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Integration of Climate Change Effects in Local Models and Urban Planning Processes

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Abstract: Results from global and regional climate scenario modelling predict significant changes in temperature and precipitation during the rest of the century [Kjellström *et al*. 2011]. Episodes of extremely high temperatures and more intense rainfall will occur more often [IPCC 2011]. Climate change will affect the urban environment and should be taken into account in long term and sustainable urban planning for adaptation to the new climate conditions. The spatial and temporal resolution of available climate models, however, is generally too low for the output to be used directly in urban planning and as input to local models. We will address several problems that need to be solved: How can the downscaled climate data be used to assess different environmental risks linked to the urban infrastructure and the health and safety of the population? How can the downscaling be designed so that it suits a larger community, including all municipalities in Europe? How can the necessary functionalities and data be provided in an interoperable and transferable way in order to be applicable for a wide range of issues? How can we technically support the integration of climate change related environmental data into local models? Within the FP7 ICT SUDPLAN project, which integrates environmental modelling and software expertise, a system of standardised services and end user applications have been developed. The system delivers long term projections of environmental data for different aspects of local modelling (air quality, hydrological conditions and intense rainfall) based on different climate scenarios. The services are interactive and require local data to improve the downscaled projections. This downscaling is necessary in order to transform the European scale information to a realistic input signal to local models. All services are provided through standardized service interfaces.

Keywords*:* climate change, urban planning, model integration, scenario management

1. Introduction

In contrast to Climate Change (CC) mitigation, which in essence is the reduction of green house gas (GHG) emissions, CC adaptation requires a more complex definition. IPCC, for example, defines this as “Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.” [IPCC 2007] The number of possible adaptation measures is potentially large, but one prominent instance is the consideration of climate change effects in urban planning. This is recognized by IPCC as one of the key adaptation strategies in an urbanized world because “proper plan-making can increase adaptive capacities in urban systems by including adaptation measures in land-use planning and infrastructure design” [IPCC 2007]. The EU identifies the availability of climate change data as a key element of CC adaptation. “To be able to take decisions on how best to adapt, it is essential to have access to reliable data on the likely impact of climate change” [EC 2009]. So reliable climate data are needed for CC aware urban planning. To infuse CC into the urban planning process one must somehow integrate CC data into the local models that are particularly designed to solve a local problem and which are normally CC unaware.

The technical preconditions for the integration of climate change effects in urban planning processes include 1) access to adequate climate change information, and 2) the tools to link this information to the individual planning problem. Both are addressed by the SUDPLAN project.

1.1 Current Situation

Climate change information adequate for urban planning purposes needs to be at least on an urban scale. For most urban planning processes Global Climate Models (GCM) with spatial resolutions of several hundreds of kilometers, and downscaled Regional Climate Models (RCM) with resolutions of tens of kilometers are much too coarse to be considered for local planning purposes. Urban scale climate data are required where the actual scale may depend on the local problem at hand. Sophisticated downscaling mechanisms can be used to provide the necessary spatial resolution [Olsson et al. 2009]. In SUDPLAN local data are used to enhance downscaling considerably.

The software that supports climate change aware urban planning today is dominated by tools that focus on climate change mitigation. General tools for urban planning to support climate change adaptation are not easily found [Condon et al. 2009]. Urban planning tools for climate change adaptation are often very specific to a particular problem and not easily transferable to another context [e.g. CARE 2009, Kropp et al. 2009].

1.2 Aim and Scope

This paper explains SUDPLAN’s approach to providing two key elements of climate change aware urban planning: 1) Downscaled climate change projections of environmental variables based on an ensemble of climate scenarios, and 2) functionalities necessary to consider and evaluate the effect of CC in local planning processes. The required functionality provides climate data integration support facilities, model control, and scenario management as well as advanced visualization capabilities. Here we focus on the general approach rather than on underlying science and technologies, which are described elsewhere [Gidhagen *et al*. 2011, Denzer *et al*. 2011].

2. SUDPLAN Approach

SUDPLAN provides the means to downscale rainfall, hydrological, and air quality data, taking climate change into consideration. These data can be used as input for local models. Moreover, the integration, visualisation and information management of local planning scenarios are supported. The main objective is to provide the means to integrate the effect of climate change into urban planning processes on all levels from the Master Plan to the individual permit.

To obtain urban scale CC data in SUDPLAN, the end-user provides local data to improve the downscaling of environmental information reflecting a future climate change (Figure 1). This approach makes it possible to deliver projections in the right scale for the local planning process [e.g. Engardt et al. 2011].

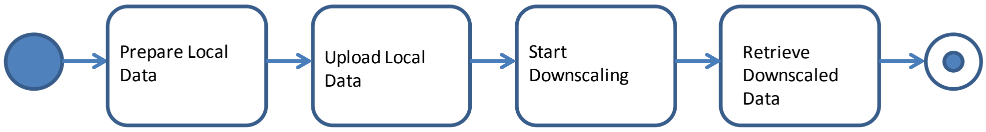

Figure 1. Retrieve Information on Climate Change Effects on the Urban Environment on a Local Scale

The downscaled data can be used just like the regular local data. For example, local models can be fed with downscaled data (Figure 2). This infuses the effect of climate change into the local model. Planners can use their conventional local models to produce local model experiments (local scenarios) where climate change is considered.

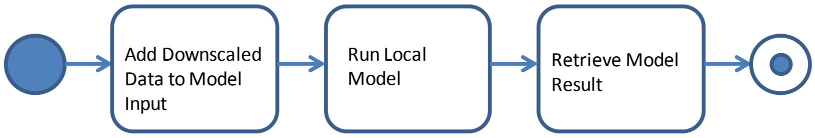

Figure 2. Use Downscaled Data to Run Local Model

Local scenarios can be used for urban planning purposes (just like the conventional model results). Downscaled data based on different climate scenarios can be used as input to local planning scenarios to illustrate the uncertainty of the climate change effect. Intervals of possible climate change effects can be identified and thus sound adaptation strategies can be considered in the plan.

The applicability of this approach to a large variety of purposes is supported by the use of prominent open standard service interfaces. The transfer of time series or gridded data is through OGC Sensor Observation Services (SOS) and the model execution takes place through the OGC Sensor Planning Services (SPS) [Bartha et al. 2012]. The use of these two standard interfaces also allows external users to access CC information in a well-defined manner and to incorporate CC data into an individual application. The services providing CC projections are called Common Services. The software to support the aspects of dealing with CC data and the integration into the local urban planning process is called the Scenario Management System.

2.1 Common Services

Common Services support a common urban downscaling functionality for all European cities, based on how relevant climatic and environmental variables will evolve according to different climate scenarios. The application of Common Services for downscaling of climatic and environmental variables in a city is simple and requires a minimum of local data. The following variables may be downscaled within selected climate scenarios:

- Rainfall intensity, frequency and duration, with consequences for urban storm water flooding and sewer system capacities
- Hydrological conditions in terms of river runoff and soil moisture, with consequences for river flooding, surface water resources and farming conditions
- Air quality and heat waves, with consequences for city population health and quality of life

Figure 3 illustrates the SUDPLAN modelling of climatic and environmental variables, going from the European scale (left) to the urban (middle), and eventually to the finer scale (right). SUDPLAN involves the Common Services modelling as well as the specific modelling required by different pilot cities.

Climate input	CS database	CS models	Local models
Regionally downscaled climate scenarios over Europe	Precalculated European data of - intense rainfall - hydrological data - air quality	Urban downscaling of - intense rainfall - hydrological data - air quality	Pilot defined modelling
SMHI's RCA model (at least in first phase)	CS models over Europe executed by SMHI	CS models over cities executed by end-users	City-specific models executed by end-users
Input from GCMs (global models)	RCA model output used as input	Precalculated CS Europe results used as input	CS downscaling results used as input
External projects	*Common Services (CS)*		*SUDPLAN pilot applications*

Figure 3. Overview of the SUDPLAN modelling of variables

The technical structure of Common Services RF (rainfall), AQ (air quality), HYD (Hydrology) is illustrated in Figure 4. The rainfall and air quality downscaling, together with the corresponding pan-European climate and environmental information have been implemented in existing software, the Airviro system [Airviro 2012]. Input and output data are either pointwise or gridded time series. The hydrological data are based on pointwise time series and irregular polygon data representing watersheds, managed through the existing HYPE model system [Arheimer et al. 2011]. The service layer streamlines communication to all Common Services, so that the external user will only have to follow the OGC standards of four services – SOS (Sensor Observation Service), SPS (Sensor Planning Service), WMS (Web Map Service) and WFS (Web Feature Service) - to establish communication. [SUDPLAN 2012a]

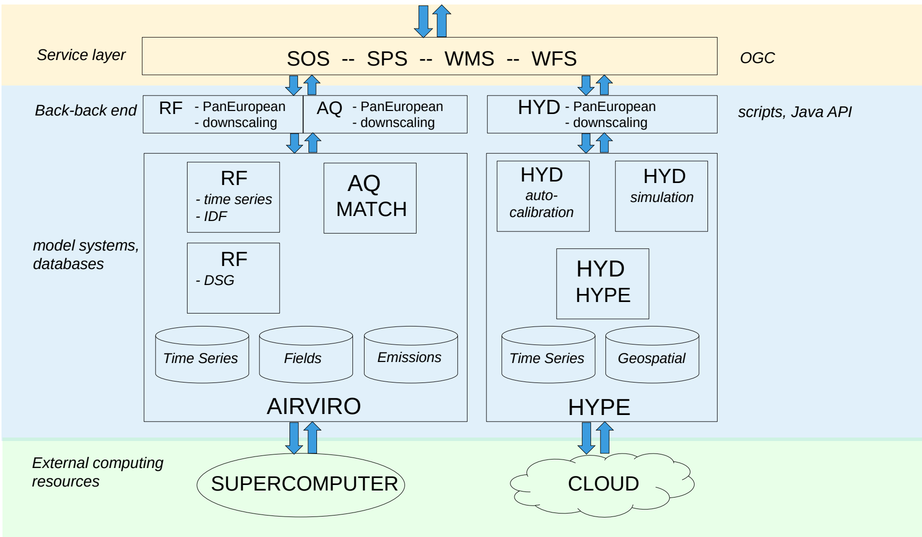

Figure 4. Overview of the Common Services Implementation Architecture

2.2 Climate scenarios

SUDPLAN uses selected climate scenarios according to IPCC directed activities prepared for the fourth and fifth Assessment Reports (AR4 and AR5) through the Coupled Model Intercomparison Project Phase 5 [CMIP5 2012]). Regionally downscaled results of CMIP5 will be available by the end of 2012. SUDPLAN uses regionally downscaled European results from some well regarded global models, and currently includes the following climate scenarios, downscaled by SMHI's RCA3 model [Kjellström et al. 2005; Kjellström et al. 2011; Nikulin et al. 2011]:

- ECHAM5 [Roeckner et al. 2006; version: initialization 3], using A1B emission scenario [Nakićenović et al. 2000]
- HADCM3 [Gordon et al. 2000; version: climate sensitivity Q0], using A1B emission scenario [Nakićenović et al. 2000]

In the final version of the Common Services, available at the end of the project (December 2012), an extended scenario ensemble will be available specifically for rainfall downscaling. It is likely to include, some more ECHAM results with different initialisations and different (A2 and B2) emission scenarios.

The scenarios for air quality may also differ in the emission scenarios for tracers (air pollutants). In the recent version of Common Services the only time-varying emissions for 1960-2100 are given by the RCP4.5 scenario. At least one or two more RCP scenarios will be included [SUDPLAN 2012a].

2.3 Scenario Management System

The Scenario Management System (SMS) is a generic integration platform on which a climate change aware urban planning application can be built for any city in Europe. The goal of providing a universal, flexible and adaptable planning tool is supported by the separation of the SUDPLAN System into several architectural layers, as shown in Figure 5.

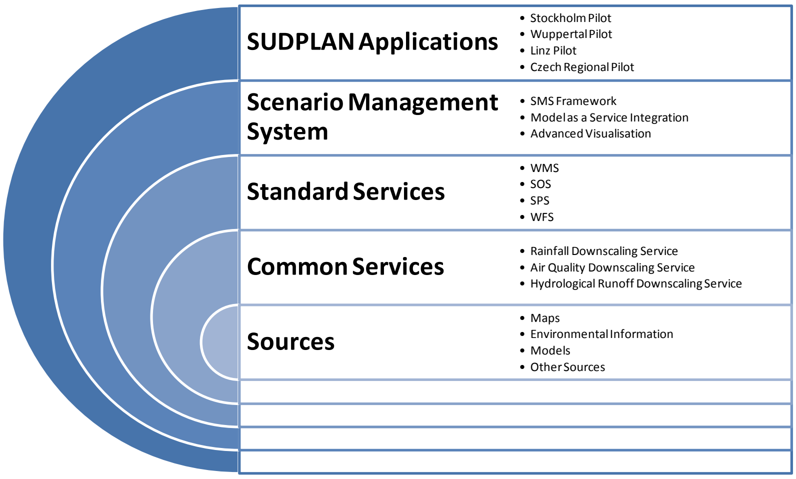

Figure 5. SUDPLAN Layered Architecture.

The top-level layer, the SUDPLAN Application itself, is the result of an extension, customisation and configuration of the underlying SMS. The SMS comes with everything necessary to provide common scenario management tasks including data integration, model management and execution, basic and advanced visualisation, and comparison of various temporal and spatial data sets. It relies upon standard services for data access and model management, and thus greatly facilitates the task of integrating new models and data sources. Consequently, the same mechanisms used for interfacing the SUDPLAN Common Services with the SMS can be used for local model and data source integration [SUDPLAN 2011a].

The core functionalities provided by the SMS include navigation, search, visualisation and manipulation of arbitrary geospatial data. For the SUDPLAN project, extensions for the management of models have been developed. These include asynchronous model execution, result storage, parameterisation and basic model result visualisation (such as 1D time series, and 2D maps). SMS development efforts are based on the open source cids geo-integration platform [Schlobinski *et al*. 2011b].

3. Case Studies

SUDPLAN project results are validated in four pilot applications with significantly different urban planning issues including different CC adaptation measures like the dimensioning of waste water pipes, the inclusion of alternative drainage options (higher road curbs) or waste water storage capacities, demonstrating the transferability of the approach.

3.1 Stockholm, Sweden

Air quality in Stockholm today is not fulfilling the standards given by EU and Swedish legislation. All plans for new or modified infrastructure that will have consequences for air quality must therefore be assessed before a decision can be taken. A typical example is the plan for a new road that will connect the southern and northern parts of the city. Such a project will take 10-20 years to complete and it is important to consider what will impact local air quality besides the local emissions. The road project shows how SUDPLAN air quality downscaling supports urban planning. Two advantages are expected from the use of the SUDPLAN Common Services. It will be possible to assess projections of long-range air pollution transport where both climate change and expected changes in European emissions have been taken into account. By combining this information with results of local models, it will also be possible to assess all temporal and spatial scales that are of interest for a particular plan or project. As an added benefit, Stockholm counts on SUDPLAN's advanced 3D visualisation of air quality modelling results, which will help them to communicate to the politicians and the public where and why air quality problems occur [SUDPLAN 2011b].

3.2 Wuppertal, Germany

With climate change the city of Wuppertal (Germany) anticipates extremely localized runoff events from increased heavy, short-term rainfall. The potential damage of public infrastructure and of private property is a major concern. The needs for future investments are huge, considering that the city has to cope with runoff from many natural and channelised creeks and a sewer system of 1,500 km. In the city of Wuppertal urban development has eclipsed the preservation of natural watercourse patterns, and numerous streams have become part of the sewer system. With a few exceptions, a separate sewer system is used for domestic drainage in Wuppertal. The Wuppertal case study is based upon two guiding ideas: The first is the development of a tool that enables planners to define and run simulations of 1D-2D sewer and surface runoff in the course of heavy storm water events and to visualise the results of these model runs. The second is to consider the effect of climate change on future rainfall patterns by using downscaled rainfall data that are provided as input to the simulations [Sander et al 2011].

3.3 Linz, Austria

The general motivation for the Linz pilot is to estimate the impact of climate change on the pollutant loads spilled from urban drainage systems into the natural environment as a result of the overflow of sewer systems. Since more frequent and heavier rainfall is expected as a result of climate change, significant impacts to the natural ecosystem could result. Therefore, long-term simulations with rainfall runoff transport models are required in the long-term planning process, where rainfall is the major system input. Having appropriate and flexible modelling tools with access to local data and consolidated and reliable climate and rainfall projections is essential in this planning process [Gamerith et al. 2012].

3.4 Prague, Czech Republic

The overall goal of the Prague case study is to use the SUDPLAN services in describing and assessing the state, trends and future development of air pollution and hydrological conditions in Prague in the context of climate change. Availability of advanced SUDPLAN modelling tools will enable the development of air quality projections for different activity scenarios (energy, transport, industry and agriculture sectors) with special focus on particulate matter and ground level ozone. SUDPLAN tools will also be applied in urban and spatial planning as well as in environmental impact assessment of large infrastructural and construction projects.

For example, planners will be able to consider the factors leading inhabitants to migrate, especially the importance of environmental quality on their decisions. They will also be able to assess the expected affect of climate change on agriculture, since crop yield is heavily influenced by changes in average temperature and rainfall [SUDPLAN 2012a].

4. Conclusions

This paper explains the technical basis for the integration of climate change effects in urban planning, including access to adequate climate change information, and describes tools to link this information to the urban planning process. The key to this approach is that the end-user provides local data to improve the downscaling of climatic and environmental variables, based on regional climate model output. It is then possible to deliver projections of environmental conditions affected by climate change in the right scale for the local planning process. Downscaling is performed by a set of Common Services that deliver data describing rainfall intensity, frequency and duration; hydrological conditions; soil moisture and surface water resources; and air quality. The urban scale projections provided may be used to assess urban storm water flooding and sewer system capacities, river flooding, and citizen health. The client side functionalities necessary to integrate, visualise and support local climate change aware analyses are provided by the Scenario Management System. The general approach, the downscaling result quality, and the soundness of the technical developments are validated through four representative case studies in Stockholm, Wuppertal, Linz and Prague.

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