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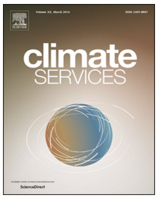

The CORDEX.be initiative as a foundation for climate services in Belgium

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ABSTRACT

The CORDEX.be project created the foundations for Belgian climate services by producing high-resolution Belgian climate information that (a) incorporates the expertise of the different Belgian climate modeling groups and that (b) is consistent with the outcomes of the international CORDEX ("COordinated Regional Climate Downscaling Experiment") project. The key practical tasks for the project were the coordination of activities among different Belgian climate groups, fostering the links to specific international initiatives and the creation of a stakeholder dialogue. Scientifically, the CORDEX.be project contributed to the EURO-CORDEX project, created a small ensemble of High-Resolution (H-Res) future projections over Belgium at convection-permitting resolutions and coupled these to seven Local Impact Models. Several impact studies have been carried out. The project also addressed some aspects of climate change uncertainties. The interactions and feedback from the stakeholder dialogue led to different practical applications at the Belgian national level.

Practical Implications

The signing of the Paris Agreement requires the engagement of nations worldwide to limit the global temperature rise well below 2°C. On different levels, initiatives are undertaken to assess the impact of climate change and to meet the associated societal challenges. These range from the continental level (e.g. European Environmental Agency (EEA, 2017), EU strategy on climate change, Climate-ADAPT) down to the urban level (Covenant of Mayors).[1] In order to achieve the national adaptation goals, the Belgian Adapation Plan 2017–2020 (www.climat.be) specifies as a first step the production of high-resolution climate scenarios for Belgium.

In March 2015 the Belgian project CORDEX.be started, funded by the Belgian Science Policy Office (BELSPO). This initiative aims to gather existing and ongoing Belgian research activities in the domain of climate modeling. In essence, CORDEX.be is a platform

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[1] https://www.covenantofmayors.eu/en/.

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for interaction between the Belgian modeling groups. This platform is used to produce and intercompare the Belgian simulations and to situate them with respect to the international CORDEX ("COordinated Regional Climate Downscaling Experiment") ensembles. This information is provided to the stakeholders to show that the data from any of the Belgian simulations are consistent with the other Belgian CORDEX.be simulations and with the CORDEX ensemble.

Although Belgium currently lacks the foundation for enabling climate services, several reasons exist why climate change is important and climate services must be established. Belgium has an Atlantic climate, is partly low-lying, densely populated, urbanized, and industrialized. Therefore it is strongly susceptible to different types of extreme weather events including urban heat stress, droughts, thunderstorms and different types of floodings (van Ypersele and Marbaix, 2004). A proper assessment of these events under climate change is highly relevant. Moreover climate services are necessary to help inform the general public and to enable decision support based on stakeholders dialogue and impact assessment studies.

In the context of the CORDEX.be project a wide range of climate model simulations has been performed that are collected on the CORDEX.be data hub at RMI and will serve as the basis of future impact studies. The model simulations are thoroughly validated by comparison with past observations and GNSS-derived products. A wide range of climate impact studies for Belgium have been performed, the results of which are extensively reported and communicated in a large stakeholders meeting. Through the organisation of three stakeholder meetings during the project, the stakeholders needs became apparent. A strong need for information on the impact of climate change on extreme precipitation, hail and on heat waves was expressed. More specifically, the Belgian Federal Service for Health was interested in the frequency of future heat-related health alerts.[2] This led to a common definition within CORDEX.be of one Urban Heat Index (UHI) that relates to health-related impact (see Section 3.3). The strong interest on precipitation extremes, on the other hand, put an emphasis on the development of Intensity–Duration–Frequency (IDF) relations (see Section 3.2). Finally, discussions with the insurance sector prioritized our climate simulations targeted for studying the impact of climate change on hail.

It is important to compare and position the CORDEX.be climate-change results to the ones that are found in international initiatives (CMIP5 and CORDEX), in order to provide an estimation of the uncertainties. To this aim, for instance, an overview table (see Table 1) is produced that includes the climate change numbers from different climate projections for Belgium. This table includes uncertainty information through a quantification of both "low" and "high" scenarios, leaving the stakeholder to choose its decision-relevant climate information. This brings together all relevant information and reduces the fragmentation of the climate information at the Belgian level. In this way, end users can use the CORDEX.be ensemble to address questions related to climate change in Belgium and they are provided with quality-controlled information, which is consistent with other Belgian and European climate information. An overview of the project results is given in Termonia et al. (2018b) while the most important results were highlighted in a climate-impact leaflet for stakeholders and the general public.

CORDEX.be focused on establishing solid foundations for Climate Services in Belgium by involving a large network of scientific experts and this led to a strong interest from stakeholders and the invitation to present the project on important occasions (e.g. recent Belgian Climate Adaptation Conference, Brussels). Based on interactions and feedback with stakeholders, different applications are already planned and ongoing that demonstrate the use of the climate data.

For instance, the interactions with the Belgian Federal Service for Health, climate unit Service public Wallonie and the Belgian Biodiversity Platform led to a CORDEX.be contribution to a recently started national project called Tracking Invasive Alien Species (TrIAS) (Vanderhoeven et al., 2017). This project aims to inform policy makers using a data-driven workflow, enabled by tracking the progression of alien species, identify the emerging problem species and assess their current and future risks. Using climate-driven niche modeling, the probability of establishment and/or physiological response of specific invasive plant or animal species will be estimated under climate change. This analysis will result in the production of high-resolution risk maps for the current and projected future climate periods. In a last step, these maps will be used for expert risk evaluation of alien species in Belgium using a recently developed online protocol to assess risks to biodiversity and human, plant, and animal health. CORDEX.be contributes by providing data and expertise of i) H-Res simulations and ii) their uncertainty estimations. It is known that H-Res climate data are necessary for robust and reliable modeling of climatic suitability for invading species, as alien species may respond more strongly to climatic extremes than to averages (Easterling et al., 2000).

Due to the close contacts with Belgian federal agencies the results of the CORDEX.be initiative are being integrated in governmental reports to international organizations. This includes the National Communications for the United Nations Framework Convention on Climate Change (UNFCCC),[3] the National Environmental Health Action Plans (NEHAPs)[4] managed by the World Health Organization, and the Sendai Framework for Disaster Risk Reduction, organized by United Nations Office for Disaster Risk Reduction (UNISDR).[5]

From the final stakeholders meeting, it was shown that a significant amount of expertise, as present within the CORDEX.be consortium was necessary for information extraction, interpretation and uncertainty estimation as the CORDEX.be climate simulations are not directly usable. Additionally, based on the CORDEX.be foundations for climate services, additional efforts are required and planned to translate the climate model data into societally-relevant climate information products and to make them accessible to different end users. Due to the interdisciplinary character of this task the competence and expertise of different research groups must be extended with close contacts with different stakeholders. In other words, a significant enhancement of two-way interactions and cooperation amongst climate modeling groups and end-users of climate information is required. This will result in prototypes and best practices that will improve the availability of climate projections. It will also provide tailored products for decision support, adaptation planning and mitigation policies.

Stakeholders interested in data from the CORDEX.be can place a comment on the CORDEX.be website www.euro-cordex.be. The CORDEX.be concept, methodology and data will in the future be used through the same website for the coordination between the Belgian climate-modeling groups and also as a contact point for the Belgian activities related to the international CORDEX project. This work could provide a reference framework for other collaborative climate initiatives aiming at the development of climate services.

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[2] www.irceline.be/en/documentation/faq/what-is-the-ozone-and-heat-plan-in-belgium-and-what-are-the-different-phases.

[3] unfccc.int/national_reports/annex_i_natcom/submitted_natcom/items/10138.php.

[4] www.who.int/heli/impacts/nehaps.

[5] www.unisdr.org/we/inform/publications/43291.

Table 1

Projected changes for precipitation and temperature based on different climate (low, mean and high) and emission/concentration (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) scenarios for Belgium over 100 years (numbers in parenthesis show changes for hourly extreme precipitation and temperature derived from Belgian LAMs under RCP8.5).

Variable	Season	Index name	Description	Climate change signal[8]															
				CMIP5							EURO-CORDEX (0.44°)		EURO-CORDEX (0.11°)		MAR	ALARO			CCLM
				Low	Mean	High	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP8.5
Temperature	Winter[1]	T_m	Mean monthly temperature	+1 °C	+2.6 °C	+5.2 °C	+1.7 °C	+2.4 °C	+2.4 °C	+3.8 °C	–	–	–	–	+2.7 °C	+0.7 °C	+2 °C	+3.6 °C	+2.7 °C
		T15	Daily temperature extremes with T = 15 y	+0.4 °C	+2.2 °C	+5.8 °C	+1.4 °C	+1.7 °C	+2.1 °C	+3.2 °C	–	–	–	–	+0.9 °C (+1.8 °C)	+1.5 °C	+1.6 °C	+2.7 °C	+2.4 °C (+2.1 °C)
		T10	Daily temperature extremes with T = 10 y	+0.4 °C	+2.1 °C	+5.5 °C	+1.4 °C	+1.7 °C	+1.9 °C	+3.2 °C	–	–	–	–	+1.9 °C (+1.4 °C)	+0.8 °C	+1.6 °C	+2 °C	+2.6 °C (+2.1 °C)
		T5	Daily temperature extremes with T = 5 y	+0.4 °C	+1.9 °C	+5.4 °C	+1.3 °C	+1.6 °C	+1.8 °C	+3 °C	–	–	–	–	+2.6 °C (+1.4 °C)	+0.5 °C	+1.1 °C	+2 °C	+2.7 °C (+2 °C)
		T1	Daily temperature extremes with T = 1 y	+0.4 °C	+1.9 °C	+4.2 °C	+1.3 °C	+1.6 °C	+1.8 °C	+2.8 °C	–	–	–	–	+2.8 °C (+1.7 °C)	+1.1 °C	+1.9 °C	+3.2 °C	+2.5 °C (+2.1 °C)
		T_{FD}	Number of frost days[3] per year	−3	−12	−36	−12	−12	−13	−16	–	–	–	–	–	–	–	–	–
	Summer[2]	T_m	Mean monthly temperature	+1 °C	+3.7 °C	+7.9 °C	+2.6 °C	+3.3 °C	+3.4 °C	+5.6 °C	–	–	–	–	+4.4 °C	+0.6 °C	+1.6 °C	+2.7 °C	+3.6 °C
		T15	Daily temperature extremes with T = 15 y	+1.2 °C	+4.4 °C	+9.1 °C	+3.2 °C	+3.6 °C	+3.8 °C	+6.4 °C	–	–	–	–	+5.5 °C (+5.5 °C)	+0.4 °C	+3.1 °C	+4.6 °C	+6.3 °C (+7.3 °C)
		T10	Daily temperature extremes with T = 10 y	+1 °C	+4.4 °C	+9.1 °C	+3.1 °C	+3.5 °C	+3.8 °C	+6.3 °C	–	–	–	–	+5.3 °C (+5.5 °C)	+0.8 °C	+3.3 °C	+4.1 °C	+4.6 °C (+7.3 °C)
		T5	Daily temperature extremes with T = 5 y	+0.9 °C	+4.3 °C	+9 °C	+2.7 °C	+3.5 °C	+3.7 °C	+6.3 °C	–	–	–	–	+5.8 °C (+5.4 °C)	+0.6 °C	+3.4 °C	+3.4 °C	+4.5 °C (+6.9 °C)
		T1	Daily temperature extremes with T = 1 y	+0.8 °C	+3.9 °C	+8.2 °C	+2.6 °C	+3.2 °C	+3.7 °C	+6 °C	–	–	–	–	+5.3 °C (+5.7 °C)	+0.8 °C	+3.2 °C	+2.7 °C	+4.2 °C (+6.3 °C)
		T_{HW}	Total number of heat waves[4]	0	+42	+74	+28	+33	+48	+51	–	–	–	–	–	–	–	–	–
		T_{SD}	Number of summer days[5] per year	+2	+33	+77	+22	+24	+45	+58	–	–	–	–	–	–	–	–	–
		T_{TD}	Number of tropical days[6] per year	0	+14	+39	+7	+12	+19	+34	–	–	–	–	–	–	–	–	–

(*continued on next page*)

Table 1 (*continued*)

Variable	Season	Index name	Description	Climate change signal[8]															
				CMIP5							EURO-CORDEX (0.44°)		EURO-CORDEX (0.11°)		MAR	ALARO			CCLM
				Low	Mean	High	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP8.5
Precipitation	Winter	P_m	Mean monthly precipitation	-1%	+12%	+41%	+9%	+11%	+13%	+22%	+11%	+22%	+12%	+25%	+14%	+2%	+13%	+20%	+22%
		R15	Daily precipitation extremes with T = 15 y	−18%	+11%	+52%	+6%	+10%	+12%	+19%	+8%	+20%	+25%	+49%	−26% (+19%)	+29%	+39%	+74% (+79%)	−5% (+14%)
		R10	Daily precipitation extremes with T = 10 y	−13%	+10%	+48%	+6%	+10%	+11%	+19%	+8%	+19%	+20%	+45%	+22% (+23%)	+30%	+31%	+66% (+70%)	−5% (+27%)
		R5	Daily precipitation extremes with T = 5 y	−11%	+10%	+40%	+5%	+9%	+10%	+18%	+8%	+19%	+18%	+43%	+42% (+30%)	+1%	+28%	+62% (+69%)	−3% (+38%)
		R1	Daily precipitation extremes with T = 1 y	−3%	+10%	+36%	+5%	+8%	+10%	+18%	+7%	+18%	+12%	+32%	+41% (+41%)	+10%	+19%	+24% (+24%)	+14% (+32%)
		R_{WD}	Total number of wet days[7]	−5%	3%	14%	+3%	+3%	+4%	+4%	+1%	+3%	+2%	+1%	−0.1%	+0.4%	+6%	0.03%	+5%
	Summer	P_m	Mean monthly precipitation	−59%	−16%	+37%	−6%	−12%	−28%	−30%	−9%	−13%	−10%	−11%	−3%	+6%	+1%	+5%	−19%
		R15	Daily precipitation extremes with T = 15 y	−27%	+13%	+63%	+13%	+23%	+26%	+7%	+2%	+6%	+17%	+17%	+31% (−18%)	+37%	+32%	+47% (+49%)	+34% (+16%)
		R10	Daily precipitation extremes with T = 10 y	−27%	+11%	+57%	+11%	+14%	+22%	+6%	+2%	+5%	+11%	+14%	+41% (−15%)	+28%	+23%	+40% (+41%)	+33% (+23%)
		R5	Daily precipitation extremes with T = 5 y	−20%	+8%	+43%	+10%	+9%	+9%	+6%	+2%	+5%	+9%	+13%	+55% (−7%)	+22%	+14%	+31% (+32%)	+24% (+20%)
		R1	Daily precipitation extremes with T = 1 y	−17%	+4%	+25%	+6%	+4%	+6%	+2%	+2%	+4%	+7%	+6%	+11% (+4%)	+1%	+9%	+3% (+8%)	+17% (+10%)
		R_{WD}	Total number of wet days	−49%	−18%	8%	−5%	−14%	−28%	−29%	−11%	−17%	−7%	−16%	−8%	−2%	−10%	−8%	−32%

[1] Winter: December-January-February.

[2] Summer: June-July-August.

[3] Frost days are defined as days with minimum daily temperature lower than 0 °C.

[4] Heat wave is defined as a period of minimum five consecutive days with a maximum temperature of at least 25°C, where the maximum temperature is greater than or equal to 30 °C for at least three days.

[5] Summer days are defined as days on which the maximum temperature is 25°C or more.

[6] Tropical days are defined as days on which the maximum temperature is 30 °C or more.

[7] Wet days are defined as days when the precipitation amount is > 0.1 mm.

[8] Climate change signal for precipitation is defined as a ratio between the values for the scenario period over those for the control period. For temperature signals, the absolute difference is used.

1. Introduction

1.1. Climate services: national and international context

According to the Global Framework for Climate Services (GFCS): "*Climate services provide climate information in a way that assists decision making by individuals and organizations.*" The GFCS prescribes four pillars required to build climate services (Hewitt et al., 2012): i) observations and monitoring, ii) research modeling and projection, iii) climate services information system and, iv) a user interface platform. At international level these aspects are, for instance, covered by the Climate Change Copernicus Services (C3S),[6] i.e. the European Union's earth observation programme. In March 2015 a Belgian project CORDEX.be was started that focuses on GFCS pillar (ii) by data-driven capacity development and community building in Belgium based on interactions with users. The overall and long-term target is to provide standardized information to the stakeholder community concerning climate-change information for Belgium. In a first effort, the impact of climate change on urban environment, storm surges and waves, impact on crop production and changes in emissions from vegetation, has been investigated and communicated. Another important aspect of the GFCS framework is the distinction between the global, regional and national levels of climate services and the emphasis on the interactions among the different levels. The national CORDEX.be effort contributes to the regional climate initiatives through the production of climate simulations with high resolutions of less than 5 km over Belgium. These resolutions will be referred to as H-Res henceforth.

1.2. From global to local through downscaling

Climate change is a global phenomenon and of strong international interest so the CORDEX.be national initiative is bi-directionally linked to existing international frameworks, such as CMIP and CORDEX. The Intergovernmental Panel on Climate Change (IPCC) in their Fifth Assessment Report (AR5, Sneyers et al., 2014) describes the so-called Representative Concentration Pathways (RCPs) for atmospheric greenhouse gases, based on which a set of Global Climate Models (GCMs) are run and collected in the 5th Coupled Model Intercomparison Project (CMIP5, Taylor et al., 2012).

CORDEX, on the other hand, is an international project for modeling and understanding *regional* climate phenomena (Giorgi et al., 2009), to evaluate and improve Regional Climate Models (RCMs), to coordinate the production of regional climate projections and to foster knowledge exchange with users of climate information. Akin to CMIP5, CORDEX provides ensembles of regional climate simulations with varying GCM model forcings, varying greenhouse gas (GHG) concentration scenarios, natural climate variability and different downscaling methods. These allow scientists to sample the uncertainties in Regional Climate Change (Giorgi et al., 2009; Jacob et al., 2014a). All of this is done using a commonly defined protocol[7] for regional domains and with predefined resolutions to produce a prescribed set of meteorological variables. Importantly also is that the CORDEX downscaling activities are based on the latest set of GCM climate runs from CMIP5. The coordination focuses on different regions worldwide, including Europe in the specific EURO-CORDEX part of the project. The CORDEX.be project follows the guidelines of the EURO-CORDEX project for the configurations of the geographical domains. Analogous to CMIP5 and CORDEX, and based on the existing Belgian expertise, CORDEX.be provides a prototype framework to go beyond CORDEX to close the gap between regional climate runs and "local"-impact assessment for climate services.

Performing H-Res simulations is crucial for impact studies. Whereas GCM runs are essential, for instance to estimate the future time point of 2°C global warming, the direct impact on society for representing the shifts in global-scale circulation and temperatures may not be clear. Climate change is felt in extreme weather events (e.g. extreme storms, floodings, heat waves, droughts, urban–heat island effect) which depend on small-scale processes. However, such processes can only be captured by models of high spatial resolution, quantified by the spacing between points on a model grid. The resolution of GCM models are typically 100–200 km while the highest CORDEX-prescribed RCM resolutions are 12.5 km. RCM runs are performed on a limited geographical domain using a top-down approach i.e. by imposing meteorological conditions at the boundaries from model simulations at lower resolution. Therefore H-Res runs critically depend on the availability of RCM runs which in turn depend on GCM runs. Moreover, all must be consistent among one another, for instance in terms of greenhouse gas concentrations. Therefore local climate impact assessment relies on the presence of a model hierarchy and a coordinated framework. The stepwise process towards high resolutions is called downscaling and, for the CORDEX.be project, is illustrated in Fig. 1.

Simulations with grid spacing below 5 km are generally considered necessary to resolve (in least in part) convective phenomena and are currently being set up over different areas in Europe, in particular in the EURO-CORDEX/Med-CORDEX Flagship Pilot Study (FPS) "Convection". Within the CORDEX.be project the H-Res models have been run at resolutions between 5 and 2.8 km while the Local Impact Models (LIMs) may have resolutions below 1 km. Proving the added value of using computationally-expensive H-Res simulations constitutes an essential aspect of the FPS "Convection" and the CORDEX.be project.

1.3. Motivation for the downscaling approach for Belgium

There are several reasons why downscaling is expected to provide added value for Belgium. Regional land–water contrast and orography are known to alter the large-scale climate-change signal due to the complex interaction between large-scale storm systems and local terrain (Vanden Broucke et al., 2017). For example, climate projections, with a mesoscale model at 15 km resolution point towards a change in intensity and distribution of precipitation over mountains due to altering direction of airflow during storms (Salathé et al., 2008). Coastal precipitation responds differently to changing ocean temperatures than more inland precipitation (Lenderink et al., 2009). These results indicate that H-Res modeling yields additional information relevant for climate change scenarios in coastal and orographic areas. The orography of Belgium (from sea level to about 700 m) is shown to have a clear effect on precipitation averages (Journée et al., 2015) and associated extremes (Brisson et al., 2011; Sneyers et al., 1989; Van Meijgaard, 1995; Van de Vyver, 2012; Wyard et al., 2017; Zamani et al., 2016). In Belgium, large-scale atmospheric circulation is affecting the climate, with a strong influence of the North Atlantic Oscillation, and conventional atmospheric circulation type classification explains 60% of the monthly winter precipitation variability (Brisson et al., 2011). Apart from orographic features, it is important to model land-use features since Belgium is one of the most densely urbanized areas in Europe and sensitive to urban heat island effect (Wouters et al., 2016; Hamdi et al., 2015; Lauwaet et al., 2015).

2. Methods

2.1. CORDEX.be targets & methods

The initiative "CORDEX and beyond" creates a framework for providing a coherent set of information available for the Belgian climate stakeholders. The information should be consistent with all of the available expertise within the Belgian climate-modeling community and coherent with the EURO-CORDEX project. This was done by realizing the following four targets (see also Fig. 1).

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[6] climate.copernicus.eu.

[7] cordex.org/experiment-guidelines/experiment-protocol-rcms.

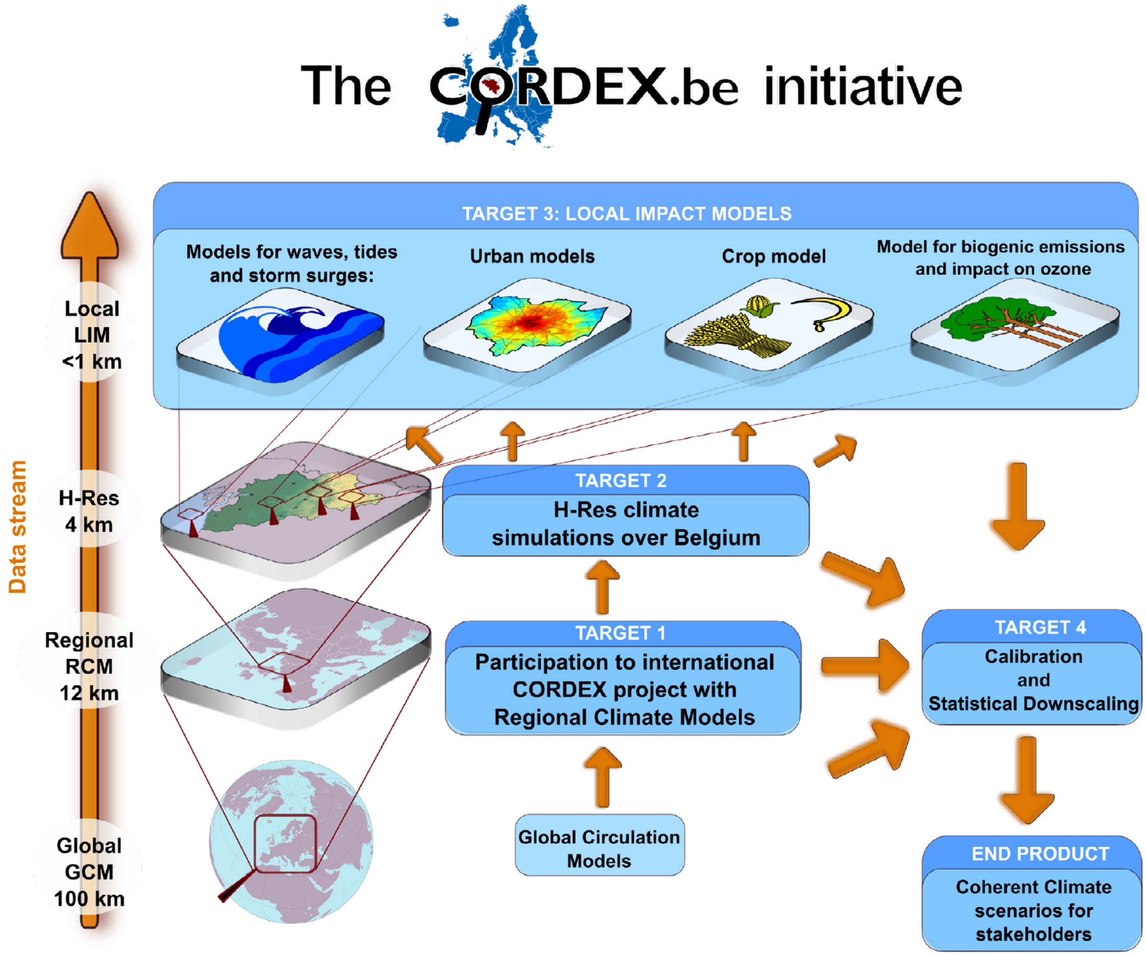

Fig. 1. The CORDEX.be framework is naturally structured by the concept of dynamical downscaling. Low-resolution model runs over large domains are nested successively to H-Res runs over small domains. This approach determines the data stream, the timing and the network structure of the Belgian research activities.

- **Target 1:** To contribute to the EURO-CORDEX project with three regional climate models for which the main technical features are outlined in Table 2.
- **Target 2:** Perform H-Res climate simulations at convection-permitting resolutions over Belgium using the same models, supplemented by their validation.
- **Target 3:** Output of Targets 1 and 2 is used to drive the following LIMs: three urban-climate models, a crop model, a model for tides and storms, a wave-height model and a model for biogenic emissions (see Table 3 for more details). Their output is used for impact studies over Belgium.
- **Target 4:** Uncertainties of the different H-Res results are inferred.

In order to attain these targets, methodologically “CORDEX and beyond” is based on two cornerstones: downscaling and the multi-model approach. Due to the dependence structure imposed by the downscaling procedure (see Fig. 1), this aspect naturally determines the data stream, the timing of the project and the structure and interactions within the network. The multi-model approach, on the other hand, allows for an uncertainty estimation, a crucial aspect of climate projections for policy-making purposes. Akin to the approach of CMIP5 and CORDEX, the aim here is to pool all available resources. This is necessary given the limited number of H-Res runs.

Within the CORDEX.be network a two-way interaction is of utmost importance and already present at the level of modelers. The downscaling approach is, by definition, a top-down approach where, “top” and “down” represent global models and user-oriented H-Res models, respectively. Nevertheless, the CORDEX.be guidelines can be considered as bottom-up. The enormous model complexity of GCM, RCM, H-Res and LIM models combined with the lengthy integration time of large climate simulations constrains the data that can be stored from each run. Therefore, prior to performing such runs, a rigorous data selection is made based on the requirements of H-Res and LIM model requirements such that the CORDEX.be guidelines can be viewed as “bottom-up” in nature.

2.2. Conventions and prescriptions within CORDEX.be

The objective to develop standardized climate information is addressed by making well-defined compatibility agreements between the partners. Decisions at different levels of the network structure were necessary before the start of the CORDEX.be model runs in order to provide as much coherence as possible. Three different working groups (WGs) were created to facilitate decision making, more specifically, one WG for RCM/H-Res modeling, one for urban modeling and one WG for uncertainty estimation.

Data Exchange – Since the network structure is mostly dictated by the downscaling approach and the ensuing data exchange, a common data format (NetCDF v. 4) was adopted. Most models required data format conversion in order to be NetCDF-compliant. The first model runs use RCMs on the EURO-CORDEX domain and part of these climate simulations, all in accordance with CORDEX conventions (Christensen et al., 2012), are transferred to the EURO-CORDEX archive. Subsequently, H-Res runs are performed on a limited domain over Belgium. The consortium agreed to take all CORDEX prescriptions (except the domain) as minimal prescriptions to the H-Res runs. In addition,

Table 2
The different RCM models employed for CORDEX.be and their main features.

Model Name	Important Reference	Resolution (km)	No. Vertical levels	Timestep (sec)	Important scheme	Focal time series/ severity index	Host GCM	Non hydro-static
ALARO-0	De Troch et al. (2013), Giot et al. (2016), Termonia et al. 2018a and Hamdi et al. (2018a)	50 & 12.5 (RCM) & 4 (H-Res)	46	900, 300 & 180	Convection scheme 3MT	hourly precipitation	CNRM-CM5	–
COSMO-CLM (UCL) V. 5.0-CLM6	Kotlarski et al. (2014)	2.8 km (H-Res)	40	20	Microphysics Scheme	Hail Mixing Ratio & Number Concentration, Detailed Precipitation	MPI-ESM	✓
COSMO-CLM (KUL) V. 6.0-CLM6	Wouters et al. (2016), Brisson et al. (2016), Rockel et al. (2008) and Wouters et al. (2015)	50 & 12.5 (RCM) & 2.8 (H-Res)	40	25	parametrization of CLIMAQs, TERRA_URB	precip, UHI	EC-EARTH	✓
MAR V. 3.6 (Modèle Atmosphérique Régional)	Wyard et al. (2017)	50 & 12.5 (RCM) & 5 (H-Res)	30		Snow variables	Snowfall events and & snowmelt events inducing floods	NorESM1, CanESM2, MIROC5	–

temporal and spatial resolutions exceeding the CORDEX prescriptions were necessary for the data that is stored and are used for coupling to the LIMs and for research purposes. Whereas CORDEX minimally requires daily-averaged (in "model time") values, most data is stored with hourly frequency, both for the RCM and H-Res runs and gathered in a Belgian hub to facilitate its use for impact studies in the future.

Climate Run Priorities – A sequence of priorities was also set regarding the RCM and H-Res runs. Since the first project Target is the participation to EURO-CORDEX, the first run is the evaluation run on the European domain. The boundary conditions for this run are provided by the ERA-Interim reanalysis over 1981–2010. The comparison of the model output with observations allows a validation of the models. Then each RCM performed the historical run on the EURO-CORDEX domain driven at the boundaries by a CMIP5 model run for the period 1976–2005. This was followed by future scenarios RCP8.5, RCP4.5 and RCP2.6. Given the limitations in available computing time the production of the future scenarios was split in three periods and computed each for the periods 2070–2100, 2040–2070 and 2005–2040 in this order. Finally, the same series of runs were planned for the H-Res run over Belgium. For adaptation planning, scenarios such as RCP4.5 and RCP8.5 are certainly of relevance. In the context of the Paris Agreement, "lower" (with respect to radiative forcing) scenarios such as RCP2.6 are also important to evaluate impact (Schleussner et al., 2016). Moreover, it has become important to distinguish the differences in terms of impact between the 1.5 °C and 2 °C global warming case and large ensembles are required to increase the ratio between the signal (climate change) and the noise (climate variability) for each case (Melillo et al., 2016).

Urban Modeling – The working group on urban modeling conducts projections and performs intercomparisons. These projections are coherent in the sense that they share the meteorological forcing from the RCM simulations of the CORDEX.be project. The city of interest is Brussels and a uniform definition of Urban Heat Index (UHI) was adopted aiming to focus on the health-related impact. Therefore an index developed together with the Flanders Environment Agency and the Belgian Federal Public health Agency (FPS) was chosen (Brouwers et al., 2015; Wouters et al., 2017). Due to the close contacts with these agencies, the CORDEX.be results are of direct use to them (see example in Section 3.3).

Uncertainty estimation – The data produced for Targets 1, 2 and 3 must be processed into climate information with a best estimate of their uncertainties using the CORDEX.be ensemble. The uncertainties can be estimated since the four modeling groups perform simulations following common prescriptions inherited from CORDEX. These runs are the only H-Res runs over Belgium following this framework. Even though such ensemble gives a better estimate of the climate change signals, the ensemble is too small to cover the full uncertainty range. Also, due to the lack of available CORDEX data that is stored with high temporal frequency, it is very difficult in practice to couple the LIMs to all the model runs in the international CORDEX database. The CMIP5 and EURO-CORDEX data and their uncertainty ranges are used with a delta-change approach to estimate low, mean and high scenarios as defined for Belgium in Willems and Vrac (2011), Ntegeka et al. (2014) and Tabari et al. (2015).

2.3. Stakeholder dialogue

2.3.1. Approach to stakeholder dialogue

Data produced by model groups are usually not of direct use for stakeholders. From discussions with Belgian stakeholders the well-known gap between what kind of information and services are needed and what the research community can offer, became apparent (Jones et al., 2014b). More specifically, such gap exists both in terms of language and lack of communication and therefore understanding. Nevertheless stakeholders take a prominent place in the setup of this initiative since its purpose is to narrow that gap. By producing and

Table 3
The different climate impact models employed for CORDEX.be and their main features.Note that acronyms are explained in the table below.

Model Name	Type of Model	Important Reference	Resolution	Time series/ severity index	Coupling to Model
SURFEX	Urban Model	Masson et al. (2013)	1 km	UHI	all H-Res
UrbClim	Urban Model	De Ridder et al. (2015)	0.1 km	UHI & UTCI	RCM ALARO-0
REGCROP	Crop Model	Gobin (2010) and Gobin (2012)	–	Crop Yield, HI, DI, WI	RCM ALARO-0
COHERENS	Storm Model	Luyten (2011)	5 km	Tides & Storm surges	RCM ALARO-0
WAM	Wave Model	Günther et al. (1992)	1 km	Wave Heights	RCM ALARO-0
MEGAN-MOHYCAN	Vegetation Emission Model	Guenther et al. (2006) and Müller et al. (2008)	1 km	Biogenic emissions, local ozone production index	RCM ALARO-0
–	GNSS reprocessing	Van Malderen et al. (2014) and Pottiaux (2009)	–	ZTD & IWV time series	all H-Res

combining a new set of climate scenarios, the foundations are created based on which a dialogue was initiated. In general stakeholders are individuals or organizations who are directly involved in the project or whose interests may be affected by the project's outcome. Climate service users in Belgium cover a wide range of economic, administrative, political and scientific bodies, within and across sectors and disciplines. Their questions concern the impact of climate change on natural and human systems as well as mitigation and adaptation strategies.

It is shown that, for the successful production of actionable science and user-oriented services, the iteration between knowledge producers and users is critical (Dilling and Lemos, 2011; Brasseur and Gallardo, 2016). Therefore different stakeholder meetings were organized at different stages of the project. First, three stakeholder meetings were held that led to a change in the project output priorities and to new ongoing collaborations for climate services (See also Section on Practical Implications). The project was concluded with a large final stakeholders meeting that included the distribution of a climate-impact leaflet, summarizing the most important project results.

2.3.2. Final stakeholders meeting

A large stakeholders meeting was organized to widen the visibility of this initiative, to build and stimulate an extensive dialogue between the participating scientists and climate stakeholders, and to structure the information at the different organizational levels for the future. This one-day even was organized at the end of the project (September 2017).[8] There were around eighty participants, more than half of whom were stakeholders. These included people from both the private and public sector, with the public sector ranging from the federal, the regional (Walloon, Flanders, Brussels) up to the city level.

The meeting consisted of two parts. The first part of the meeting was intended for a general public and featured different stakeholders presentations. The second part constituted of four parallel break-out sessions on urban climate, agriculture, air quality and hydrology. In order to stress the potentially dramatic impact of climate change on the Belgian population, a national-television weather man presented a hypothetical weather forecast for an intense heat wave. This 13-day heat wave was taken out of future simulation of the year 2063, generated with a regional model that is also used for weather forecasting purposes. This "weather forecast" was followed by a thorough explanation to what extent this was (not) a real weather forecast. Based on scientific results, the presentations highlighted that climate change poses new challenges associated with a range of weather-related hazards (e.g. sea-level, extreme flooding, heat waves and droughts) that strongly impact nature and society.

3. Results

The CORDEX.be project resulted in a vast amount of scientific output (see e.g. Wouters et al., 2017; Giot et al., 2016; Saeed et al., 2017; Bauwens et al., 2017; Hamdi et al., 2016; Hosseinzadehtalaei et al., 2017; Tabari et al., 2016; De Troch, 2016; Wyard et al., 2017) and we refer to the final report (Termonia et al., 2018b) for a summary and detailed results. The overall project objective, more specifically, establishing the foundations of climate services for Belgium by initiating the provision of standardized climate-change information to the Belgian stakeholder community, was realized in the final stakeholders meeting. Such provision was only possible through the realization of all four project targets, as explained in detail below.

3.1. Target 1: EURO-CORDEX contribution

The aim of Target 1 was to contribute to the EURO-CORDEX project with three regional climate models and resulted in various climate simulations by each of the four climate modeling groups, all of them following the EURO-CORDEX prescriptions. The performed simulations on the EURO-CORDEX domain are shown as the "RCM" runs in Table 4 amounting to around 540 simulation years. More specifically, the data of the ALARO model simulations (see description below) has been archived on the Earth System Grid Federation (ESGF) archive[9] while all other data is centralized in a Belgian database. As shown in Table 4, the RCM groups have performed a wide range of climate simulations, mostly targeting the period 2070–2100 but data for all scenarios and periods are available. With respect to climate change over Europe the results for precipitation and temperature is in line with the EURO-CORDEX ensemble. More specifically, the Scandinavian region has stronger warming in winter compared to Southern Europe, and there is a drying of the Mediterranean region, while precipitation increases in Northern Europe (see Jacob et al., 2014a).

3.2. Target 2: H-Res simulations over Belgium

The CORDEX.be initiative has gone beyond the highest prescribed resolution of CORDEX (12.5 km) by performing over 780 simulation years of H-Res climate simulations at resolutions of 2.8 to 5 km over Belgium. These are all gathered in a central database. The performed simulations on the EURO-CORDEX domain are shown as the "H-Res" runs in Table 4. Note that, supplementary runs include COSMO-CLM simulations following three land-use scenarios (Wouters et al., 2017), and, three evaluation runs with MAR using different reanalysis datasets (Wyard et al., 2017).

The evaluation runs served to validate the climate models with respect to station and gridded observations (Wyard et al., 2017) and more sophisticated and tailored data such as GNSS-derived water vapour observations of high spatial and temporal resolution (Van Malderen et al., 2014; Pottiaux, 2009; Termonia et al., 2018b; Ning et al., 2013).

H-Res simulations include more detailed descriptions of the model physics than low-resolution simulations. Therefore they are expected to produce more realistic results. Highlighting such added value has been

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[8] www.euro-cordex.be/meteo/view/en/33176277-CORDEX.be+stakeholders+meeting.html.

[9] esgf-data.dkrz.de.

Table 4
Climate simulations that were performed (✓) with the regional climate models. The “RCM” indicates runs done over Europe while the “H-Res” runs were over Belgium only. More details are provided on www.euro-cordex.be.

MODEL	Period	Evaluation	Control	RCP2.6	RCP4.5	RCP8.5
ALARO-0 RMI RCM 50 & 12 km	1950–1976	✓	✓	–	–	–
	2005–2040	–	–	✓	✓	✓
	2040–2070	–	–	✓	✓	✓
	2070–2100	–	–	✓	✓	✓
ALARO-0 RMI H-Res 4-km	1950–2005	✓	✓	–	–	–
	2006–2040	–	–	✓	✓	✓
	2040–2070	–	–	✓	✓	✓
	2070–2100	–	–	✓	✓	✓
COSMO KUL RCM 12 km	1979–2014	✓	–	–	–	–
	1975–2005	–	✓	–	–	–
	2069–2100	–	–	–	–	✓
COSMO KUL H-Res 2.8 km	1979–2014	✓(x3)[1]	–	–	–	–
	1975–2005	–	✓	–	–	–
	2069–2100	–	–	–	–	✓
MAR H-Res 5 km	1950–2015	✓ (x3)[2]	–	–	–	–
	1980–1999	–	✓(x2)[2]	–	–	–
	2080–2099	–	–	–	–	✓(x2)[3]
MAR H-Res 50 km	1981–2003	✓	✓	–	–	–
	2077–2099	–	–	–	–	✓
COSMO UCL H-Res 2.8 km	1979–2014	✓	–	–	–	–
	1975–2005	–	✓	–	–	–
	2070–2100	–	–	–	–	✓
COSMO UCL RCM 12 km	1979–2014	✓	–	–	–	–

[1] The H-Res evaluation run with COSMO-CLM at KU Leuven were all forced using ERA-Interim but used three land-use schemes: using urbanization of the year 2000, a vegetation land-use scenario and using the projected urbanization of the year 2006.

[2] The H-Res evaluation model runs with the model MAR are performed with four sets of reanalysis datasets: ERA-Interim, ERA-40, ERA20C and NCEP-NCAR-v1.

[3] The H-Res control and projection run of MAR are forced with different three GCMs: NorESM1, MIROC5 and CanESM2.

an important aspect of the project and was done in Termonia et al. (2018b), Vanden Broucke et al. (2017) and Tabari et al. (2016). To illustrate this, Fig. 2 (partly reproduced from Tabari et al., 2016) shows the Intensity–Duration–Frequency (IDF) relation of summer precipitation intensity against aggregation level. Return levels of 1 and 10 years for two evaluation runs with CORDEX.be models (ALARO-0 and COSMO-CLM) are compared with gridded (E-OBS) and station observations at Uccle. Extreme subdaily model rainfall amounts are close to the observed ones for finer model resolutions. This is a clear sign of added value for both models. Moreover, this gives confidence in the results of the impact of climate change on extreme precipitation for which the spatial distribution for different H-Res models is shown in Fig. 3. Here extreme precipitation is defined as 99th percentile of daily rainfall amount. The signal of relative change is clearly positive throughout Belgium with an average of 12%. These results are in line with the findings of the CORDEX ensemble (Jacob et al., 2014a) from which also uncertainty estimates were extracted (See Section 3.4). It has been investigated to which extent the climate change signal is modified by increasing the resolution from the CORDEX scales (50 km & ±12.5 km) to the convection-permitting scale (±4 km) over Belgium.

IDF relations are of relevance for the application sector of transport and mobility for the determination of flooding frequencies. For instance, it is known that the dimensioning of different drainage systems in Belgium are based on 30-year old analysis of historical precipitation observations (Demarée et al., 1985) and require improvements in analysis and incorporation of climate-change impacts.

3.3. Target 3 – Coupling to local impact models

The model outputs of the CORDEX.be ensemble were used to drive the local impact models. These include the land-surface models with urban modules (SURFEX, Urbclim and CLM in in-line mode), a crop model (REGCROP), a model for tides and storm (COHERENS), a wave-height model (WAM) and a model for biogenic emissions (MEGAN-MOHYCAN). The outcomes of these runs are high-resolution past and future time series including GNSS-derived products (e.g. hourly Zenith tropospheric Total Delay, ZTD), Urban Heat-Island indices for Brussels, yields for the dominant arable crops across the different Belgian agro-ecological zones, storm surges and wave heights and biogenic emmisions. The results are past and future time series of severity indices, directly usable for impact studies.

Focusing on the end of the 21th century using a scenario with the largest greenhouse gas emissions (RCP8.5), the most prominent impacts of climate change for Belgium include:

- A strong increase in tropical days and heat wave days.
- An increase in winter precipitation and long extremely wet periods.
- Intensification of summer precipitation extremes, especially in urbanized areas. The precipitation intensity with hourly time scale and 10-year return period may increase up to 100%.
- An increase of a factor 3 to 4 in the number of heat waves in the Brussels urban environment.
- An increased variability for biomass production and yields. Average yields for fodder maize and late potatoes will also decline.
- Severely reduced winter snow height maxima (above 500 m altitude).
- An increase of 51% of biogenic emissions from isoprene with the highest emissions in the Ardennes and Campine forests (disregarding the CO_2 inhibition effect).
- Indications exist that there will be less hail events but increase of mean hail size.

Whenever available, results were compared with those available from other projects and seem to agree well with them. For instance the increase in temperature, winter precipitation and extreme rainfall agrees well with the finding of WGII of the IPCC for the European region and Belgium (Jones et al., 2014b).

As a more detailed result from a LIM (UrbClim, De Ridder et al., 2015), also presented to the Brussels environmental department (IBGE/BIM), the impact of climate on the city of Brussels was quantified for a few indicators. Table 5 shows the average value in summer in dense urban areas of a set of heat stress, energy use and productivity loss indicators for both the reference and the future (2081–2100 following RCP8.5). Although the average UHI intensity is not strongly affected by climate change, the amount of heat stress for citizens of Brussels is expected to rise significantly. Also the number of Heat Wave Days undergoes a fourfold increase towards the end of the century and the amount of time the temperature exceeds 25°C (expressed in Cooling Degree Days, an indicator for air-conditioning and energy use) will more than double. Based on Wet Bulb Globe Temperature (WBGT) thresholds from the Belgian government for different types of work,[10] the amount of obligatory work breaks was calculated for every type, expressed in the Lost Working Days indicator. Clearly, climate change will have a significant impact on the outdoor productivity in the city of Brussels. Note that these results were obtained by downscaling the output from a single regional model (ALARO-0) with a single emission scenario (RCP8.5), such that no uncertainty estimate can be provided.

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[10] www.werk.belgie.be/defaultTab.aspx?id=608#.

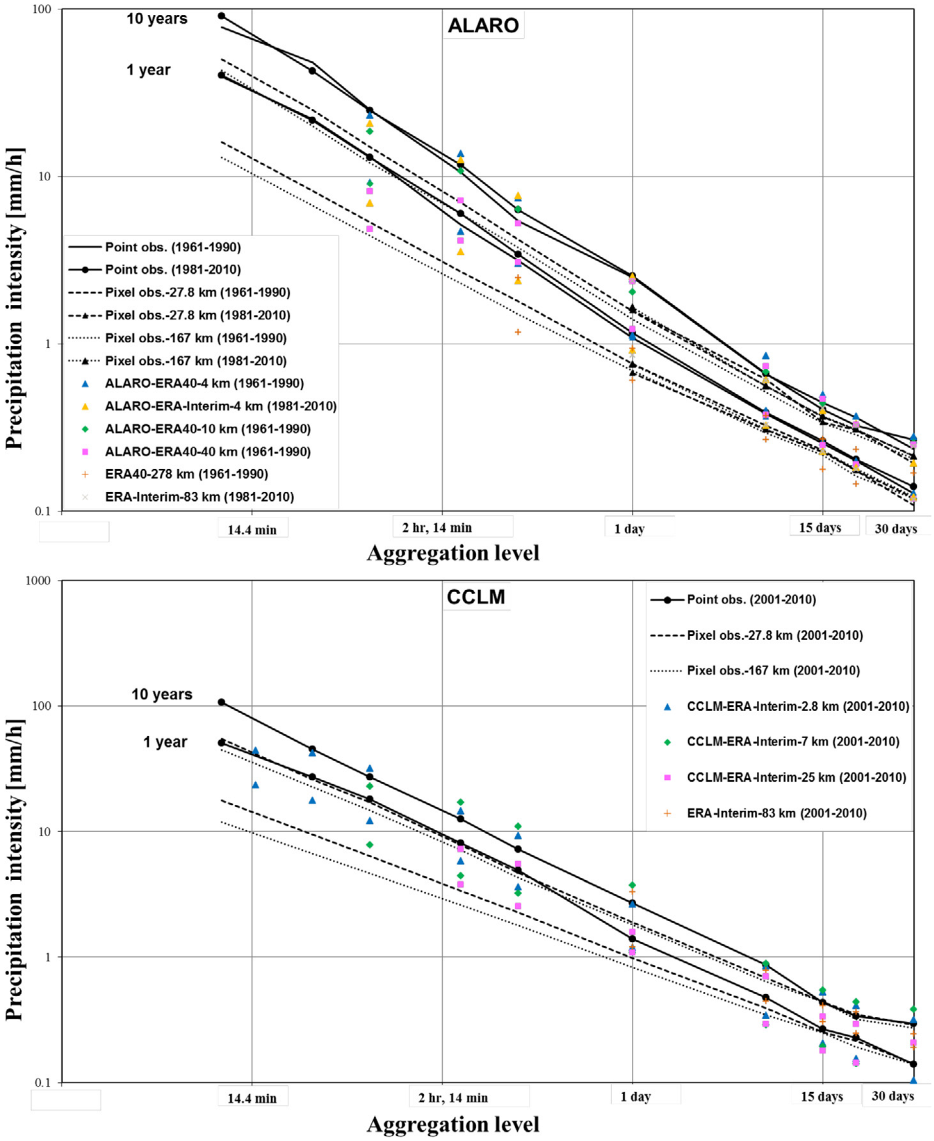

Fig. 2. Comparison of historical IDF relationships based on point and pixel interpolated Uccle observations, with COSMO-CLM, ALARO-0 and the driven by ERA-Interim reanalysis for the summer season (IDF curves for the E-OBS pixel data were extrapolated for the sub-daily timescales based on extreme value distribution). This figure is partly reproduced from Fig. 6 of Tabari et al. (2016).

3.4. Target 4: uncertainty estimation

Target 4 aimed to supplement the climate information of the H-Res runs with the uncertainty information gathered from the CMIP5 and the CORDEX project, all at the Belgian level. This is for instance done in Table 1 where the climate change results of the H-Res CORDEX.be mini-ensemble are put against the CMIP5 and EURO-CORDEX ensembles. Therefore the H-Res results can be positioned within these ensembles. The CMIP5 ensemble ranges or uncertainty bounds are determined by use of all available ensemble members for each emission scenario and are expressed through the use of three scenarios: “Low”, “Mean” and “High” (defined according to Willems et al., 2010) in Table 1. These scenarios are constructed according to the delta-change approach, more specifically, by extracting quantile changes from the distributions of future (scenario) and reference simulations, for each month separately. The “Low”, “Mean” and “High” scenarios coincide with 5th, 50th, and 95th percentile values of the above mentioned changes, respectively. We refer to Tabari et al. (2016) for the methodology used to determine the changes in extreme events. In order to obtain a full picture of the climate changes for a variable and scenario of interest, a stakeholder is therefore suggested to combine the following information: i) the concerned H-Res results, ii) their positioning within the CORDEX and CMIP5 ensembles and iii) the spread of the CMIP5 ensembles.

3.5. Conclusion from stakeholders interaction

Delivering Climate Services is a networking effort requiring the collaboration of different experts at different levels of the climate-

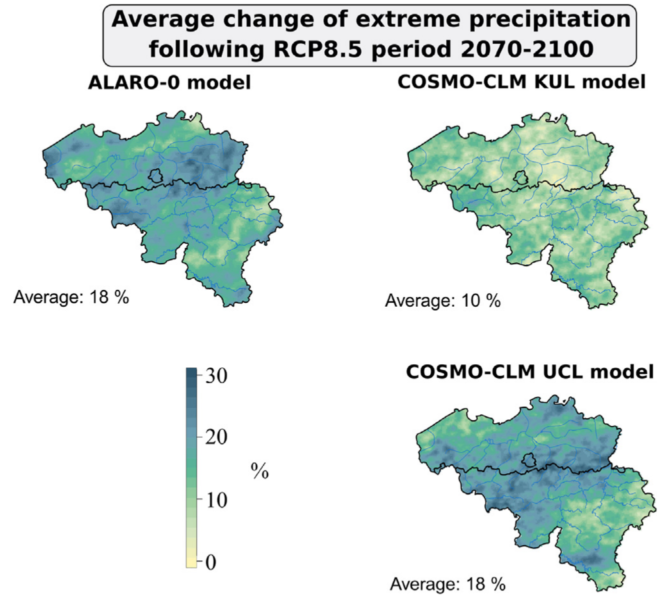

Fig. 3. Spatial distribution of relative change of extreme precipitation for the period 2070–2100 following RCP8.5, relative to the control period 1976–2006. The model projections are simulated with the three H-Res CORDEX.be models and averages over Belgium are indicated below the maps.

Table 5
Potential impact of climate change on annual averaged indicators for heat stress, energy use and productivity losses for dense urban areas (soil sealing >90%) in Brussels.

	1986–2005	2081–2100 (RCP8.5)
UHI intensity [°C]	3.7	3.9
Heat Wave Days	4.2	15.9
Cooling Degree Days	28.2	74.0
Lost Working Days		
→ Light work	0.9	2.6
→ Medium-heavy work	1.1	3.4
→ Heavy work	3.0	6.3
→ Very heavy work	8.8	15.6

services chain, from the scientific to the stakeholders level with frequent interactions between the levels. CORDEX.be was a networking and modeling effort to produce the foundations of Climate Services for Belgium. However, future steps still are required to complete this chain for Belgium. More specifically, there is a need for a more thorough analysis of the enormous amount of produced data in order to establish a coherent picture of the climate-change impacts on Belgium. For instance, the impact of climate change on drought and forest fires is an important issue that remains to be investigated for Belgium based on the CORDEX.be results. Droughts are relevant in the context of water availability and agriculture, and require an impact study by season.

From the interaction at the final stakeholders meeting, the following key messages were taken:

- Most impact studies done within CORDEX.be address the future period 2070–2100 for which the climate-change signal is mostly well pronounced. Most stakeholders, however, are interested in climate changes with time horizon of maximally 30 years. Studies at this time horizon mostly involve a full uncertainty analysis, gathering both local, regional and global climate studies.
- There is a need to list of climate impacts that will potentially be affecting Belgium, in order of impact severity, per season and per time range (20 up to 100 years). This could be supplemented with maps that show the spatial distribution.
- The risks of future multi-component disasters should be addressed. For instance the risk of a combined storm surge (coastal flooding) and river flooding, or, having a severe droughts two years in a row.
- The integration of the current and future impact analysis into the design of Belgian adaptation policy measures would benefit from a vulgarizing effort to condense the most prominent CORDEX.be results in a language that can be easily understood by the general public. Climate change of extreme events could thereby for instance be expressed in terms of frequency changes of well-known high-impact events such the Belgian “Pukkelpop” storm (De Meutter et al., 2015).

4. Discussion & conclusion

While Belgium does not formally have a national climate center (Fonteyn, 2013), the CORDEX.be project provides a platform for data exchange and communication among the Belgian climate-modeling groups. This is coordinated through the website www.euro-cordex.be. After the finalization of the project this website will be maintained and updated with new results. It will serve as a link between the Belgian activities and the international ones of the CORDEX project.

Different countries including Australia, Germany, the Netherlands, Switzerland, UK and US have established climate-impact reports for the general public (CSIRO, 2015; Attema et al., 2014; C2SM, 2011; Masson et al., 2014; Murphy et al., 2009; Brasseur et al., 2017). For Belgium such a report was already made in 2004 (van Ypersele and Marbaix, 2004). More recent reports focus on the hydrological impact (Willems et al., 2010) and on the Flanders region (Brouwers et al., 2015). Therefore there is a need to cover Belgium entirely and in an integrated way and to update previous reports based on the high-resolution CORDEX.be model results. The CORDEX.be summary report (Termonia et al., 2018b) updates and goes beyond these previous efforts based on the high-resolution model results and a range of supplementary impact assessments.

There are several research projects as well as personal efforts, without which the CORDEX.be initiative would not have been possible including an exploration among three Belgian RCM groups (De Troch et al., 2014; Tabari et al., 2016). CORDEX.be can be seen as the follow-up of the CCI-HYDR report by Willems et al. (2010) that mainly focused on the hydrological impact of climate change in Belgium. H-Res runs were already performed and analyzed (using COSMO-CLM) in the context of the Belgian MACCBET project.

The CORDEX.be initiative lays the foundation of climate services in Belgium. Not only is it a backbone for providing tailored climate information for the Belgian user community, it also fostered the scientific dialogue and collaboration within Belgium. CORDEX.be is therefore an indispensable first step for setting up Belgian climate services. Moreover the network could be easily extended, both nationally and internationally. The proposed coordination framework could also serve as an example for regions or countries where the climate-research capacity is present but the methodology is lacking to integrate and distill it.

Abbreviation	Description
ALADIN	Aire Limitée Adaptation Dynamique Développement International
AR5	Fifth Assessment Report
ARPEGE	Action de Recherche Petite Echelle Grande Echelle
BELSPO	Belgian Science Policy
CLM	Comunity Land Model
CMIP5	Fifth Coupled Model Intercomparison Project
CNRM	Centre National de Recherches Météorologiques
COHERENS	Coupled Hydrodynamical-Ecological Model for Regional and Shelf Seas
CORDEX	Coordinated Regional Climate Downscaling Experiment
COSMO	COnsortium for Small-scale MOdeling
DI	Drought Index
ECC	Ensemble Copula Coupling
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA-Interim	Global atmospheric reanalysis data from 1979
FPS	Flagship Pilot Study
GCM	Global Climate Model
GNSS	Global Navigation Satellite Systems
HI	Heat Index
H-Res	High Resolution
IDF	Intensity–Duration–Frequency
IFS	Integrated Forecast System of ECMWF
IPCC	Intergovernmental Panel on Climate Change
ISBA	Interactions between Soil, Biosphere, and Atmosphere
IWV	Integraged Water Vapor
LBC	Lateral Boundary Condition
LIM	Local Impact Model
MEGAN	Model of Emissions of Gases and Aerosols from Nature
MOHYCAN	MOdel of HYdrocarbon Emissions from the CANop
MOS	Model Output Statistics
MPI	Max Planck Institute
NWP	Numerical Weather Prediction
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SISVAT	Soil Ice Snow Vegetation Atmosphere Transfer
SURFEX	Surface Externalisée, surface model from Météo France
TEB	Town Energy Balance
UHI	Urban Heat Island (effect)
UTCI	Universal Thermal Climate Index
WBGT	Wet Bulb Globe Temperature
VMM	Vlaamse Milieu Maatschappij or Flamish institute for environment
WG	Working group
WI	Wetness index
ZTD	Zenith tropospheric Total Delay

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