Climate scenario development: mechanisms of climate change in the Netherlands

Work package leader: dr. ir. G. Lenderink (KNMI)

Content

1 Description work package

1.1 Problem definition, aim and central research questions

In recent years, it is becoming increasingly clear that there are local mechanisms that could influence the local (future) climate significantly. For example, the influence of sea surface temperature changes could strongly affect coastal precipitation (Lenderink et al. 2009). Daily precipitation extremes differ by about 40% even within the Netherlands (Overeem, 2009). Local shower intensities are strongly dependent on the amount of moisture in the atmosphere, and related latent heating in the cloud, and this could even give rise to increases of hourly precipitation extremes of 14% per degree temperature rise, exceeding increases in daily extremes considerably (Lenderink and Van Meijgaard, 2008). Therefore, besides simply adding the smaller scales to the course resolution global climate modeling results, regional climate models (RCMs) also add a number of relevant processes acting at a local/regional scale that could strongly influence our future climate.

Our main goal is therefore to "**estimate and understand the potential impact of local/regional drivers on the future climate within the Netherlands**"

Present-day regional climate models operate at a resolution of typically 25 km, using dynamical cores based on hydrostatic dynamics (see e.g. the recent state-of-the art model ensemble in the ENSEMBLES project). It is envisaged (and confirmed by analysis of the ENSEMBLES data) that these models do not resolve local processes well enough. Therefore, here we will primarily focus on a new generation models that use nonhydrostatic dynamics and run at a very high resolutions of typically 2 km. These models resolve meso-scale circulations, which is in particular important for atmospheric convection and the interaction between the atmosphere with the land and sea surface.

Non-hydrostatic climate models are computationally very expensive. It is not feasible to perform long climate integrations of typically 150 years, which is usually done with the present-day generation hydrostatic models (as in the ENSEMBLES project), and to make integrated assessments using ensembles of these type of model integrations. Instead, we mainly investigate a number of cases for which we have (strong) evidence that local mechanisms play an important role. As such, we focus on the impact of:

1. The **sea** surface temperature, and changes herein (WP1.2, **WP1.3**, **WP1.5**)
2. The **land** surface (including lakes) and land use, and changes herein (**WP1.4**, WP1.1)
3. Changes in **atmospheric** meso-scale and convective circulations due to increased latent heating (**WP1.5**)

1.2 Interdisciplinarity and coherence between the projects

Providing local, high resolution climate information is the key focus in this project.

Climate information at a resolution of 25 km will be provided in projects 1.1 & 1.2. This information will be passed to WP2 (in order to assess uncertainties) and the other projects in this work package. Also a module for the North Sea will be implemented in order to provide more realistic sea surface temperatures for the nonhydrostatic models.

Climate information at a local 2km scale will be provided in projects 1.3, 1.4, and 1.5. Project 1.3 provides showcases of severe weather characteristics (hail, wind extremes, wind gusts, precipitation) for the future climate. In addition, it will evaluate the model performance on this wide range of characteristics for the present-day climate. Projects 1.4 and 1.5 (PhDs) provide underlying research, with a stronger focus on understanding changes at a process level.

Project 1.4 provides through the link with changing land use (and urbanization) a strong link to Theme 2.

An important goal of this project is the delivery in WP1.3, 1.4 and 1.5 of a number of very high resolution showcases for the future climate, showing the influence of landsurface changes, rising sea surface temperatures change in the North Sea, and local thermodynamics of the atmosphere. Lateral boundaries for these showcase will be provided by a joint effort in WP1.2 and WP2.3.

Traditionally, climate research is dominated by large spatial scales and long time scales. However, impacts of climate change will mainly occur at a local scale and for weather type events. The latter area is the focus of the (limited area) weather prediction community. In this project, a bridge is made (or strengthened) between the climate and weather prediction community in order to provide the best information of climate change at the local scale.

1.3 Stakeholders

The stakeholders are users in the hotspots of KfC. For Schiphol these are primarily capacity planners of the airport, for shallow lakes these are the water boards and water managers. Information on local precipitation extremes or mainly important for urban areas and Schiphol, whereas influences of the North Sea on precipitation are important for all hotspots in the western part of the Netherlands (Haaglanden, Schiphol, Rotterdam).

2 Project 1.1 Collaboration with SMHI on modeling results and model development

Project leader: Patrick Samuelsson

2.1 Problem definition, aim and central research questions

In this project we will collaborate with the regional climate modeling section at SMHI on model data exchange and analysis of hydrostatic regional climate model integrations (point 1), and development and analysis of the nonhydrostatic model HARMONIE (point 2). The main goal is the transfer of knowledge and data between SMHI and the Dutch community.

1. It is well known that the future regional climate is not only determined by regional processes, but that processes acting on the larger scales play an important role as well. For the regional climate models (RCMs) much of the information about the future climate is imported through the boundaries of the regional model domain. As such, the regional model inherits the large scale circulation change and global (or continental) temperature rise from the global climate model (GCM) that has been used to force the regional model. For seasonal and annual mean precipitation, near surface temperature and wind speed changes it has been shown that the major part of the uncertainty in the future climate (at a intermediate scale; that is, e.g. for Central Europe, or Scandinavia) is due generally to uncertainty in the GCM forcing (Déqué et al. 2007; Pryor et al., 2005). An exception is mean precipitation change in summer for which the choice of the regional model is equally important. However, for more extreme events the partitioning between uncertainty arising from the global model (or emission scenario) and uncertainty arising from the regional model shifts. For extremes in temperature (Kjellström et al. 2007), precipitation (Lenderink et al. 2009) and wind speed (Rockel and Woth, 2007) the role of the regional model is much larger.
   To distinguish between the source of uncertainty arising from the representation of the larger scales (the GCMs) or the smaller scales (the RCMs) ensembles of simulation are necessary. Ideally, each RCM should perform simulations for each GCM simulation that is available, thus filling in a complete matrix between RCM and GCM simulations. Due to computing limitation, this is not the present state-of-the-art. In the early PRUDENCE project most RCM simulations have been driven by only one GCM boundary (Christensen and Christensen, 2007). In the recent ENSEMBLES project a much larger focus was on covering the GCM uncertainty (van der Linden and Mitchell, 2009). Despite this focus on covering GCM uncertainty, in ENSEMBLES there is no RCM that covers the complete GCM uncertainty.
   SMHI has a very large ensemble of 20 140-year long regional climate simulations driven by a large number of GCM boundaries (Kjellström et al., 2009; Kjellström et al., 2010; Nikulin et al., 2010). This includes; different GCMs, different emissions scenarios and in one case different initial conditions in one GCM under one emissions scenario. All simulations have been completed with the same version of the Rossby Centre regional climate model RCA3.0

(Kjellström et al., 2005; Samuelsson et al., 2010). Most simulations have been undertaken at 50 km horizontal resolution but there are also some at 25 and a few at 12.5 thus enabling us to address uncertainties related to the resolution. This SMHI model ensemble provides an excellent opportunity to establish the impact of uncertainty arising from the large scale on the regional climate.

2. At present, a new generation atmospheric models based on non-hydrostatic dynamics is being developed. Non-hydrostatic models (NH models) explicitly resolve convection, and do not need (or only in a simple form) to parameterize convection. The interaction between convection and the surface conditions is a new and exciting field, which may have important consequences for the water availability in summer . For example, Hohenegger et al. (2009) showed that the influence of soil drying on atmospheric convection in a non-hydrostatic model was of opposite sign that in current generation hydrostatic climate models. This reflects the importance of a realistic description of the horizontal heterogeneity in soil moisture conditions. In some parts of Europe irrigated crops cover a substantial part of the land surface. As irrigation changes hydrological conditions and therefore the energy portioning into sensible and latent heat flux it has an impact not only on the near-surface climate but also on the triggering of convection. Kueppers et al. (2008) have shown that replacing natural vegetation in models with irrigated crops can induce a cooling effect on near air-temperature climate of 1-2 $_{o}$C and create an increase in atmospheric humidity of 10-30%.
Within the context of the mesoscale modeling system HARMONIE we will investigate the impact of heterogeneity in surface conditions, e.g. with respect to irrigation, on convective activity. This investigation will benefit from implementation of new processes in the externalized land-surface scheme SURFEX which is a part of HARMONIE. These new processes relate to the description of vegetation. The vegetation will be separated by its own energy balance components with respect to the underlying surface.

2.2 Approach and methodology

In this project we will:

1. explore the uncertainty in regional climate predictions that are caused by the larger scales. This is done by analyzing the model ensemble at SMHI, in comparison with runs done at KNMI and within ENSEMBLES.
2. test how heterogeneity in surface physiography may affect surface fluxes and the triggering of convection, for example on the impact of irrigated surfaces on convection. This will be done in the non-hydrostatic version of HARMONIE at SMHI.

2.3 Scientific deliverables and results

With this project we aim to quantify the role of uncertainty at the regional scale (in this case, The Netherlands) that arises from uncertainty in large scale changes (that are provided by the GCMs). In addition, the role of the surface conditions on convection will be investigated.

2.4 Integration of general research questions with hotspot-specific questions

This project is not directly linked to hotspot-specific questions. However, the collaboration with SMHI will facilitate different projects within Theme 6. As such, it links with the work on the surface conditions and on HARMONIE in WP1. It also provides regional climate model data to be used in WP2 for the assessment of uncertainty.

2.5 Societal deliverables and results

Each estimate of regional climate change should be accompanied by estimates of the uncertainty, and the SMHI model ensemble will facilitate this.

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3 Project 1.2. RACMO climate integrations: estimation influence of SST on coastal precipitation and provision boundaries for nonhydrostatic modeling.

Project leader: G. Lenderink

3.1 Problem definition, aim and central research questions

In work package 1 we aim perform integrations for the present-day and future climate employing a very high resolution, non-hydrostatic mesoscale model at a scale of typically 2km. In particular, a number of showcases of severe, high impact future weather conditions will be explored in order to be able to estimate their impact on society. Also the impact of changing land use will be investigated at high spatial resolution.

In order to be able to perform these very resolution non-hydrostatic integrations, these models must be driven at their boundaries with meteorological data. The data from present-day global climate models, however, is much to coarse to do this, and the regional climate model RACMO2 is used as an in between, downscaling GCM results with a typical resolution of 200 km to a resolution of 10-20 km. The non-hydrostatic models will be nested into the results of RACMO2.

It has been shown that the influence of North sea temperatures on the Dutch climate could be substantial. Regional model simulations and observations display a significant (up to 14 % per degree temperature rise) dependency of coastal precipitation on the sea surface temperature (Lenderink et al. 2009). Also daily precipitation extremes in the coastal area mainly occur during autumn for which sea surface temperatures are high (Overeem et al. 2009). In addition, a trends towards a wetter coast is observed in the climate record over the last 50 years. The KNMI'06 scenarios do consider potential influences of the North Sea on regional climate change within the Netherlands.

The present-day generation regional climate models commonly use sea surface fields directly inferred from the global climate models. As such, the lack spatial details. In particular, this applies to a shallow coastal sea, like the North Sea. In the ENSEMBLES project (Hewitt and Griggs, 2004) a large number of regional model scenario integrations have been performed for the period 1950-2000. All of these integration use prescribed SSTs. An analysis of these runs reveal relatively small increases in sea surface temperature, basically following the mean sea surface temperature over the northeastern part of the Atlantic ocean, with a lack of spatial detail. This strongly limits the ability of the regional models to predict regional differences with the Netherlands.

The goal of this project is to extend the regional climate modeling system RACMO2 with a simple module representing the North Sea, and perform a long term climate simulation with this updated system in order to estimate the (long term) statistics of coastal precipitation, and provide boundaries for a selection of cases to be studied with the very high resolution nonhydrostatic models.

3.2 Approach and methodology

In this project we will:

1. Built in and evaluate a simple model for the North sea in RACMO2 that provides a better representation of the local temperatures along the Dutch coast. This model will consist of a simple oceanic mixed layer model that can be coupled to the oceanic output of the global climate models.
2. Rerun one scenario integration (150 years or several 30-year time slices) including this update to estimate coastal effect in precipitation
3. Provide boundaries for the case studies to be run with the non-hydrostatic models.

The first two tasks follow up on the work started in the project KKF Future Weather of the first tranche of KfC.

3.3 Scientific deliverables and results

An improved understanding of the local hydrological cycle in coastal areas, and estimates of the influence of changes herein on coastal precipitation (extremes) cumulating in a paper/scientific report.

3.4 Integration of general research questions with hotspot-specific questions

The long term climate integration will provide estimates of regional differences in precipitation, in particular concerning the coastal amplification, which are of use for the hotspots Schiphol, Haaglanden, and Rotterdam. Yet, due to the hydrostatic model and the resolution (10-20 km) these estimates are expected to be rough, in particular in space. Refinement using non-hydrostatic modeling for selected cases will be done in WP1.3 and WP1.5.

3.5 Societal deliverables and results

See D.

3.6 Most important references

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4 Project 1.3. High impact weather, with a special focus on wind and precipitation (extremes) at Schiphol Mainport: present-day evaluation and showcases for the future.

Project leader: Dr. J. Barkmeijer

4.1 Problem definition, aim and central research questions

The operations at Mainport Schiphol are highly sensitive to a number of critical weather parameters, most notably precipitation, the local wind field and visibility. For save and efficient airport operation now and in the future, under the condition of a changing climate, routinely monitoring and prediction of these critical weather parameters is essential. It is the objective of this project to study primarily the local precipitation and wind at Mainport Schiphol though a modeling and measurement exercise.

The model, which will be employed in this project is HARMONIE, a non-hydrostatic model with a spatial resolution of around 2 km (see B). We aim to obtain a better insight in the model behaviour in simulating various aspects of precipitation, for example how well the distribution (in space and time) of precipitation amounts compare to observations. There will be a focus on the model performance in situations of severe precipitation. HARMONIE is capable to differentiate between various types of precipitation, including snow and hail, their model properties will be studied as well. Also with respect to wind, the present-day model climate will be investigated. Here special attention will be given to sudden strong fluctuations in wind speed (gusts). The work on HARMONIE will be performed by a PostDoc researcher.

The measurement platform which will be deployed at Schiphol is WindVisions, a system consisting of a cross-wind scintillometer and a high-resolution SODAR that measures the 3D-windfield and visibility in the vicinity of airport runways. WindVisions is currently being developed by a junior researcher as part of the 2 year KvK-project HSMS01 (Holtslag and Hartogensis, 2009). The continued work on WindVisions in synergy with the current project will enable the junior researcher to finish a complete PhD on the subject.

The following research questions are central to this project:

1. How is the performance of HARMONIE for (extremes in) precipitation? Various aspects of precipitation will be considered, such as, intensity and type (snow, hail), including their high resolution distribution in space and time.
2. How is the performance of HARMONIE for the 4D (space and time) wind field at high resolution? Emphasis will be put on the intensity, direction and fluctuations (gusts) of wind. WindVisions will provide crucial validation data.
3. How could the above aspects of precipitation and wind change in a future climate?

Emphasis will be put on cases relevant for Schiphol Mainport, and the measurements and model evaluation will be specially targeted at the Schiphol area. The future cases will translate a number of these selected cases into the future, and show potential climate impacts for the Schiphol area.
In assessing the performance of HARMONIE for precipitation and wind, we also hope to gain knowledge

about the dominant physical mechanisms, which are responsible for producing these critical weather parameters. This may help to address predictability issues when events of heavy precipitation or strong winds occur .

4.2 Approach and methodology

In this project the non-hydrostatic model HARMONIE will be employed. This model is currently being developed in a cooperative project between the European Numerical Weather Prediction (NWP) consortia HiRLAM and ALADIN (see www.hirlam.org). The non-hydrostatic approach enables us to explicitly resolve vertical (convective) motion with its implications for forecasting precipitation (e.g. Kato 1997). Further, a consistent treatment of sub-grid processes has led to a unified approach for the physical parametrization of clouds, turbulence and convection in the atmospheric boundary layer of the model (Siebesma *et al.* 2007; De Rooy and Siebesma 2008). With a typical gridsize of 2km and a state-of-the-art physics package we should be in a position to better include the effects of local land-use or temperature contrast between land and sea in triggering extreme events.

The first phase of WindVisions aims at development and testing of the system e.g. at Cabauw. In the currently proposed second phase we will move towards an operational system, which will be tested and operated at Schiphol airport and will provide validation data for the HARMONIE model runs. More details on WindVisions can be found in (Holtslag and Hartogensis, 2009).

We plan assess model performance by means of comparing model results to a number of relevant observation sets, such as obtained from WindVisions, but also rain gauge networks (Wauben 2006) or the recently derived 10-year radar-based climatology of precipitation (Overeem *et al.* 2008), and wind measurements at the Cabauw site and Schiphol. The comparison between the high-resolution model data and observations will require advanced verification tools, see e.g. Kok *et al.* (2008).

Besides a general evaluation of the statistics of wind and precipitation in HARMONIE using results of (short) climate integrations, also a number of cases from the historical record will be evaluated. As such, not only cases with extreme weather (such as, meso-scale convective systems or winter storms), but also more quiet situations with persistent boundary layer clouds or mist (which have a high impact on Schiphol airport) will be studied. For these cases an in depth analysis of the model performance will be made. This will also include an assessment of how the uncertainty present in various aspects of the model, such as, the area size, resolution or model physics parameters, affects the characteristics of the model performance.

By employing an interface (to be developed in IMPACT) it is possible to perform HARMONIE model integrations with the large scale lateral boundary conditions provided by the regional climate model RACMO (developed in WP1.2) and thus perform integrations for the future climate. For a number of the above cases, future analogous will be created that are consistent with scenario predictions of the future climate. This will create a data base of very high resolution future weather events that are consistent with present climate scenarios.

4.3 Scientific deliverables and results

This project develops an innovative measurement platform for wind and visibility and provides knowledge about the performance of the non-hydrostatic model HARMONIE for simulating high impact weather events, in particular focused on precipitation and wind(gusts). Nonhydrostatic models are relatively new in numerical weather prediction and climate modeling, and therefore it is important to assess their performance. This is even more so since there is evidence that nonhydrostatic models may change climate feedback considerably compared to the present-day generation hydrostatic models (Hohenegger et al. 2009). As such the scientific deliverables are:

- Knowledge on the quality of HARMONIE for the present-day climate with respect to a range of aspects of precipitation and wind (type, time and spatial distribution), with particular emphasis on Schiphol Mainport.
- Showcases of a number of future extreme events at very high resolution
- Publication of these results in peer-reviewed journals

The integration of both horizontally averaged wind-measurements (by cross-wind scintillometers) and the vertically sensing instrument (SODAR) into one system to monitor the 3D-wind field between the surface and several hundreds of meters height is innovative.

4.4 Integration of general research questions with hotspot-specific questions

The measurements provided by WindVisions and the gained insight on the performance of HARMONIE with respect to the critical weather parameters precipitation and wind is of direct use for hotspot Schiphol Mainport. It should help in their decision process to make optimally use of runway capacity. Also the evaluation of present-day and future severe events may provide guidelines for Schiphol Mainport of how to respond to a future climate. The research carried out in this project will be useful for other hotspots as well. For example, Rotterdam region, which is interested to obtain more local information on the effects of climate change on their airport, harbour and their water management. Another interested party may be the regional Dutch water boards.

4.5 Societal deliverables and results

Better insights in extremes/ high impact weather situations in (present and) the future climate, in particular connected to mesoscale convective systems (and related windgusts, hail, thunder) quantified by a number of high resolution future cases. In addition, a innovative operational system, WindVisions, to monitor wind and visibility along airport runways.

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5 Project 1.4 The impact of land surface, land use changes and atmospheric boundary layer processes on the future climate at a local scale.

Project leader: Ronald Hutjes (WUR)

5.1 Problem definition, aim and central research questions

Climate scenarios downscaled to high resolution are a prerequisite for the development of adaptation measures at the local scale. High resolution scenarios should realistically reflect persistent fine-scale spatial patterns, as well as provide proper statistics on temporal variations of both means and extremes. As a means of obtaining such information dynamical downscaling plays an increasingly important role.

The higher the resolution of the regional model to be used in dynamical downscaling the more important a proper representation of the surface becomes. Weather patterns like the climatological rainfall maximum found east of the Veluwe in the Netherlands cannot be reproduced without proper representation of topography and vegetation (ter Maat, Moors et al. 2008); urban heat islands cannot be reproduced without proper parameterizations for these combined with land surface maps that resolve cities (Steeneveld and van Hove 2008); coastal precipitation extremes cannot be reproduced without accounting for very sharp SST gradients in coastal waters (Lenderink and van Meijgaard et al. 2009).

At the same time we know that the atmosphere is not always equally sensitive to the land surface. Analytical tools to study its dependency exist but are applicable mostly at larger scales and for convective situations (Findell and Eltahir 2003)(Tuinenburg, Hutjes et al. in prep); their usefulness at small scales and in synoptic conditions remain to be confirmed.

Our use of the land is not static. Future scenarios of land use for the Netherlands and surroundings show continuing further urbanization and expansion of built-up areas, abandonment of agricultural land and expansion of (semi-) natural lands and forests (Westhoek, van den Berg et al. 2006; Verburg, Eickhout et al. 2008). These land use changes will have an impact on future weather in addition to those mediated through greenhouse gases.

Overall objective of the present project is to systematically assess the influence of a (changing) land surface on the regional climate in the Netherlands

The following sub-objectives together address the overall objective:

- to assess the sensitivity of weather to local land surface in various conditions using conceptual and 1D numerical models
- to implement improved land surface models (LSM) and appropriate state of the art land cover (scenario) maps in 3D, high resolution non-hydrostatic regional models in support of future dynamical downscaling activities.
- to assess the added skill of the improved 3D model in reproducing small scale spatial patterns in averaged near surface meteorology and the magnitude of extreme (rainfall) events, through a systematic validation of the coupled system against high resolution datasets
- to assess the potential effects of future land cover changes on future regional weather and climate for a number of selected showcases

5.2 Approach and methodology

To address these four objectives of the project we plan three consecutive phases:

1. conceptual analysis of land surface interaction with the local and regional climate in the Netherlands
2. coupling of improved LSMs to the 3D high resolution, non hydrostatic model and associated skill assessment
3. use of this improved model to simulate a limited set of (show) cases representing future spatial arrangements of land cover combined with synoptic conditions representative of future climate

phase 1) In the first phase of the project conceptual tools (Ek and Holtslag 2004) will be used to asses the impact of the land surface on weather (rainfall patterns mostly) in the Netherlands. This will focus on representative weather conditions for average situations and extreme events. Using prescribed surface conditions based on observations for various surface conditions (e.g. anomalous phenological dynamics, urban surface temperatures, shallow lake temperatures both from airborne satellite IR images), together with atmospheric soundings representative of extreme weather, we will determine which surface modulation has the largest effect and in the second phase focus our work on that particular aspect.

phase 2) In the second phase of the project an improved LSM (vegetation or urban or surface water) will be selected based on the outcomes of phase 1, and coupled to the 3D-model. For each of the alternatives below *separately funded research in the group is ongoing that will deliver the improved LSM*, Here we will implement and test the coupling. Options are:

- *vegetated surfaces:* If chosen, we will link the improved vegetation / phenology models with the work ongoing in (Kruijt, Kabat et al. 2009), using data and analyses from previous national projects for cropland, grassland and forest (Jacobs, Jacobs et al. 2007; Moors 2010; Jans, Jacobs et al. subm 2009).
- *urban landscapes:* If chosen we start with existing urban canopy schemes already implemented in the NWPM (Grimmond, Blackett et al. 2009), later to be updated and validated based on the work (including measurements in Dutch cities) foreseen in the KvK Theme 4 programme.
- *shallow waters* and tidal flats: also here we will start with prescribed, observed water temperatures, to asses the potential benefits, only in later stages to be replaced by a prognostic model for non stratified, shallow water temperatures based on ongoing developments by (van Vliet, Ludwig et al. 2009) relevant for the large dutch inland waters (e.g. IJsselmeer).

Present day land cover maps to be used in the model will be based on newest LGN6 (2009). The nonhydrostatic model, coupled to the improved LSMs and run at resolutions of ~2km, will be laterally forced by the RACMO boundary conditions that downscale global, 100km resolution simulations to about 25km resolution, generated in project 4.2 of this work package, for selected events in the past and future.

Validation will be against data from the operational weather station network, the much denser precipitation network and selected campaign based datasets (e.g. from urban monitoring in KvK theme 4). Assessment of added model skill for extremes will be done by hind-casting a limited number of selected, representative extreme events (e.g. droughts, heat waves, cold spells, extreme rainfall). Assessment of added model skill in reproducing fine scale spatial patters will be done by one or a few multiyear simulations (depending on available vs required compute resources).

phase 3) In the final phase this improved model will be used to simulate a limited set of (show) cases representing future spatial arrangements of land cover combined with synoptic conditions representative of future climate (e.g. from the 2003 record hot/dry year, august 2006 extreme precipitation). Showcases will be selected in further consultation with stakeholders from the hostpots -and based on the potential effects assessed in the phase 1 and 2- and may include new urbanization patterns near the coast, new agricultural patterns, new water management options, etc.

Future land cover scenarios will be based on the EURuralis products (http://www.eururalis.nl/) for the larger domain, possibly being refined for specific areas in the Netherlands based on the spatial planning work in WP3.4 project and related activities. For some case studies (events) also the effect of certain adaptation measures, developed elsewhere in the KvK programme, on weather modulation may be assessed. E.g. in theme 4 adaptation measures in cities will be parameterized for the urban LSM. Or in themes 2 and 3 certain water retention or storage measures may be developed that can be parameterized in our LSM. Here, the effectiveness of such measures in specific situations may be analyzed.

5.3 Scientific deliverables and results

The project will deliver

- an analytical assessment of the sensitivity of weather in the Netherlands and surroundings to local land surface and small scale surface patterns
- a suite of improved LSMs optimally parameterized for representative Dutch land cover classes, and implemented in a high resolution, non-hydrostatic NWPM
- an quantitative assessment of the skill of this new coupled model in reproducing small scale spatial climate patterns and extreme events
- an evaluation of the effect of future land cover changes in the Netherlands and surroundings on small scale spatial climate patterns and extreme events

5.4 Integration of general research questions with hotspot-specific questions

The results of the current project are of more general use for the development of next-generation high resolution climate scenarios for the Netherlands and as such of long term relevance to all KvK hotspots. Hotspots that may profit particularly from the project results are:

- HSRR (and HSRS and HSHL) because of (their involvement in) the development of the urban canopy model improving urban near surface climate simulations and weather modulation through interactions with the urban heat island
- HSZD, HSWZ, HSOV because of the development of the shallow water and tidal flats model, allowing better simulation of water temperatures and near surface meteorology in these areas
- HSDR and HSOV because of the development of improved land surface schemes for grasslands, croplands, forests and nature areas, allowing better simulation of near surface meteorology in these areas and weather modulation through interactions between atmosphere and complex landscapes.

5.5 Societal deliverables and results

The results of the current project are of more general use for the production of next-generation high resolution climate scenarios for the Netherlands and as such of long term relevance to all of society as they will allow better development of adaptation measures. Also the feedback of larger scale adaptation measures (e.g. large scale water management, green cities, novel crops) on future weather will be aided by the developments foreseen here.

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6 Project 1.5 Local precipitation extremes derived from non-hydrostatic modeling.

Project leader: Pier Siebesma

6.1 Problem definition, aim and central research questions

Events of extreme precipitation have a huge influence on society. They are associated with flooding, erosion, and water damage and may have impacts on transport and safety. It is commonly expected that precipitation extremes will increase as the climate warms. The primary reason why precipitation extremes are expected to increase follows from the fact that a warmer atmosphere can “hold” more moisture (Trenberth 2003).

In this project we will primarily focus on extremes at the local scale and with a relatively short duration (hourly) that are of convective origin and that occur mostly in summer, and compare these with changes at larger temporal (that is, daily) and spatial scales. Relations derived from on hourly observations of the present-day climate suggest that local, hourly precipitation extremes could increase about twice as fast with temperature (up to a rate of 14% per degree temperature rise) than daily precipitation extremes (Lenderink and Van Meijgaard, 2008).

Despite the general understanding why precipitation extremes are expected to increase, model predicted changes display very large uncertainty bands. A recent regional model ensemble from the ENSEMBLES – with state of the art regional climate models that have been operated at the highest resolution (typically 25 km) that can be afforded at a European scale – displays a range in changes of hourly precipitation extremes between +10 and +70%. The upper range in the predictions appears to be consistent with the relation between hourly precipitation extremes and temperature derived from the present-day climate (that is, increases in intensity of 14 % per degree temperature rise). However, most models predict significantly smaller changes than inferred from the relation found for the present-day climate observations (see also Allan and Soden, 2008). A first analysis indicates that a major part of this uncertainty is connected to the representation of convection, in particular how convection reacts to changes not only in absolute humidity (following the mean temperature increase) but also to changes in relative humidity. Although the absolute humidity in the atmosphere will very likely increase in the future, decreases of relative humidity in summer are expected by the end of this century. It appears that many present-day regional climate models are (much) too sensitive to a decrease in relative humidity, and consequently predict rather low increases in precipitation extremes (Lenderink and Van Meijgaard 2009).

The current generation climate models (that have used in the ENSEMBLES project, for example) is based on hydrostatic dynamics. In these hydrostatic models convection is not resolved, but has to be parameterized instead. Such a parameterizations use simple rules to express the impact of convection on the mean fields in terms of the mean fields.

At present, a new generation atmospheric models based on non-hydrostatic dynamics is being developed. Nonhydrostatic models (NH models) explicitly resolve convection, and do not need (or only in a simple form) to parameterize convection. Nonhydrostatic models may react completely different to predicted decreases in relative humidity than the hydrostatic models currently employed. For a case study Hohenegger et al. (2008) found that precipitation *increased* over a dryer soil in a non-hydrostatic model, whereas hydrostatic models showed *decreases* of precipitation.

By using a NH model the lifecycle and meso-scale organization of convective storms is also expected to become more realistic. This influences the diurnal cycle of convective precipitation over land, for which hydrostatic models display longstanding deficiencies (Guichard et. al, 2003). But more importantly, this also impacts on the distribution of precipitation along the coastal zone and the distribution of the extremes, For August 2006 – a case with a strong northwesterly flow over a warm North Sea -- Lenderink et al. (2009) showed that the distribution of precipitation was shifted towards to sea, with the most intense precipitation occurring just over sea instead of just inland of the coast as observed. Also, the highest daily precipitation sums were underestimated, apparently caused by a lack of mesoscale organization of the convective systems.

Besides the more fundamental differences between hydrostatic and nonhydrostatic models, the difference in resolution also matters. The typical resolution of 2 km in nonhydrostatic models allows the exploration of precipitation extremes at different scales: from the local kilometer scale to a scale of tens of kilometer. This is not feasible with the current hydrostatic models that run at present at a resolution of around 20 km resolution. Scale dependencies of precipitation extremes are expected to considerable since at small scales and short time scales the convective cloud dynamics play an important role (giving rise to a 14% per degree increases in the observations), whereas at larger scales the moisture availability (7% per degree) could act as an important limitation. Therefore our hypothesis is that there are strong dependencies of the change in precipitation extremes on the spatial scale (up to a factor of two).

Both the dependency of the intensity of hourly precipitation extremes on temperature (Lenderink and Van Meijgaard, 2008) as well as the dependency of coastal precipitation on sea surface temperature (under favorable circulation conditions with strong convection) (Lenderink et al. 2009) are approximately 14% per degree. Combining these, this could imply that with a temperature increase of 4-5 degrees (which appears possible at the end of this century) shower intensities under certain conditions could be twice as large as presently observed.

The observational relationships between precipitation intensities and the mean atmospheric profiles of temperature and humidity profiles in the Netherlands will be explored using radiosondes and radar data and compared with the model derived relationships (Nuijens et al. 2009), as well as the relationships between the cloud sizes and the precipitation intensities (Neggers et al.). This will provide critical tests on the realism of the resolved precipitating clouds in the high-resolution HARMONIE model.

In summary, our main goal is to study changes in convective precipitation in the future climate, focusing on small scales and regional differences within the Netherlands.

6.2 Approach and methodology

In this project we will explore local precipitation extremes the Netherlands within the newly developed NH model HARMONIE. This is done by:

1. Exploring the relations between hourly precipitation extremes, atmospheric temperature and atmospheric humidity for the present-day climate as done in Lenderink and Van Meijgaard (2008, 2009). This is a necessary evaluation of the model quality with respect to the simulation of the present-day climate.
2. Exploration of scale dependencies derived from rain radar data and comparison to model results.
3. Exploring how changes in absolute humidity and relative humidity derived from future climate model results impact on precipitation extremes.

Further regional differences in extreme precipitation are studied within HARMONIE, with a focus on the influence of warm temperatures in the North Sea. This is done by:

4. Exploring meso-scale organization and regional differences in convective precipitation for the present-day climate, with a focus on cases with a strong coastal effect due to warm north sea temperatures (like August 2006).
5. Exploring future analogues of Summer/August 2006, with a special emphasis on the potential of very severe showers (+100%) in the future.

A small portion of this project (one year PhD continuation of the project IMPACT of the KvK first tranche) is devoted to the further evaluation and development of the meso-scale dynamics in HARMONIE and providing output statistics.

6.3 Scientific deliverables and results

Nonhydrostatic climate modeling in new and rapidly developing field. Our main scientific goal is to establish how atmospheric convection responds to the expected increase in absolute humidity in the future, combined with changes (presumably a reduction) in relative humidity, with emphasis on

1. estimating changes in precipitation extremes at different at spatial and temporal scales in general
2. establishing whether and under which conditions the scaling of hourly precipitation extremes on temperature and humidity derived from the present-day climate can be used as a predictor of climate change.
3. understanding (and narrowing down) uncertainty ranges in present-day state of the art simulations.

6.4 Integration of general research questions with hotspot-specific questions

The occurrence of precipitation extremes at different scales is important for many hotspots. Local, hourly (or even sub-hourly) precipitation extremes are mainly important for the urban area (Hotspots Haaglanden and Rotterdam) and Schiphol. Precipitation extremes at larger scales are important for the rural area (Hotspots rural areas and shallow waters). The intensity of showers is important Schiphol airport safety and capacity planning. The hotspots Haaglanden, Rotterdam, and Schiphol airport could all be affected by possible coastal effect in precipitation.

6.5 Societal deliverables and results

Expected results to serve society are

- Better quantified estimates of small scale (sub) hourly precipitation extremes.
- Estimates of spatial and temporal scales of (changes in) precipitation extremes.
- A quantified indication whether (or not) very severe showers with intensities of +100% compared to presentday are possible in the future.

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