combine the remote-sensing analyses with regionally downscaled estimates of precipitation extremes of current and expected future climate to enable 2-D overland flow simulations and flood-hazard assessments. The individual and combined impacts of urban development and climate change are quantified by examining the variations in flooding between the different simulations along with the corresponding uncertainties. In addition, two different assumptions are examined with regards to the development of the capacity of the urban drainage system in response to urban development and climate change. In the "stationary" approach, the capacity resembles present-day design, while it is updated in the "evolutionary" approach to correspond to changes in imperviousness and precipitation intensities due to urban development and climate change respectively. For all four cities, we find an increase in flood exposure corresponding to an observed absolute growth in impervious surfaces of 7–12 % during the past 30 years of urban development. Similarly, we find that climate change increases exposure to pluvial flooding under both the RCP 4.5 and RCP 8.5 scenarios. The relative importance of urban development and climate change on flood exposure varies considerably between the cities. For Odense, the impact of urban development is comparable to that of climate change under an RCP 8.5 scenario (2081–2100), while for Vienna and Strasbourg it is comparable to the impacts of an RCP 4.5 scenario. For Nice, climate change dominates urban development as the primary driver of changes in exposure to flooding. The variation between geographical locations is caused by differences in soil infiltration properties, historical trends in urban development and the projected regional impacts of climate change on extreme precipitation. Developing the capacity of the urban drainage system in relation to urban development is found to be an effective adaptation measure as it fully compensates for the increase in runoff caused by additional sealed surfaces. On the other hand, updating the drainage system according to changes in precip-

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