Hydrological Modelling for Assessing Climate Change Impacts at different Scales (09-063180-DSF)

MIDTERM REPORT – SCIENTIFIC PROGRESS AND STATUS (January 1, 2008 – June 30, 2010)

Contents

1. Scientific progress during the first half project period

1.1 Project plan

1.1.1 Objectives

The scientific objectives of HYACINTS are:

- To make a full dynamic coupling of a climate model code (HIRHAM) and a distributed physically based hydrological model code (MIKE SHE).
- To further develop precipitation downscaling and bias correction methods when converting climate model results to hydrological model inputs.
- To develop grid refinement methods for hydrological models and methodologies for optimal conceptualisation, simulation and downscaling of complex geological environments.
- To develop new methods for estimation of precipitation from remote sensing data, particularly aimed at mountainous regions with poor data coverage.
- To establish a coupled climate-hydrological model for the entire Denmark based on the regional climate model HIRHAM and the MIKE SHE based national hydrological model (DK-model) and to assess the hydrological change at local scale at selected cases.
- To assess the uncertainties related to prediction of climate change effects on water resources at local scale, including all sources of uncertainty (climate scenarios, model structure, geological interpretations, model parameters and adaptation strategies).

1.1.2 Partners

The HYACINTS consortium comprises the following 12 partners with the responsible scientists listed in brackets:

- GEUS, Geological Survey of Denmark and Greenland (Jens Christian Refsgaard)
- KU, Department of Geography and Geology, University of Copenhagen (Karsten Høgh Jensen)
- AU, Department of Earth Sciences, University of Aarhus (Steen Christensen)
- DMI, Danish Meteorological Institute (Jens Hesselbjerg Christensen)
- DHI (Mike Butts)
- ALECTIA A/S (Jens Dyrberg Nielsen)
- GRAS, Geographic Resource Analysis & Science A/S (Mikael Kamp Sørensen)
- VCS Denmark (former Odense Water Ltd) (Troels Kærgaard Bjerre)
- KE, Copenhagen Energy (Michelle Nørmark Kappel)
- AKV, Århus Water & Wastewater (Jørn-Ole Andreasen)
- MC-Odense, Environment Centre Odense, Ministry of Environment (Dirk-I. Müller-Wohlfeil)
- MC-Roskilde, Environment Centre Roskilde, Ministry of Environment (Jens Asger Andersen)

In addition

- I-GIS (Niels-Peter Jensen)

is associated through a SME project.

1.1.3 Project elements

The project is organised in workpackages (WPs) with the following key elements:

- WP1.1: Coupling of HIRHAM and MIKE SHE (PhD project - Søren Højmark Rasmussen, DMI with supervisors from KU, DMI, DHI, GEUS)
- WP1.2: HIRHAM migration to OpenMI (Postdoc activity – Martin Drews, DMI)
- WP1.3: MIKE SHE migration to OpenMI (scientist activity – Mike Butts and colleagues, DHI)

- WP2.1: Telescopic mesh in groundwater models (scientist activity – Mike Butts and colleagues, DHI)
- WP2.2: Complex geology (PhD project – Troels Norvin Vilhelmsen, AU)
- WP3.1: Precipitation and remote sensing (PhD project – Lars Boye Hansen, GRAS. Converted to Postdoc – Mads Olander Rasmussen, GRAS with supervision from KU and GRAS)
- WP3.2: International test case (scientist support – Jens Dyrberg Nielsen and colleagues, ALECTIA)
- WP3.3 Coupled model for Denmark (PhD project – Morten Andreas Dahl Larsen , KU with supervision from KU, GEUS, DMI, DHI)
- WP3.4 Conversion of DK model to coupled model (Postdoc – Mikkel Mollerup, GEUS)
- WP4.1 Geological uncertainty (Postdoc – Dorthe Seifert Teide, ALECTIA)
- WP4.2 Uncertainty on hydrological change (PhD project – Lauren Paige Seaby, GEUS with supervision from KU, GEUS, DMI)
- WP5.1: Project management and dissemination (Jens Christian Refsgaard, GEUS)

In addition a SME project is associated to HYACINTS:

- Digital Geological Modelling Software (Niels-Peter Jensen, I-GIS)

1.2 Project activities - progress

1.2.1 PhD and Postdoc staffing

The status of the five PhD projects are:

- Søren Højmark Rasmussen, DMI, started in August 2008. Søren has had paternal leave for a 5 months period. Compared to the original project plan this PhD project is delayed by 9 months, partly due to a late recruitment and partly because Søren has had a paternal leave in 2009.
- Troels Norvin Vilhelmsen, AU, started in October 2008. Troels has passed his midterm exam and finished most of his teaching obligations as well as all his mandatory PhD courses. The remaining year will therefore mainly be focused on scientific work. The study largely follows the original study plan. Troels' PhD is co-funded (1/3) by AKV.
- Lars Boye Hansen, GRAS, started April 2009 – later than expected due to delays in the recruitment procedure. The scientific work proceeds as planned but due to personal reasons Lars Boye Hansen has decided not to continue with the PhD. The input will continue as a post doc and a new candidate is in place - Mads Olander Rasmussen will start in September 2010. The change will only involve a small delay compared to the work plan for Lars Boye Hansen.
- Lauren Paige Seaby, GEUS, started in August 2009. Lauren's project is proceeding according to the original work plan. Lauren's PhD is co-funded by FIVA (samfinansieret stipendium fra FI, sagsnr. 645-08-0116).
- Morten Andreas Dahl Larsen, KU, started in December 2009. Morten's PhD is, in accordance with the plans, still in its start phase and has included considerable teaching and framing of the research activities.

The status of the three postdoc projects is:

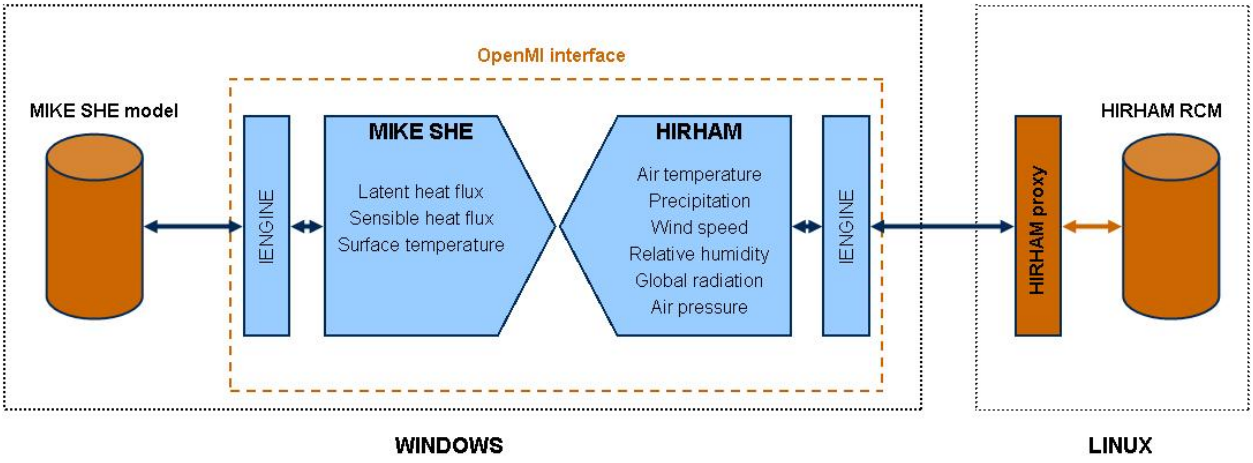
- Martin Drews, DMI, has worked on preparing the HIRHAM code for the coupling with MIKE SHE on a part time basis since the beginning of 2008. Martin has had part-time paternity leave from May 2010 to October 2010.
- Dorthe Seifert Teide, ALECTIA, started in January 2009 spending about 75% of her working time on the postdoc activities and the remaining work time at other ALECTIA activities. The postdoc activities are carried out at GEUS who is providing office and computer facilities. Dorthe is on maternal leave during the period January – September 2010.
- Mikkel Mollerup, GEUS, has been recruited specifically for a 12-months postdoc position starting February 2010.

As can be seen, the HYACINTS activities started “soft” with limited activities in 2008 and full staffing not achieved until 2010. A soft start with limited activities during 2008 was also initially planned, but this has been amplified by delays of recruiting two of the first three PhD students and by paternal/maternal leaves.

1.2.2 Scientific activities (WPs1-4)

MIKE SHE – HIRHAM coupling and applications to Denmark (WPs 1.1, 1.2, 1.3, 3.3, 3.4)
The coupling of HIRHAM and MIKE SHE was recognised as the most high-risk HYACINTS activity, because the two codes are both large and complex and furthermore running on two different software platforms (Windows and Linux) that cannot in a straightforward manner communicate with each other. The coupling, illustrated in the figure below, has had the following key elements:

- The two model codes MIKE SHE and HIRHAM has been prepared for the coupling by migrating them to the OpenMI standards (Gregersen et al., 2007). This has involved significant modifications of both codes. For MIKE SHE this has involved upgrading of a new Soil Vegetation Atmosphere Transfer module (MIKE SHE SVAT) originally developed by Overgaard (2005). For HIRHAM this has involved the design and implementation of a new run-time scheme to allow execution of the model to be controlled externally during a run, i.e. by the OpenMI coupler. Furthermore, a model proxy was developed in order to make the model virtually OpenMI compliant.
- Establishment of a communication software solution between the Windows and Linux platforms. This has required substantial efforts and is now functioning in principle by use of amongst others the mono™ software development platform – an open-source implementation of the widely used Windows dot-NET platform. The developed solution principally allows for HIRHAM to run on a massively parallel Linux-based computer with MIKE-SHE still running on the Windows platform.
- New software for upscaling/downscaling information from MIKE SHE and HIRHAM that operates on different spatial grids and time steps.



The most difficult and risky issues of the coupling have all been successfully solved. The first simulation results of an operational coupling are expected to be produced in October 2010. The remaining work will deal with fixing the remaining bugs and making the coupling scheme more efficiently. Ultimately, the coupled code will be based on HIRHAM running on DMI’s high performance Linux computer system (Cray XT5) communicating with MIKE SHE running on a high performance Windows PC.

In parallel to the work with the coupling of the two model codes, a number of tests have been carried out to prepare studies of coupled versus uncoupled models, both for the FIFE experimental site in Kansas

(Sellers et al., 1992), for the Skjern Å catchment where comprehensive research data from amongst others flux masts exist from the HOBE project (www.hobecenter.dk) and for Denmark as a whole.

Scaling of hydrological models – telescopic mesh (WPs 2.1, 2.2)
Two alternative approaches for using refined grid (telescopic mesh) around model sub-areas of particular interest are being investigated, namely one based on further development of MIKE SHE technologies and another based on a new MODFLOW Local Grid Refinement module (MODFLOW-LGR) developed by Mehl and Hill (2007).

The MODFLOW-LGR method has been tested against a hypothetical setup with complex geology. This has shown somewhat surprising results (see Section 1.3.2 below) which are being analysed in close cooperation with the USGS developers. Furthermore, work is in progress for testing it on one of AKV's well fields, Ristrup, which is an area with buried valleys and complex geology.

For the MIKE SHE approach it was originally envisaged to exploit the OpenMI potential for coupling a local and a regional MIKE SHE model. This approach is in principle similar to Mehl and Hill (2007) which experience has shown may have drawbacks in terms of computational efficiency (see Section 1.3.2). Therefore it was decided to follow an alternative approach coupling the MIKE SHE surface water processes (Butts and Graham, 2008) to a finite element groundwater code FEFLOW (Diersch, 2002). A design document for the MIKE SHE_FEFLOW coupling has been prepared and the software work has been initiated. The case studies to be used for testing and evaluation of this method have been identified together with Environment Centre Odense and the water company VCS Denmark.

Application in data sparse areas (WPs 3.1, 3.2)
The originally planned HYACINTS activities in this field were focused on development of a new methodology for estimating precipitation from remote sensing data in mountainous areas with limited field data availability and testing of this in an international test case. Due to lack of suitable in-situ data in an area with significant orographic effects the scope has been changed towards more generalised spatial downscaling of existing satellite products and with a focus on Western Africa to ensure synergy with numerous other research activities at KU/IGG in the region.

The most promising methodology for remote sensing based precipitation estimation in such areas has been identified. Furthermore, a suitable test area in Western Africa has been selected and cooperation with the EU research project AMMA (African Monsoon Multidisciplinary Analyses) has been established. The decisions in this regard have been supported by interactions with the internationally leading research group at University of Columbia, New York during Lars Boye Hansens's PhD stay there. During the stay at University of Columbia the concept of a novel method for spatial disaggregation of the information from existing satellite based rain fall products was developed and tested. The overall principle is to merge the information from another and higher resolution data source to identify omission/commission errors in the rain fall products and thereby improve the rain fall determination accuracy at a higher spatial resolution. Specifically this can be done by using land surface temperature in app. 4 km grid resolution as a means of verifying precipitation events at the original scale of 25 km. The results looks very promising and additional tests will help to further develop the method in the coming months. The method was presented to the Columbia community at a seminar in June 2010 and was positively received.

The international test case is intended as use of HYACINTS methods in a practical case. The methods to be tested should include - but not necessarily be limited to - the remote sensing based precipitation. In accordance with project plans this activity is located towards the end of the project, where a number of

HYACINTS methodologies can be expected to be developed. Hence, no specific activities have been carried out until now.

Uncertainty (WPs 4.1, 4.2)
HYACINTS will assess how different sources of uncertainty cause uncertainty on climate change impacts on hydrology. The two sources of uncertainty being investigated are: (a) uncertainty on geological interpretations and hydrogeological parameters in groundwater models; and (b) uncertainty on climate models and downscaling/bias correction methods.

The Langvad Å catchment south of Roskilde has in cooperation with KE and MC-Roskilde been selected as the field site for studying the importance of geologically related uncertainty. Data from five different 3-dimensional hydrostratigraphical (geological) models have been collected. These models differ from each other with respect to number of layers and location of geological units. A hydrological model covering a total area of 465 km^2 has been constructed and five alternative models that are identical except for the different geologies have been established. The five models have been calibrated against measurements of hydraulic head and river discharge and validated using split-sample tests. Based on this it was concluded that the five models are equally plausible. The next step in the analysis will be to impose climate change signals to the five alternative models and see how different they react, or in other words to which extent the five different geologies result in uncertainty on the predicted climate change impacts.

The analysis of uncertainties on climate models is based on results from the ENSEMBLES project that are available through a database created and hosted by DMI. Daily climate data from a combination of three Global Climate Models (GCMs) and nine Regional Climate Models (RCMs) are downloaded for the entire Denmark for the period 1960 - 2100. The data are made ready for use in hydrological models by two different bias correction methods. When this has been completed the different climate change projections from the combinations of GCMs, RCMs, bias correction methods and time periods will be used as input to GEUS national water resources model (the DK-model).

1.2.3 SME project

The project was initiated in February 2009 by calling for SMV cooperation. Two companies applied for the project, and meetings were held with both. The best qualified SMV was selected for cooperation (I-GIS). A workshop was held and potential needs for new technologies within the field of digital geological modelling of complex geology were identified. Activities to develop improved software tools have been initiated in two fields: (a) voxel (=volume pixel) grid modelling, which has large advantages for complex geologies compared to the traditional handling of geology by continuous layers and lenses; and (b) improved interaction between the geological modelling and the groundwater modelling.

The workflow of developing new tools and procedures to enhance voxel modelling is done in close collaboration between a HYACINTS geological modelling group and the SME software developers. The first stage is agreeing on the details of the new functionality. The developers then implement the ideas and hereafter the geological modelling group tests the new functionality and uses it for modelling. By using the new functionality, new ideas of further development evolve. This gives the project a smooth flow, the added functionality is used from day one, and a strict plan for the development does not need to be in place from the start. However, this iterative approach slows down the implementation speed, and it is expected that the project completion date needs to be rescheduled to the end 2011.

1.2.4 Project management and dissemination (WP5)

Six combined project and steering committee meetings (full days) with participation of all partners were held during the first 2½ years. At these meetings project progress and methodologies have been discussed and project work plans have continuously been detailed and updated. In addition, many meetings with only a few partners have been held, typically addressing issues of particular interest for a single WP.

HYACINTS has arranged two seminars with presentations from international and Danish scientists:

- September 23, 2008. Climate Change Impacts on Water Resources.
- September 10, 2009. Uncertainties in Climate Change Impacts on Water Resources.

Both seminars had more than 70 participants from universities, research institutes, public authorities, water companies, consulting firms and NGOs. The seminars have formed a basis for dissemination and discussion of the objectives and goals of the HYACINTS as international and national scientists working at similar projects have participated and presented their related activities. Furthermore, end-users from the Danish water management community have given feed-back to the HYACINTS project and partners at these events. This has not resulted in substantial changes in the project but contributed to the widening-up of activities and perspectives.

The dissemination has been supported by news at the project website www.hyacints.dk and electronic newsletters.

1.3 Scientific achievements and perspectives

The HYACINTS project elements comprise scientific novelty and perspectives as described below.

1.3.1 HIRHAM – MIKE SHE coupling

Traditionally, climate change impacts on hydrology have been simulated by forcing hydrological models with output from general circulation models (GCM) or regional climate models (RCM). This uncoupled approach neglects feedback from the land surface to the atmosphere. As a proper representation of land surface conditions, in particular the root zone soil moisture, is recognized to be crucial for describing the energy balance of the land surface – atmosphere interaction (Sellers and Hall, 1992), research studies using fully coupled land surface – atmosphere models have investigated to which extent the uncoupled approach affects the simulation results (Overgaard, 2005; Maxwell et al., 2007; Maxwell and Kollet, 2008). Maxwell and Kollet (2008) concluded that the groundwater depth, which results from lateral water flow, plays a critical role for the land-energy feedback. The fully coupled models reported so far in the literature have not included coupling of a hydrological model with lateral flow components to an RCM, like in HYACINTS. We are aware that other international research groups are working on similar ventures, e.g. a coupling of the HydroGeoSphere hydrological code to NCAR's Earth System Model code CCSM4 (Therrien, 2010). The HIRHAM-MIKE SHE coupling is novel and unique, and it will comprise scientific perspectives of broad international interest. It will be implemented in a well tested national scale model comprising the most important hydrological processes including feed back mechanisms. Hence it is expected to enable more accurate climate change predictions and reduce the overall climate modelling uncertainty.

1.3.2 Telescopic mesh

The novelty of the HYACINTS research in this field is related to (a) the investigations with two different methodologies; and (b) the investigations of the methods in highly complex geologies. The two methods under investigation have different strengths. The MODFLOW-LGR is unique in the sense that

it allows grid refinement both in the horizontal and the vertical directions. The MIKE SHE-FEFLOW only allows refinement in the horizontal directions. However, due to its finite element basis this approach is more flexible, allows higher levels of mesh resolution and hence is potentially more efficient than the finite-different based MODFLOW LGR.

The MODFLOW-LGR method was initially tested by its developers for application with relatively simple model setups showing that it leads to improved results and reduced computational time compared to other traditional telescopic mesh refinement methods such as variably spaced grids (Mehl and Hill, 2002). The initial investigations with the MODFLOW-LGR module carried out in HYACINTS suggest, however, that the routine can have so long execution times for models with more complex geologies and when the refined area occupy a large fraction of the entire model domain that the benefit of using the LGR option disappears. These results are being analysed

Combining the telescopic mesh with climate change modelling, e.g. using the coupled HIRHAM-MIKE SHE, will make it possible to propagate climate change projections down to very small scales, where the boundary conditions are suitably accounted for.

1.3.3 Data sparse areas – international test case

The initial results from the concept definition and first tests show promising results in terms of identifying omission/commission errors in the existing rain fall products based primarily on physically based analyses of surface properties at a higher spatial resolution. The statistical performance of the rain fall products is thus expected to increase while at the same performing a spatial downscaling of the satellite based precipitation.

1.3.4 Uncertainty

Previous studies have assessed the importance of geological uncertainty on various aspects of groundwater model predictions (Højberg and Refsgaard, 2005, Troldborg et al., 2007; Seifert et al., 2009) but no studies, like the one in HYACINTS, have been reported on the importance of geologically related uncertainty on climate change impact predictions.

The uncertainty analyses constitute a natural next step on top of the climate change impact assessments that previously have been made in Denmark (Roosmalen et al., 2007, 2010). Some studies have reported on the differences of outputs from combinations of several GCMs and RCMs (Déqué et al., 2007), but no studies have been reported with so comprehensive analyses as presently being carried out in HYACINTS with effect studies using combinations of GCMs, RCMs and bias correction methods. The ENSEMBLES data are quite new and of broad scientific and practical interest. These data have so far only to a very limited extend been exploited beyond the ENSEMBLES project itself. It is planned to apply the HYACINTS results in the CLIWAT INTERREG project.

Combining the geological uncertainty and the climate modelling uncertainty makes it possible to assess the relative importance of the various sources of uncertainty as well as the combined uncertainty. We expect that the uncertainty of alternative prediction variables (e.g. river discharge, groundwater well capture zones, stream-aquifer interaction) will be dominated by different sources of uncertainty.

1.3.5 Digital geological modelling software - SME project

The innovative aspects of the digital geological software tools being developed are the improved functionalities to handle complex geologies fully three-dimensionally in a manner that makes it easy to use the geological information in groundwater modelling.

1.4 References

Butts, MB, Graham DN (2008) Evolution of an integrated surface water-groundwater hydrological modelling system. In Proceeding of IAHR International Groundwater Symposium - Flow and Transport in Heterogeneous Subsurface Formations: Theory, Modelling & Applications, Istanbul, Turkey, June 18-20, 2008.

Gregersen JP, Gijsbers PJA, Westen SJP (2007) OpenMI: Open modelling Interface. Journal of Hydroinformatics, 9(3), 175-191.

Déqué M, Rowell DP, Giorgi F, Christensen JH, Rockel B, Jacob D, Kjellström E, Castro Md, Hurk Bvd (2007) An intercomparison of regional simulations for Europe: assessing uncertainties in model projections. Climatic Change, 81, 53-70.

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Højberg AL, Refsgaard JC (2005) Model Uncertainty - Parameter uncertainty versus conceptual models. Water Science and Technology, 52(6):177-186.

Maxwell RM, Chow FK, Kollet SJ (2007) The goundwater-land-surface-atmosphere connection: Soil moisture effects on atmospheric boundary layer in fully-coupled simulations. Advances in Water Resources, 30, 2447-2466.

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Mehl S, Hill MC (2007) MODFLOW-2005, the U.S. Geological Survey modular ground-water model -- documentation of the multiple-refined-areas capability of local grid refinement (LGR) and the Boundary Flow and Head (BFH) Package: U.S. Geological Survey Techniques and Methods 6-A21. 13p.

Overgaard J (2005) Energy-based land-surface modelling: New opportunities in integrated hydrological modelling. Ph.D. Thesis. Environment and Resources DTU, Technical University of Denmark.

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Roosmalen Lv, Christensen JH, Butts M, Jensen KH, Refsgaard JC (2010) Quantifying climate change signals for Denmark and assessing the robustness for hydrological impact studies. Journal of Hydrology, 380, 406-419.

Seifert D, Sonnenborg TO, Scharling P, Hinsby K (2008) Use of alternative conceptual models to assess the impact of a buried valley on groundwater vulnerability. Hydrogeology Journal, 16:659-674.

Sellers PJ, Hall FG (1992) FIFE in 1992 – Results, scientific gains and future research directions. Journal of Geophysical Research, 97(D17), 19091-19109.

Sellers PJ, Hall FG, Asrar G, Strebel DE, Murphy RE (1992) An overview of the first international satellite land-surface climatology project (ISLSCP) field experiment (FIFE). Journal of Geophysical Research, 97(D17), 18345-18371.

Therrien R (2010) Personal communication. University Laval, Quebec, Canada.

Troldborg L, Refsgaard JC, Jensen KH, Engesgaard P (2007) The importance of alternative conceptual models for simulation of concentrations in multi-aquifer system. Hydrogeology Journal, 15:843-860.

2. Publications and other dissemination activities

2.1 International journal papers

None so far.

2.2 International papers in conference proceedings and books

2.3 Oral presentations at international conferences

- Refsgaard JC, Højberg AL, Troldborg L, Sonnenborg TO (2008) The Importance of Geological Uncertainty for Flow and Transport Modelling. Eos Trans. AGU, 89(53) Fall Meet. Suppl., Abstract H41H-01
- Drews M, Rasmussen SH, Christensen JH, Butts MB, Overgaard J, Lerer SM, Refsgaard JC (2009) Hydrological Modeling for Assessing Water Availability Due to Climate Change Impact at Different Scales. Invited talk and abstract at the International Workshop on Climate Information Services in Supporting Mitigation and Adaptation to Climate Change in Energy and Water Sectors, Jakarta, Indonesia, March 2009
- Drews M, Rasmussen SH, Christensen JH, Butts MB, Overgaard J, Lerer SM, Refsgaard JC (2009) Dynamical coupling of the HIRHAM regional climate model and the MIKE SHE hydrological model. Poster presented at the 2nd Lund Regional-scale Climate Modelling Workshop on "21st Century Challenges in Regional-scale Climate Modelling", May 2009. Poster S2-136
- Seaby LP, Sonnenborg TO, Refsgaard JC, Christensen JH (2010) Quantification of climate change signals and uncertainty in hydrological change simulations for Denmark. Geophysical Research Abstracts Vol. 12, EGU2010-14622, EGU General Assembly 2010

2.4 Poster presentations at international conferences

- Butts MB, Overgaard J, Styczen M, Gudbjerg J, Lønborg M, Lørup JK, Graham D, Sinding P (2008) Expanding integrated modelling capabilities using OpenMI. Eos Trans. AGU 89(53), Fall Meet. Suppl., Abstract H41G-0960
- Rasmussen SH (2008) Coupling of a meteorological and a hydrological model for climate purpose. Poster presented at the EU project WATCH General Assembly, November 2008
- Rasmussen SH (2009) Coupling of a meteorological and a hydrological model for climate purpose. Poster presented at LGGE PhD School, January 2009.
- Seaby LP, Refsgaard JC, Sonnenborg TO, Jensen KH (2009) Uncertainty in Hydrologic Simulations of the Effects of Climate Change in Denmark. Poster presented at the ENSEMBLES Final Symposium, November 2009
- Rasmussen SH (2009) Coupling the regional climate model HIRHAM with the hydrological model MIKE SHE to improve land surface feedback processes. Poster presented at the EU project WATCH General Assembly, November 2009
- Vilhelmsen T N, Christensen S (2009) Testing MODFLOW-LGR for simulating flow around Buried Quaternary valleys - synthetic test cases. Poster presented at AGU Fall Meeting, December, 2009

2.5 National publications and popular articles

- Refsgaard JC, Sonnenborg TO (2008) Anvendelse af hydrologiske modeller til at vurdere klimaændringers effekter på grundvand og vandløb. ATV Vintermøde, Vingsted, 8 sider.
- Refsgaard JC, Sonnenborg TO, Henriksen HJ (2009) Klimaændringer i Danmark – hydrologiske effekter og usikkerheder. Vand & Jord, 16(4), 124-127.

2.6 National presentations and outreach activities

- Refsgaard JC (2008) Anvendelse af hydrologiske modeller til at vurdere klimaændringers effekter på grundvand og vandløb. ATV Vintermøde, Vingsted, 4-5 marts 2008.
- Refsgaard JC (2008) Klimaforandringernes betydning for vandkredsløbet. Workshop om det åbne land og klima arrangeret af Region Sjælland, Sorø, 24. november 2008.
- Refsgaard JC (2009) Klimaændringers effekter på grundvandsforhold. Interview til DR P1 og DR2 Deadline. 24. juni 2009.
- Vilhelmsen T N, Christensen S (2009) Test af to versioner af MODFLOW-LGR til simulering af grundvandsstrømninger i områder med begravede dale – syntetisk studie . ATV Vintermøde, Vingsted, 9-10 marts 2010.
- Rasmussen SH (2010) Klimaændringer og Vandets Kredsløb. Foredrag under Forskningens Døgn, Brønderslev Gymnasium, 22. april 2010.

2.7 HYACINTS seminars

- Copenhagen, 23 September 2008. Climate Change Impacts on Water Resources, 7 national and international speakers, 75 participants
- Copenhagen, 10 September 2009. Uncertainties in Climate Change Impacts on Water Resources, 8 national and international speakers, 70 participants

2.8 HYACINTS newsletters and flyers

- Flyer presenting HYACINTS, its objectives and expected outputs. February 2008. www.hyacints.dk
- Newsletter no 1, May 2008. www.hyacints.dk
- Newsletter no 2, June 2009www.hyacints.dk

2.9 Other dissemination activities

- Distribution of HYACINTS flyers at the COP 14 conference in Poland, December 2008.
- Web page on HIRHAM-MIKE SHE coupling: http://www.dhigroup.com/News/2009/02/02/OpenMIForClimateModelling.aspx

2.10 Internal reports

2.10.1 Technical notes

- Rasmussen SH. Aggregation and disaggregation; HIRHAM-MIKE SHE. June 2009
- Drews M. Note on linking MIKE-SHE (Windows) and HIRHAM (Linux) using the mono™ development platform. June 2009
- Lerer S, Butts M. MIKE SHE coupling tests. June 2009
- Seifert Teidi D. Description of the hydrological model for Langvad Stream catchment area. June 2009

2.10.2 HYACINTS steering committee meetings

- SCM#1: Copenhagen, 14 January 2008
- SCM#2: Copenhagen, 22 September 2008
- SCM#3: Aarhus, 23 January 2009
- SCM#4: Odense, 11 June 2009
- SCM#5: Copenhagen 19 October 2009
- SCM#6: Aarhus, 9 February 2010
- SCM#7: Copenhagen, 2 September 2010

2.10.3 HYACINTS annual reports to the Danish Research Council

- Short status report, March 30 2008
- 1st Annual status report, March 30 2009
- 2nd Annual status report, March 30 2010
- Mid-term report, September 30 2010

2.10.4 Other reports

Vilhelmsen T N (2010) Progress report of PhD study: Evaluation of the practical application of two versions of MODFLOW-LGR within regional scale groundwater models, Aarhus University, 26th of March, 2010

3. Submitted and planned publications – international journal papers

3.1 Submitted

- Refsgaard JC, Christensen S, Sonnenborg TO, Seifert D, Højberg AL, Troldborg L. Strategies for handling geological uncertainty in groundwater flow and transport modelling. Submitted to Advances in Water Resources, June 2010. In review.
- Vilhelmsen TN, Christensen S. Evaluation of the practical application of two versions of MODFLOW-LGR within regional scale groundwater models. Submitted to Ground Water, September 2010

3.2 In preparation

- Rasmussen, SH, Butts MB, Lerer SM, Refsgaard JC. Regional climate model sub-grid representation of surface fluxes and soil moisture by MIKE SHE SVAT
- Rasmussen, SH et al. Domain size and resolution in HIRHAM local climate simulations.
- Larsen, MAD et al. Modelling of three surface types using a combined MIKE SHE/SVAT model
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