Knowledge for Climate

KKF-Model platform coupling

Inventory of available and accessible data and models and design and first setup for a pilot system

KfC/038B/2011 KKF01b

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(1) Deltares

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1 Summary

This research carried out an inventory of the currently available hydrological and hydrodynamic models for the Rhine/Meuse watershed including the delta of The Netherlands and the North Sea. These models are linked using existing technology (Delft-FEWS) into a data and model framework. This allows the quick and consistent determinations of climate scenarios based on the outcome of global or regional climate models. It is concluded that the existing models can be linked without having to adjust the models and initial trails show that run-times remain acceptable. The end product of the research, a test version of the coupled system, can be used in further research and may be extended to include other models such as habitat and nature models.

2 Introduction

Development of adaptation strategies or natural resources management (water, nature, air) to deal with climatic change in the Netherlands requires information of possible future development of physical boundary conditions as well as changes in socio economic development. During the past years much research has been carried out to provide this type of information at various research centres. The results are published in many reports and scientific papers. The quantitative results of this research, to be used for further analysis are, however, not easy to access by third parties.

This project aims at *(1)* consolidate these results and tools that were used to provide them and making these more useful and easily accessible for further analysis (in close cooperation with sub-project tailoring) *(2)* to develop interfaces between the climate models and climate impact models *(3)* carry out selected pilot studies based on the integration of the different components (in cooperation with sub projects Tailoring and Future Weather).

The end product will be a data and modelling platform that facilitates the supply of consistent scenarios for physical boundary conditions as well as for other boundary conditions. Initially this platform will be limited to data exchange; later fully coupled models may be constructed. Such a platform allows for regularly updating and guarantees that the scenarios will be based on up-to-date science and technology.

By setting up a platform for coupling results and models used for impact assessment studies by different research organisations, the objective of the KfC Climate facility coupling sub-project, is to facilitate the supply of more consistent scenario's for physical boundary conditions. These scenarios can be used for natural resources management and spatial planning. Such a facility is also able to capture new models and run those with the same consistent data set. As such, it will be possible to investigate uncertainties associated with these models by comparing them side by side within the same environment and learn from news model as they evolve.

The research questions will be the following:

1. Which data and models are available that can be used to supply scientifically sound information on future changes in natural and socio-economic boundary conditions and their effect on spatial planning in the Netherlands?
2. Which combinations of modelling results provide consistent future scenario's and how can we conceptually correctly use the one model results as input of the next model?

3 How can we translate the parameters supplied by the models describing the physical system into parameters needed to generate natural resources management strategies?

4 The characteristics of climate change are uncertain. What are the main sources of the uncertainty with respect to impact studies, i.e. what is the magnitude in terms of impact assessment and to what extent is this relevant for the design of adaptation strategies?

3 Approach and workplan

The section describes the approach taken in this project to come to a design and prototype of a model platform (to be called the KKF-System hereafter) that can be used to investigate the effects of different climate scenarios and forcings on the water systems of the Netherlands. The KKF-System will be based on existing models and technology; the climate scenarios are delivered by the KNMI. The KKF-System reads and stores those scenarios's and makes them available to the models within the KKF-System. Geographically the KKF-System will include the whole of the Rhine/Meuse basin, The Netherlands and the North Sea.

The FEWS-NL GRADE system (de Wit & Buishand 2007) is used as a starting point to build the KKF-System. As such, the core of the KKF-System will be Delft-FEWS. Delft-FEWS is used to provide a consistent user interface and data storage. In addition, it will run models and retrieve and analyse results. The different models withint the KKF-System will be linked using time series of boundary conditions. The KKF-System will be designed to be able to run scenario's up to 150 years in length. Detailed models like high resolution versions of the North sea model cannot be included into the KKF-System without adjustments because running these kind of models for 150 years is not feasible[1]. We will use the same procedure as already pioneered in FEWS-NL GRADE. Here, fast running models are employed for the whole period using daily time steps. However, during periods of interest, more detailed models that have longer run times (and require smaller timesteps) may be run. Within the KKF-System it should be possible to run models at daily time steps and use the results of these runs as a starting point for modeling certain periods at smaller time steps.

The building blocks for the KKF-system will be taken as much as possible from current (operational) systems build with Delft-FEWS. The advantage is that it requires little effort to copy these building blocks to the KKF-System but also that new developments in these systems can be easily incorporated later.

For this project the climate forcing data will be used as-is. We will assume that the climate data that the KKF-System will ingest is the best available. The KKF system will provide the framework to apply bias correction but they will be no bias correction development within this project. Earlier work with Delft-FEWS and seasonal forecasting systems (J. Schellekens et al. 2008) showed that Delft-FEWS can handle the tasks needed for bias correction of climate models easily.

1. *During the later stages of the project it became clear that KNMI is not able to supply the full 150 year before the end-date of this project. This means that although we have designed the system to be able to run with 150 years of data the actual pilots will be executed with the available data: 30 years*

In, addition, the KKF-System itself can be used to facilitate the determination of bias corrections.

Little time will be spent in this phase looking at user needs. The rationale behind this is that we will use and link existing models that are already tailored to end user needs. The linking of the models provides the added value to existing users.

The work will be executed using the following steps:

5 Make an inventory of the different models and Delft- FEWS systems that are available. *In this stage we will not make any new models but only use already available models. Once better -- or "more official" -- models are available they can easily be plugged into the system to replace the components we have chosen now..*

6 Make a link and forcing diagram of these models. *This will show how the models may be connected and the forcings needed for each model. Within the model we will regard different land-use due to changes in nature/ecology or socio-economic developments as independent forcings to the model*

7 Investigate techniques to quickly find times of interest in the long series of climatic forcing. *This can be done by combining an analysis of the climate forcing and output of the available fast running (but not the most accurate) models. These periods can later be investigated with more detailed models in the system.*

8 Make the pilot KKF-System. *The selected models and parts of other Delft-FEWS systems will be merged into the KKF-System. The database of the KKF-System will be filled with the available climate scenarios. Simple test will be executed to ensure the model links are set-up properly*

9 Perform case studies. *Use the KKF-System to perform calculations with the climate scenarios focusing on specific results for the case studies (i.e. the combined occurrence of a storm surge and a high flow in the River Rhine).*

10 List alternative (hydrological) models for later improvement of the KKF-System. *Many (hydrological) models are specially calibrated to perform best at current climatological conditions. This may not be the case in a changing climate. The use of alternate models and multi model ensembles (to get a better idea of the uncertainties involved) will be investigated.*

4 Overview of available hydrological systems and models

4.1 Introduction

The different modelling systems for the water infrastructure in The Netherlands are divided based on their application (real-time, scenario studies), the user(s) of the system and the geographical area they cover. For the purpose of this work, we focus on systems that:

- Can run using daily timesteps or on an event basis.
- Run fast enough to allow the systems to run over approximately 150 years.
- Can be adjusted relatively simple to fit the first two requirements

Geographically we can identify the following systems:

- Systems that include models to predict the flow for the main rivers (Rhine and Meuse) upstream of the Dutch border
- Systems that (in detail) model the main Rivers within The Netherlands
- Systems that model the local (Waterboard) systems within The Netherlands (excluding Lake IJssel)
- Systems that include models for the coastal water level in the North sea and the Waddenzee

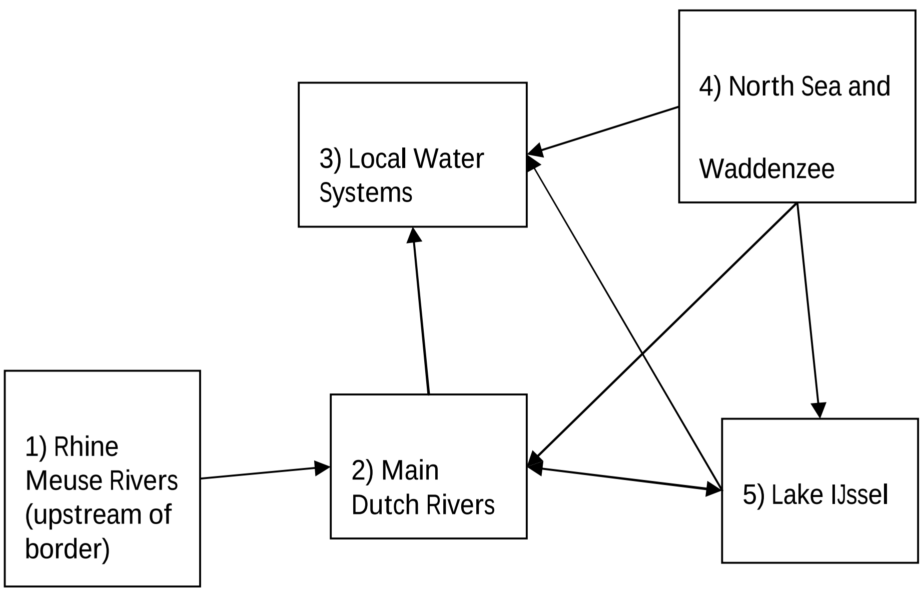


Figure 4.1 Schematical layout of the available systems. Arrows indicate assumed connections, either one-way or two-way

For each system an inventory of the following points is needed:

1. Climate forcing: parameters, time steps and resolution
2. Boundary conditions
3. Link with other systems
4. Run-time of the models (e.g. number of seconds per day simulation)

4.2 GRADE (Rhine/Meuse rivers, main rivers)

Generator of Rainfall and Discharge Extremes (GRADE, de Wit & Buishand 2007) will be used to model the Meuse and Rhine discharges under different scenarios. The focus in the beginning of the project will be mainly on the hydrological modeling. GRADE includes a stochastic rainfall, temperature and evaporation generator to generate very long synthetic time series (>1000 years). These timeseries are used to drive the models in GRADE. We will replace the synthetic hydrological forcing by forcing from the KNMI climate scenarios.

4.2.1 Forcing

The HBV hydrological model for the Rhine needs daily precipitation and temperature, the model for the Meuse needs daily precipitation, temperature and evapotranspiration. These can straightforwardly be extracted from the meteorological variables.

4.2.2 Time steps

GRADE can be driven by daily timestep climatic forcing. The system can run selected periods using hourly timesteps with more sophisticated SOBEK hydrodynamic models. It downscales the HBV results to force the hydrodynamic models for these periods. Originally, the SOBEK models generated daily accumulated flows, while the model timestep was hourly. This has been changed to provide hourly upstream boundary conditions for the lower stretches of the Rhine-Meuse basins.

4.2.3 Links

The output of GRADE at Werkendam, Krimpen a/d lek, and Keizersveer can be used to feed models of the lower stretches of the Rhine/Meuse basin. Earlier versions of the hydrodynamic models in GRADE stopped at Lobith and Borgharen. This latest version of GRADE already includes a portion of the main rivers taken from the FEWS-NL/FEWS-RIVERS merger (van der Veen 2006; van der Veen & Buiteveld 2005) built from a set of 8 SOBEK models for the.

Table 4.1 The basic models used to build the complete SOBEK model for the Rhine in GRADE (taken from van der Veen & Buiteveld 2005)

Naam	prefix
Fews_Rijn Rhein Maxau-Mainz	MM1
Fews_Rijn Rhein Mainz-Andernach versie 2004.3	RM1
Fews_Rijn Rhein Andernach-Lobith Niederrheinstudie 2002_NRW_M	AL1
Fews_Rijn Rijntakken 2004.2	RT2
Fews_Rijn Neckar Rockenau-Muendung	NE1
Fews_Rijn Main Raunheim-Muendung	MA3
Fews_Rijn Lahn Kalkofen-Muendung	LA1
Mosel Cochem-Muendung	MO1

4.2.4 Run-times

The HBV model for the Rhine takes about 30 seconds per year while the model for the Meuse takes about 10 seconds per year. The Muskingum routing for the Rhine takes about 1 minute per year.

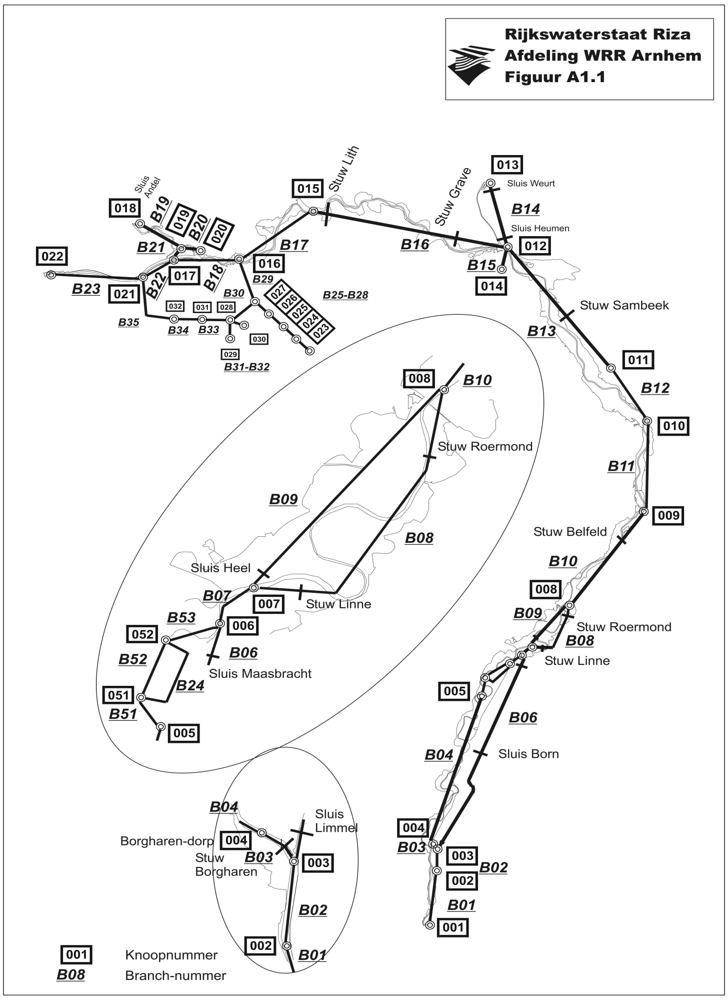


Figure 4.2 Layout of the SOBEK Meuse model. Figure taken from (van der Veen 2006)

Run-times of the detailed hydraulic models for the Rhine included in GRADE (SOBEK/SYNHP) are about 90 minutes per year for the Rhine and about 45 minutes per year for the Meuse River. GRADE is originally meant to compute time series within the order of 10,000 years. Therefore, GRADE only runs SOBEK in case a certain threshold is exceeded. In this project, it is expected that the maximum run-time will be about 150 years. Therefore the threshold exceeding function has been omitted in this pilot and the SOBEK models are run over the full period.

4.2.5 Improving hydrological modeling in GRADE

One of the problems in climate change studies is the fact that hydrological models are calibrated under current and past climate conditions. This increases the uncertainty in the results of these models when different climate conditions are used as an input. Although for operational use many people find that the the simplest model perform best in most events (e.g. Te Linde et al. 2008). In addition, the imperfections in the current HBV model in GRADE necessitated some 'tweaks' to make it suitable for peak flows only and those tweaks might not scale properly in climate scenario's (see also (de Wit & Buishand 2007)[2]).

A possibility to get some insight in this uncertainty is to use different hydrological models. Within Deltares different models of the Rhine are available and can be coupled to GRADE without too much effort. With Baysian Model Averaging (BMA) it is possible to determine the influence of model uncertainty on the results of modeled climate scenarios. The table below shows a couple of available models that can be implemented without too much effort:

Model	Description	Calibrated?	DELFT-FEWS Adapter?
SMHI-HBV (Bergström 1992)	Operational version of HBV using daily timesteps (Switzerland?)	yes	Yes
HBV PCRaster	Distributed version of HB	Yes (based on lumped)	Yes

[2]. *Most notably a 5% decrease of the HVB modeled flow of the main tributaries of the Rhine has been implemented to account for backwater effects during high flows See chapter 7, page 27 of de Wit and Buishand for more information..*

Sacramento	Distributed version of the Sacramento model	no	Yes
wflow	Distributed model that does not need much calibration. Used in research and Deltares demonstration project in Indonesia	no	Yes

VIC (Liang et al. 2003)	Distributed model, see also (Te Linde et al. 2008)	yes	partly
REW (Reggiani & J. Schellekens 2003)	Physically-based semi distributed model. Used in research. Tested in operation setting in UK	no	Yes
LARSSIM ((Gerlinger & Demuth 2000; Haag & Luce 2007))	Distributed model used in Germany. Setup for the whole Rhine basin is being made by Bfg	yes	no

4.3 Main rivers

The following systems can be used to model the main rivers in The Netherlands:

- Sobek models included in the GRADE system
- Northern Delta Basin model (SOBEK)
- Distribution Model (DM)

4.3.1 GRADE

Detailed hydraulic models (SOBEK) for the Lower Rhine, Meuse, Waal, Lek and IJssel rivers are included in GRADE. These models can be linked to the SOBEK Northern Delta Basin model (paragraph 4.3.2) and to the Lake IJssel model (paragraph 4.5). More information about GRADE can be found in paragraph 4.2.

4.3.2 SOBEK NDB model

The Northern Delta Basin is the area where the rivers Rhine and Meuse discharge into the North sea. The western part of the Northern Delta Basin model has two boundary conditions: the Nieuwe Waterweg (Maasmond) and the Haringvliet in the North sea. The (inflow) boundaries in the eastern part of the model area include the river Lek at Hagestein, the river Waal at Tiel and the river Meuse at Lith. The northern part of the area (Nieuwe Maas, Nieuwe Waterweg, Hartel-Beer and Calandkanaal) is mainly influenced by the harbor Rotterdam. The southern part of the area (Biesbosch, Hollandsch Diep and Haringvliet) consists mainly of recreational and nature areas.

In 2001 the first SOBEK-model of the Northern Delta Basin was delivered by RIZA under the name “NDB_1_0_0” (Zetten 2000). The schematization of the model is based on elevation and depth measurements taken during the years 1990 – 1993. Furthermore the schematization was adapted to the following new situation:

- Opening of Beerdam in 1997 (open connection between Beerkanaal and Hartelkanaal)
- Because of opening the Beerdam the depth profile of Hartelkanaal changed and in 1998 new depth measurement were taken and included in the model schematization in 2000
- Missippi-harbor in open connection with the Hartelkanaal
- Nieuwe Waterweg and Hartelkanaal storm surge barriers became operational

This model was calibrated for the period 1 August – 15 November 1998. In 2002 SOBEK-model NDB1_1_0 of the Northern Delta Basin was delivered by RIZA (Kraaijeveld, 2004). Starting point for the model schematization of NDB1_1_0 was SOBEK-model NDB1_0_0. NDB1_1_0 was specifically calibrated on the salt movement in the model area and resulted in changed roughness and dispersion coefficients compared to NDB1_0_0. In 2006 SOBEK-model “RVB1_3_0” was developed by RIZA to model hydraulic constraints for testing of the primary water barriers. Starting point for the model schematization of RVB1_3_0 was SOBEK-model NDB_1_1_0. Upstream from Krimpen aan de Lek and Werkendam de rivers Lek and Waal were respectively replaced by parts of SOBEK-Rijn model and upstream from Keizersveer the Bergsche Maas is replaced and extended with SOBEK-Maas. The upperstream boundaries are now located for the Waal at Pannerdense kop, for the Nederrijn at IJsselkop and for the Maas at Mook. In the upper part of the Nieuwe Merwede NDB1_0_0 and NDB1_1_0 overestimate water levels when the river flow extends significantly sideways. In 2001 a new schematization was developed by ‘HKV-lijn in water’ for the Nieuwe Merwede, Beneden Merwede with Sliedrechtse Biesbosch, Wantij, the Brabantse Biesbosch, a part of Hollandsch Diep (upstream of Moerdijkbruggen), Zuid-Maartensgat, the Amer and a part of the Bergsche Maas (downstream of Keizersveer) to solve the overestimation of water levels. Projects and measures up till December 2003 are included in the model schematization.

Time steps

The NDB SOBEK schematization runs at 10-minute time steps.

Run-Time

The run-time of the NDB model is yet unknown but is expected to be an order of magnitude higher than the SOBEK models of the upper Meuse and Rhine in GRADE because of the complexity of the model.

Forcing

The NDB-SOBEK model requires discharges at upstream boundaries (Lek, Waal and Maas)

withdrawal and discharge within the area (drinkwater, industry and agriculture), water levels at downstream boundaries (Maasmond, Haringvliet south and Haringvliet north), internal wind field (wind speed and direction) and salt concentrations at boundaries.

Output

The model gives water levels, discharges and salt concentrations at forecast points within the Noordelijk Deltabekken.

A FEWS implementation has been built to support real-time control of the Maeslantkering. This FEWS configuration has been implemented and coupled to GRADE and the Dutch Continental Shelf Model (DCSM) in the KKF-System. The upstream boundaries are delivered by GRADE, which delivers flows and water levels at Hagestein, Tiel and Lith (see Figure). Wind direction and speed are computed from the KNMI climate wind fields. The downstream boundaries (Hoek van Holland and Haringvliet) are delivered by the DCSM. Variability in salt concentration are not considered at this stage of the KKF project. Therefore, long-term average values are being provided.

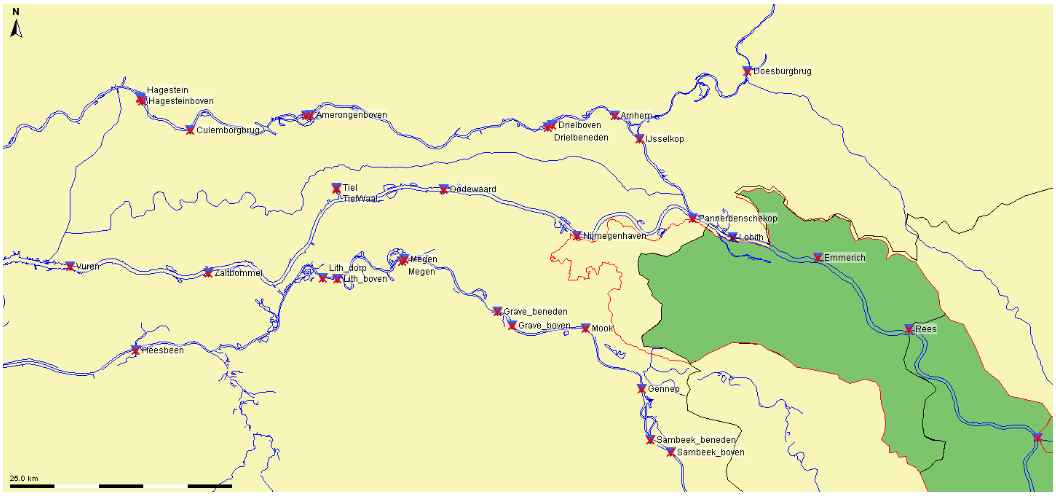


Figure 4.3. Output points of the GRADE SOBEK

Model links:

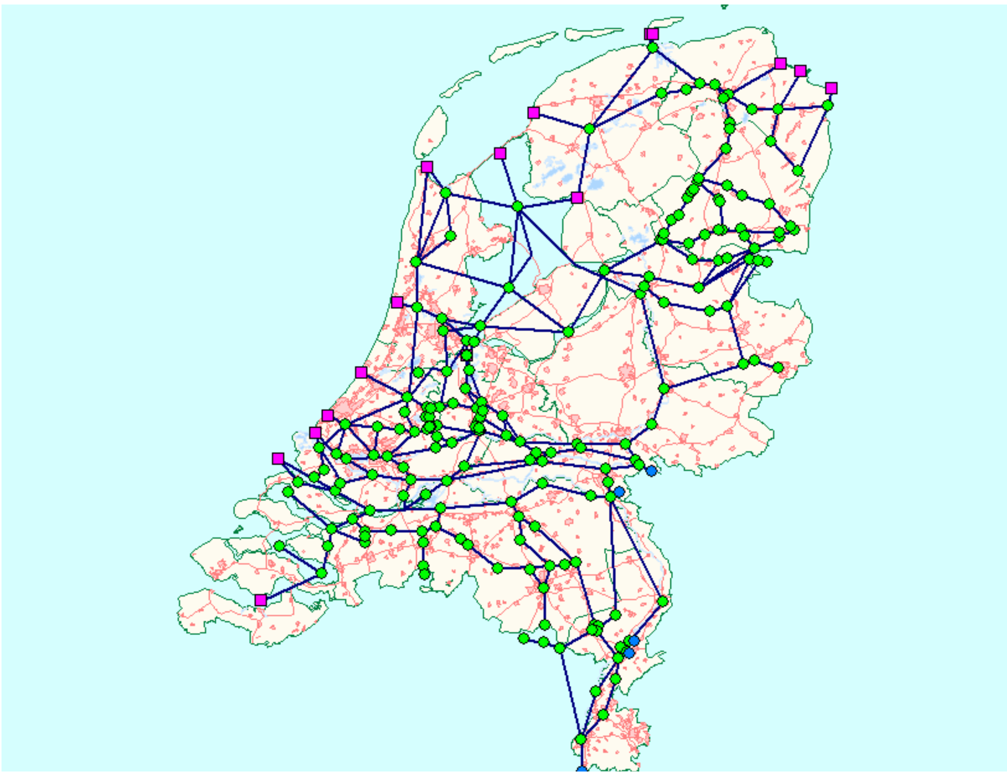
The downstream boundary conditions at Hoek van Holland and Haringvliet are provided by projected boundaries from the DCSM. GRADE provides the upstream boundary conditions. Since GRADE runs at hourly time steps and NDB at 10-minute steps, the hourly values provided by GRADE are being disaggregated to 10-minute values within FEWS.

4.3.3 DM model

Within the National Hydrological Instrumentarium (NHI) a distribution model (DM) is used to model the main rivers in the Netherlands. DM is a water balance model that calculates the distribution of water based on the availability and need of water in certain areas. A special case is the Northern Delta Basin. For this area the SOBEK-model NDB1_1_0 is used to calculate salt concentrations that after pre-processing are used by DM to distribute water in the Northern Delta Basin.

Normally in NHI, DM is linked to regional water areas (districts) through the MOZART distribution module that based on the water balance in these districts withdraws or discharges water to the nodes of DM. Discharge to and withdrawal from DM nodes need to be read in from a file when DM runs stand-alone. The calculation time for running DM stand-alone for 1 year is 20 minutes. A disadvantage is that DM always assumes it is able to discharge water to model boundaries (like the North Sea and the Wadden Sea) (Geert Prinsen, *pers. comm.*). This may not always be the case when modeling climate scenario's for 150 years. Paragraph 4.4 contains more information about NHI and DM.

Figure 4.3. Schematic DM network: nodes (green), branches (blue) and boundary nodes (purple)



4.3.4 WAQUA models

2D WAQUA models are available for the rivers Rhine and Meuse and the Northern Delta Basin. These are detailed hydrodynamic models and will have much larger run times than the models mentioned before (1D SOBEK-NDB, DM and GRADE(SOBEK)). Because of the associated run times with 2D WAQUA models, these models will be used during critical periods (low and high flow) within the full 150 years of climate data.

4.4 Local water system

For the local water system the National Hydrological Instrumentarium (NHI) is considered. The regional surface water in NHI is schematized in the MOZART model, which divides the regional surface water into 8500 local surface water (LSW) areas. The LSW's are part of a MOZART district (catchment area), in total there are about 140 districts.

4.4.1 National Hydrological Instrumentarium (NHI)

Deltares, Alterra, the national Environmental Assessment Agency (PBL) and the Ministry of Transport, Public Works and Water Management (V&W) are building a new hydrological model of the Netherlands: NHI (Delsman et al. 2008). The purpose of this model is to provide consistent hydrological input to policy- and operational studies at the national and regional scale. Research question include water distribution, effects of climate change, nutrient emissions and pesticide leaching.

NHI describes the complete interconnected hydrological system, as it models both saturated and unsaturated flow. NHI consists of the following coupled models:

- MODFLOW saturared zone (groundwater)
- MetaSWAP unsaturated zone
- MOZART regional surface water
- DM (Distribution Model) national surface water
- SOBEK-NDB* salt intrusion Rhine delta
- NHI-zoetzout* saline groundwater transport

* no online coupling

MODFLOW models groundwater flow in a 250m grid, with 7 layers representing aquifers and aquitards in the Netherlands. The parametrisation is based on a national hydrogeological database, REGIS. MetaSWAP models the transfer of water in the soil – vegetation – atmosphere system. MetaSWAP is a metamodel of the well-known SWAP model. MetaSWAP is coupled online to MODFLOW, exchanging groundwater recharge, heads, and storage in the unsaturated zone.

Surface water is accounted for in the MOZART and DM box-type models. MOZART models water flow in local and regional surface water. MOZART is coupled to MODFLOW and MetaSWAP, receiving drainage, infiltration, seepage fluxes, as well as water demand fo sprinkling. MOZART in turn supplies MODFLOW-MetaSWAP with surface water levels, and the availability of water. MOZART aggregates water inflows and outflows for large districts, which are coupled to the national water system (DM). Together, DM and MOZART allocate the available water to meet the various water demands, using different priorities for different water users.

Salinization of the water system is accounted for on various levels. Firstly, intrusion of the salt wedge from the North Sea up the Rhine river is modelled by the hydrodynamical SOBEK model (SOBEK-NDB). Modelled salt concentrations are used by DM as input for various quality-dependant water management rules (e.g. intake at Gouda). Secondly, the intra-year variations in saline seepage from saline groundwater into the surface water system are modelled by the TRANSOL model, a post-processing model that uses the soil water balance from MetaSWAP, and a fixed groundwater salt concentration. Thirdly, longterm variations in the salt concentration of groundwater by the slow upward movement of saline groundwater is modelled by the 'NHI-zoetzout' (NHI-saline) model. NHI-zoetzout models the slow transport of saline groundwater in the subsoil, using the density-dependant groundwater flow model MOCDENS3D.

Results of NHI are input to a number of 'effect models', that model the effects of a changing hydrology to e.g. agricultural revenues and terrestial ecology.

Forcing

NHI needs precipitation, potential evaporation, discharge at upstream boundaries (Rhine and Meuse) and salt concentrations. North Sea and Wadden Sea boundaries are not used; DM assumes it can always freely drain to these boundaries. Longterm scenarios should also include projected land subsidence and changes in landuse.

Time steps

MOZART and DM run with a time step of 10 days (will change to 1 day in the future). MODFLOW and MetaSWAP run with a timestep of 1 day. MOCDENS3D runs with a 1 year time step.

Output

DM/ MOZART:

Discharge (per branch), water levels (per node), salt concentrations (per node). Salt concentrations, water supply (demand and shortage), water levels and drainage in MOZART districts.

MODFLOW/ MetaSWAP:

Seepage, infiltration, drainage, groundwater levels, evapotranspiration, soil moisture, soil moisture deficit, salt concentrations in the rootzone, groundwater recharge, salt loads to surface water.

Run-times

When DM/ MOZART is coupled to MODFLOW/ MetaSWAP the calculation time for 1 year is 24 hours. When running DM standalone the calculation time for 1 year is 20 minutes. Calculation time for MODFLOW/MetaSWAP standalone for 1 year is 3.5 hours.

4.4.2 NHI-light

Within the study ‘Fresh water supply’ there is a request for a ‘NHI-light’ model with the following features:

- A 12 hour calculation time for a 30 year climate dataset
- Effects for agriculture and shipping can be determined
- Consistent with NHI
- Effects of measures can be determined

To obtain a model that complies with these requests, the resolution in space and time of the original NHI model is lowered to a 1 km grid, and 10 day timesteps. A procedure will be developed to preserve consistency between both models, as NHI will be subject to further development in coming years. NHI-light will become available September 2010.

4.4.3 NHI-repro

Deltares (Daniel Tollenaar, *pers comm.*) is working on NHI-repro as part of the project ‘Fresh water supply’. This version of NHI will replace the MODFLOW/ MetaSWAP part in the original NHI by simple bucket models (one unsaturated zone- and one groundwater bucket). The model parameters of the bucket models are calibrated against data (evapotranspiration, infiltration and drainage) from original NHI model runs. The advantage of this approach is a much faster model run time. A disadvantage of this approach is the need for re-calibration each time NHI changes (inflexible). Furthermore, a large amount of different NHI runs are needed for a good calibration.

4.5 Lake IJssel

4.5.1 SOBEK-Bekken

The least computationally intensive model available for Lake IJssel is the SOBEK-Bekken model. SOBEK-Bekken is a highly simplified 1D-SOBEK schematization of the Lake IJssel area. In this model, every lake (IJsselmeer, Markermeer, and the boundary lakes) is schematized as one node which conceptualises the lake as one rectangular unit. Important structures are included in the model. The local water level around the structures are estimated as a function of the water level in the lake node itself, with a superimposed estimate of local wind lift. The wind lift is computed using so-called repro-functions, which relate wind lift with local water level, wind speed and wind direction (details given in Fokkink 1998). There is as yet no FEWS configuration for this model but it can be made with relatively little effort and will be done within the scope of this project as part of the pilot application. A schematic overview of the model is given in below.

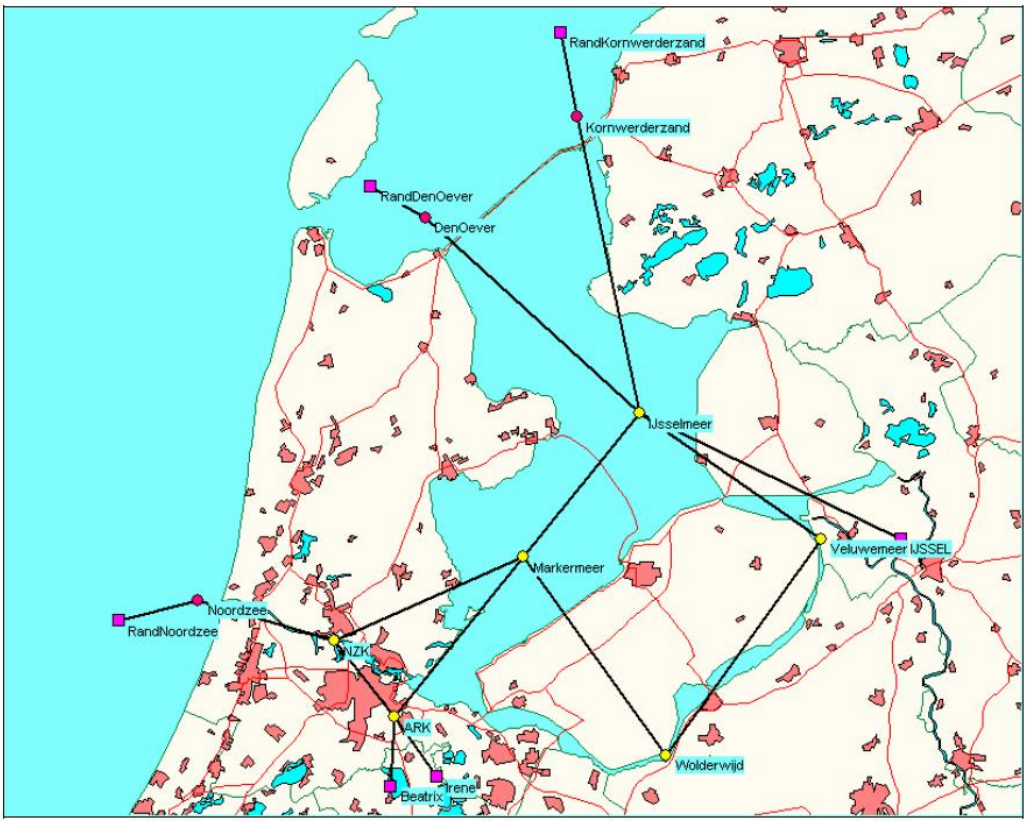


Figure 4.4. Overview of the SOBEK-Bekken model

Features:

- Volumetric water balance of the Lake IJssel area
- Local wind lift
- Discharges at structures, dependent on water levels around structures.
- Pumps at Den Oever and Kornwerderzand, which are controlled by operating rules, related to the desired water level of Lake IJssel.
- Pump and/or release capacities can be altered in scenario-mode if this is desired.

SOBEK-Bekken does not compute the effect of waves on water levels.

Time steps:

The run time step of SOBEK-Bekken is 30 minutes. The model gives output at this time scale.

Forcing:

The boundary conditions in the SOBEK-Bekken model are represented by discharges at the IJssel River near Lake Ketel, the inlet at the Beatrix sluices on the Amsterdam-Rhine channel, the inlet (discharges) of the Irene sluices on the Amsterdam-Rhine channel, water levels at the sea-side of the Afsluitdijk at Kornwerderzand, Den Oever (Wadden sea) and the North Sea at IJmuiden.

Furthermore, the lakes in the model receive precipitation and are subject to open-water evaporation. Finally, SOBEK-Bekken contains one cumulative lateral which is a combination of flows from the Vecht River and some other regional water bodies.

Run time:

The model is relatively simple and therefore suitable for long runs of multiple years. This is demonstrated by (2009). It takes approximately 1 minute to make computations for 10 years.

Output:

The SOBEK-Bekken model gives water levels in the lakes in the Lake IJssel as output (see Error! Reference source not found.).

Model links:

The precipitation and open-water evaporation estimates can be generated from the KNMI scenarios. Furthermore, the IJssel discharge at Lake Ketel can be easily derived from the SOBEK Rhine model in GRADE. This model stretches as far as Kampenbovenhaven, which is close to the boundary condition, needed by SOBEK-Bekken.

The laterals can be estimated as a fraction of the inflows of the IJssel. The sluice inlets can be estimated from the DM model.

The wind lift needs effective wind estimates (speed and direction). These will be derived from the KNMI scenarios

4.5.2 WAQUA/SWAN Models

More detailed models are being created in the FEWS-Meren project. The “Waarschuwingsdienst Dijken IJsselmeergebied” (WDIJ) has the task to warn a dike manager when safety levels are or are going to be exceeded during a storm. To this end, predictions of these water levels are needed.

Rijkswaterstaat has therefore developed a model instrument for the whole IJsselmeer area (Markermeer, Gooi-Eemmeer, Ketelmeer and IJsselmeer) to make these predictions. This is done using the model computation core WAQUA, in combination with wave lift, modelled in SWAN. These models are 2D and consist of a large number of grid points. The model chain consists of :

- Importing of HIRLAM 22 km grids for wind speed and direction
- Importing of MATROOS measured boundary conditions
- Downscaling of HIRLAM fields to model resolution
- WAQUA run (water levels/wind lift)
- SWAN run (waves)

Run time:

The run time of the SWAN model with some pre-defined settings for convergence criteria is dependent on spatial resolution as given below. This table gives the results of a test run in which wave conditions are computed at all grid cells given a certain wind field. The results have been computed with 50 iterations to reach convergence on a system with 2.5 Ghz clock speed and 1GB internal memory.

Grid spatial resolution [m]	Run time [min]
200	30
160	45
120	85

These results show that if the combination WAQUA/SWAN is used, only a certain selection of situations should be selected to perform analysis in this detail. For the tranche 1 pilot system, these models will therefore not be considered yet. In the second tranche, WAQUA/SWAN can be employed to make detailed computations during critical situations. The SOBEK-Bekken model can then be used to identify critical periods within the full 150 year time series, similarly to the way SOBEK is employed in GRADE when a critical flood wave is detected in HBV.

4.6 North Sea and Wadden Sea

For the North Sea and Wadden Sea different WAQUA models are available that cover different areas and have different resolutions. Below we describe three different models (from a coarse to fine grid).

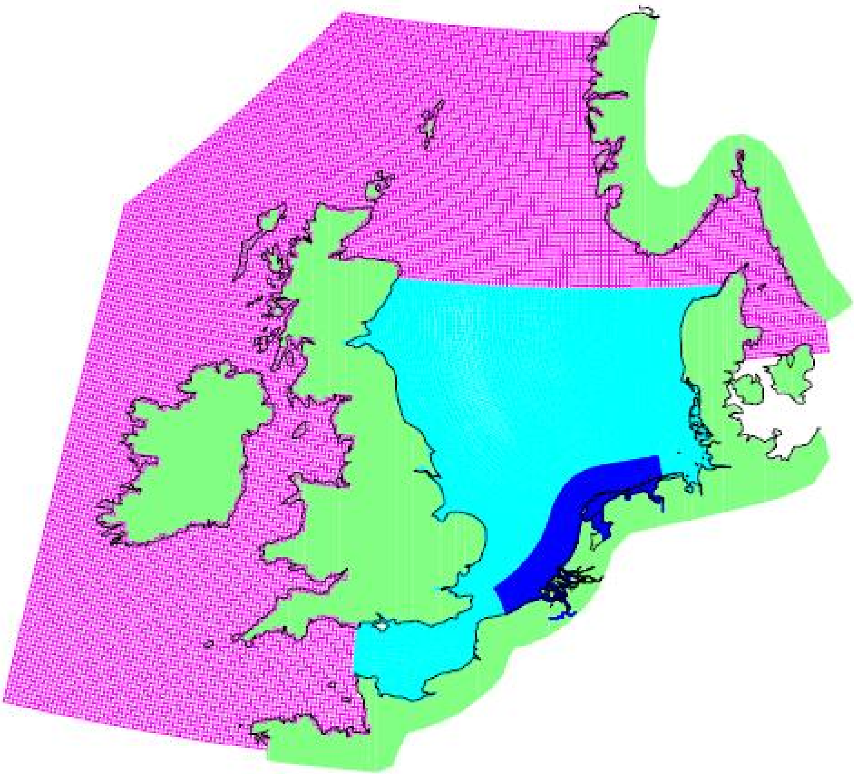


Figure 4.5 An overview of the different North Sea and Wadden Sea hydrodynamic model grids. Purple is the DCSM grid, light blue is the ZUNO grid and dark blue is the Kuststrook grid

The Dutch Continental Shelf model (DCSM) is a storm surge model developed by Rijkswaterstaat, Deltares and KNMI. DCSM covers the northwest European continental shelf with a spherical grid resolution of 1/8 degree by 1/12 degree (about 8x8 km). DCSM needs at the model boundaries astronomical tides and spatial and temporal varying wind speed at 10 m and pressure at sea level as input. The run time of the model is slightly less than a minute for 48 hours and the model runs with a time step of 10 minutes. Operationally, DCSM runs in the following way: first DCSM is run with both astronomical tides and wind and pressure as input, secondly DCSM is run with only astronomical tides. The storm surge is calculated as the difference between the two model runs.

A model with a finer resolution (1-2 km near the Dutch coast) is the Southern North Sea Model (ZUNO) which covers the Southern North Sea and the Canal. The run time of this model is about 4 minutes for 48 hours and the model runs with a time step of 2,5 minutes. The Kuststrook-grof model covers the whole Dutch coast and has a grid resolution at the North Sea boundaries varying between 600 to 1600 m by 5 km and near the coast about 600x600 m. The run time of this model is about 15 minutes for 48 hours and the model runs with a time step of 2 minutes.

Other more detailed models that cover parts of the Kuststrook model are available and may be used during periods of interest (e.g. extreme wet or dry conditions, see also paragraph 5.2). The following more detailed models in the Kuststrook area are available:

- Lake Lauwers model (3D)
- Lake IJssel model
- Lake Marker model
- IJmond model (2D and 3D)
- Northern Delta Basin model
- Kust-zuid model

Within project SOS2012 (Samenhang Operationele Systemen 2012) there is a need to run WAQUA River models in FEWS. This will be realized in two steps:

- Coupling FEWS with OpenDA
- Coupling OpenDA with WAQUA (through a WAQUA adapter)

The plan is to realize this in July 2010. The advantage of this coupling is that it provides a way to run models parallel. Another option is to run these models in Delft3D. A Delft3D adapter already exists, however parallel model runs in Delft3D are not possible.

4.7 Temperature modeling

For temperature modelling two model systems are available:

- SOBEK national temperature model
- Rhine temperature model in FEWS

4.7.1 SOBEK national temperature model

The SOBEK national temperature model (Boderie et al. 2006) covers the Netherlands (Figure 4.3). This model is based on the national SOBEK-RE model version NL2005_1 by converting SOBEK-RE to SOBEK-Rural. The hydrodynamical part is modeled as 1D flow and for water temperature the waterquality module DELWAQ is used.

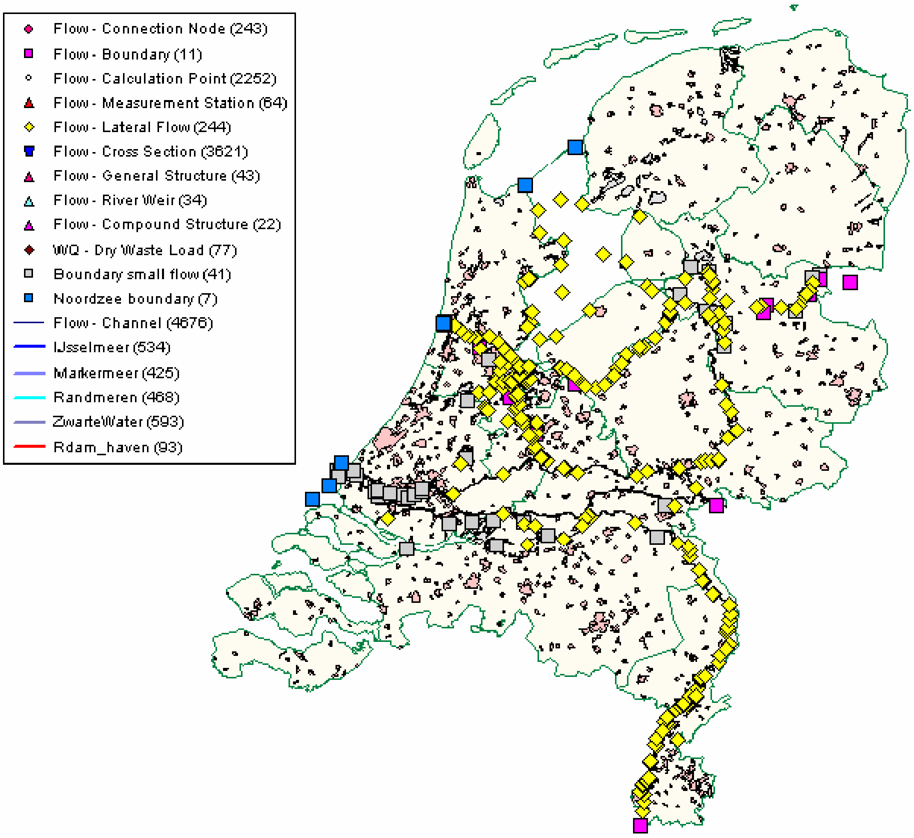


Figure 4.6 Model boundaries of the national temperature model; sea boundaries (blue), main rivers (purple), small flows (grey) and laterals (yellow) taken from (Boderie et al., 2006)

Time steps:

The run time step of SOBEK national temperature model is 10 minutes. The model gives output at this time scale.

Forcing:

The boundary conditions in SOBEK national temperature model are represented by discharges at the river Vecht (Emlichheim), the river Rhine (Lobith) and the river Meuse (Eysden), water levels in the North Sea (Haringvliet, Hoek van Holland, IJmuiden) and Wadden Sea (Den Oever and Kornwerderzand). Lateral discharges in the model are calculated by rainfall-runoff relationships. Furthermore, for the North Sea boundaries temperature is represented by measurements at Hoek van Holland. The water temperature for laterals is represented by the measured air temperature at the Bilt (moving average over 15 days). The model uses measured water temperature at the boundaries river Rhine (Lobith) and Meuse (Eysden) and for boundary river Vecht (Emmerlich) the measured temperature at Lobith are used (no measurements are available at this location).

The heat balance model (DELWAQ) needs the following meteorological variables to calculate the water temperature: wind speed and – direction, air temperature and - pressure, humidity, global radiation and hours of sunshine. Furthermore the model needs the location and discharges of heat spills.

Run time:

It takes approximately 9 hours to make computations for 1 year.

Output:

The SOBEK national temperature model gives water levels, discharges and temperature as output.

Model links:

The meteorological variables can be generated from the KNMI scenarios (including air temperature to estimate water temperature for laterals). Temperature at the North Sea boundaries can also be generated from the KNMI scenarios. The Rhine and Meuse discharges can be derived from the SOBEK models in GRADE. Water levels for the North Sea and Wadden Sea boundaries can be derived from the North Sea and Wadden Sea model used (e.g. DCSM). Finally, water temperature at the river boundaries could be estimated from the relationship between measured air – and water temperature at these locations.

4.7.2 Rhine temperature model

For the river Rhine a temperature model implemented in FEWS is available (Peñailillo & Lemans 2009) and is based on FEWS-NL. The Rhine temperature model includes:

- Hydrological model HBV (see also paragraph 4.2)
- Two hydrodynamic models in SOBEK-RE (Maxau-Rijntakken and Lobith Rijntakken) that were imported into SOBEK-Rural (controllers were not checked and no calibration)
- DELWAQ waterquality model for modeling of water temperature

Time steps:

The run time step of the Rhine temperature model is 1 hour. The model gives output at this time scale.

Forcing:

Temperature and precipitation for HBV models. Meteorological variables mentioned in paragraph 4.7.1 for the DELWAQ model. Boundaries for temperature are located in the river Rhine (Maxau), river Neckar (Rockenau), river Main (Raunheim), river Lahn (Kalkofen-neu) and river Mosel (Cochem). Measured water temperatures were available for locations Maxau, Raunheim and Rockenau. Relationships between measured water – and air temperature for these locations were used for locations (model boundaries and laterals) that lacked temperature measurements. Furthermore the model needs the location and discharges of heat spills in the Rhine.

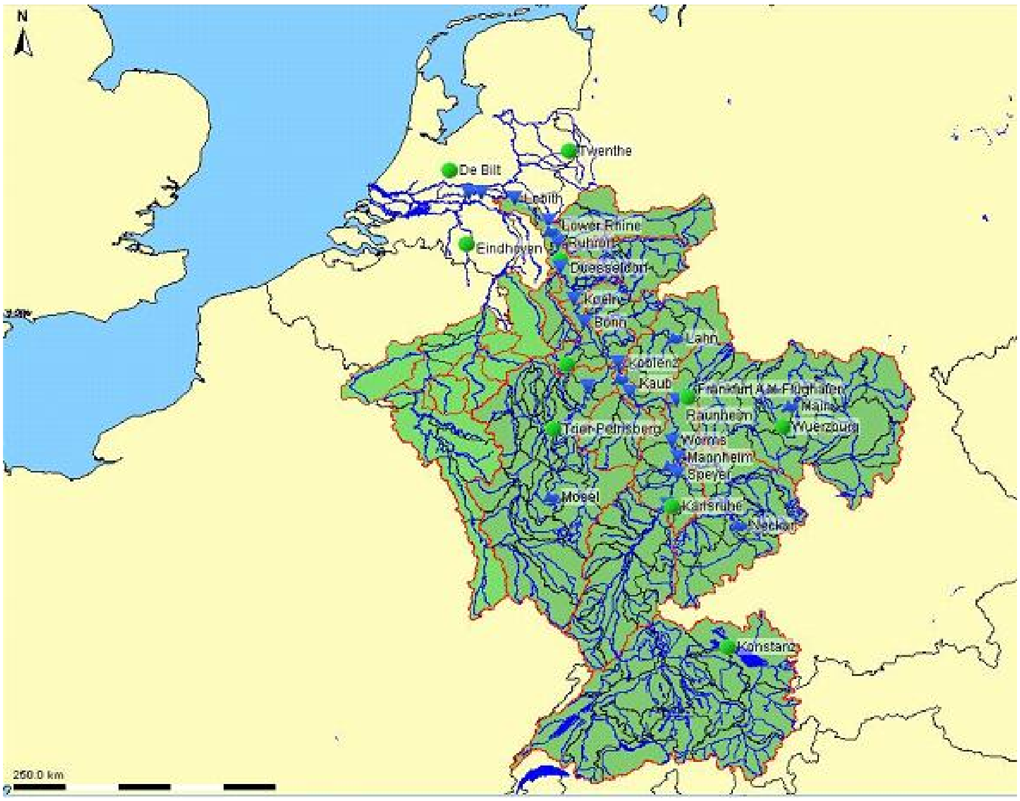


Figure 4.7 Overview of Rhine temperature model in FEWS taken from (Peñailillo and Lemans, 2009)

Run time:

It takes approximately 6 hours to make computations for 1 year (Lemans, *pers. comm.*).

Output:

The Rhine temperature model gives water levels, discharges and temperature as output.

Model links:

Meteorological variables (for DELWAQ and HBV) can be generated from the KNMI scenarios. Temperature for model boundaries and laterals can be estimated from relationships between measured air- and water temperature.

4.8 Modelling habitat conditions

The habitat suitability of an area for certain species can be predicted by the HABITAT software (Haasnoot 2009). HABITAT is a GIS-based model environment that uses cause-effect relations between environmental variables for prediction of habitat suitabilities. Such variables may include temperature, water quality parameters, water depths, water turbidity, and many more. The suitability for different species is expressed as a number between 0 and 1 (see for example Error! Reference source not found.). For Lake Marker and Lake IJssel, HABITAT models are available.

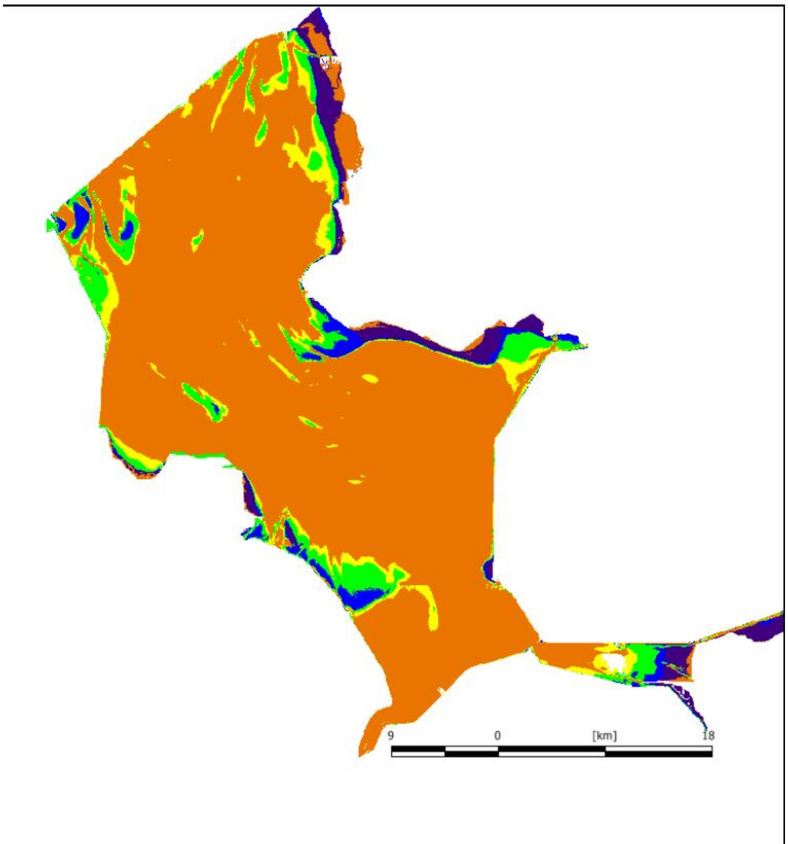


Figure 4.8 An example of a habitat output map. This map gives the suitability for waterplants in Lake IJssel under reference conditions. Orange: low suitability; Blue: high suitability

Time steps

HABITAT computes habitat suitabilities as a steady state cause-effect relation between environmental conditions and the suitability.

Forcing:

The main forcing of the HABITAT models for Lake IJssel and Marker are water depths (average, minimum, maximum and summer water levels) and the land use at the banks and islands (see figure below)

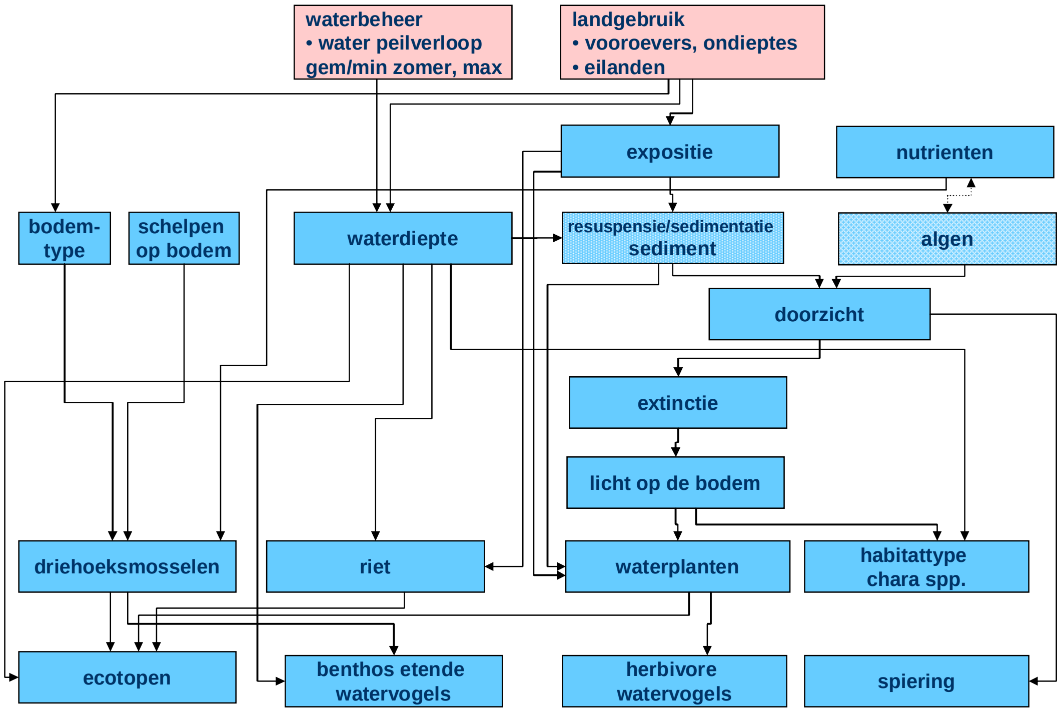


Figure 4.9 Overview of cause-effect relations (in dutch) of the HABITAT models of Lake IJssel and Lake Marker

Run time

The run time of the models is at this moment not known. Since the model runs in steady state, it can be forced once over a long period of time. Therefore the computation is expected to be small compared to other models.

Output:

The models provide habitat suitability indices for several shellfish, (water)plants, birds.

Model links:

The DM model provides water levels for both Lake IJssel and Lake Marker.

4.9 Socio-economical models (future land-use)

The Free University of Amsterdam, Institute for Environmental Studies (IVM) is leading in the development of socio-economic models and scenarios. A number of forcings will be developed and delivered by the Free University of Amsterdam as input to KKF. It is yet uncertain whether this will be done in the first or second tranche. Below, an overview is given of the role of land use in KKF (detailled description is given in Appendix B).

The coupling of land use change models/scenarios with other physical impact models (e.g. hydrological models) provides a very useful way to include key socioeconomic drivers and impacts of climate change in a coupling platform such as that strived for in this study. Preliminary offline couplings of the impacts of land use change on runoff have been made for the Rhine and Meuse catchments, showing the possibilities of such an approach (e.g. Hurkmans et al. 2009). There is a double-sided impact on flood risk: First, upstream changes in land use can lead to changes in infiltration, evapotranspiration and runoff, and hence changes in flood hazard. Second, land use changes in flood prone areas can cause an increase in potential damage or loss of lives in the event of a flood.

There are some key limitations to be mentioned in view of including land use changes in the KKF-modelling platform:

- Spatial resolution: some land use models work at a high spatial resolution while the data does not support this resolution. For flood damage potential, a relatively high resolution is required because land use may be highly heterogeneous in flood prone areas, while it is key to potential damage estimation.
- Time span: Most land use scenario's do not exceed 20 years simulation time, because their uncertainty becomes very large after this period.
- Compatibility between land use classes of the land use scenario and hydrological / damage models.

To estimate the effect of land use changes on hydrological responses in the Rhine and Meuse rivers, existing scenarios from the CLUE scenario model (Veldkamp & Fresco 1996) can be used. This model produces scenarios at 1x1 $(km)^2$ spatial resolution (produced in the EURURALIS project, see http://www.eururalis.eu/). This would be an offline model coupling. The parameters of the HBV models in the Meuse and Rhine are currently not coupled to land uses. Therefore, this coupling will not be included in the KKF pilot system but will be considered in the second tranche project wherein other hydrological models (with land use related parameters) for the Meuse and Rhine will be considered.

A full coupling of CLUE with hydrological models can open doors to full integration of hydrological flood risks and land use modelling (e.g. economic modelling with (low) flood risk as one of the explanatory variables for the occurrence of development). This would require months to several years of research and is beyond the scope of trance 1 KvK.

For the estimation of changes in potential flood damage, in the future, the Ruimtescanner will be used (Schotten et al. 1997) to estimate land use developments (at a higher resolution of 100x100m than CLUE). When a land use scenario is available at this spatial scale, for instance flood risks can be estimated, given these developments. This would require the further coupling of a 2D inundation model to estimate flood hazards, coupled to the already envisaged 1D hydraulic models of Rhine, Meuse and NDB. Alternatively, a(n number of) already existing flood inundation map(s), belonging to certain discharges in Rhine and Meuse can be used. Besides this, the damage scanner (available in PCRaster and MATLAB, easy to couple with FEWS) can be used to estimate flood risk as a result of flood hazard and potential damage. The damage scanner consists of relations between inundation depths and potential damage. The damage scanner can produce flood risk maps by combining an inundation map, a recurrence time belonging to this inundation map (coming from the 2D hydrodynamic model) and a land use map (coming from the ruimtescanner).

5 Forcing data

5.1 Climate data input KNMI

KNMI is involved in the IS-ENES (European Network for Earth System Modelling) work package 11 /JRA5 'Bridging Climate Research Data and the Needs of the Impact Community'. Aims of this work package are to improve the use of Earth System model simulations (data), enhance the dissemination of model results and enhance the interaction with decision makers and user communities, mainly concerned by climate change impact studies. These aims are reached by describing the data and making the data accessible in a standardized way.

KNMI is providing model results in NETCDF format from the EC-Earth model through ftp at the moment. The EC-Earth model is developed by a consortium of European Weather Services and university groups and is based on the ECMWFs seasonal forecast system. The EC-Earth model results contain the following parameters:

- Land sea mask [-]
- Surface solar radiation upward en downward [W m^{-2}]
- Surface thermal radiation upward en downward [W m^{-2}]
- Evaporation [kg m^2 s^{-1}]
- 10 metre U wind component [m s^{-1}]
- 10 metre V wind component [m s^{-1}]
- 2 metre temperature [K]
- Sea level pressure [Pa]
- Near surface specific humidity [kg kg^{-1}]
- Precipitation [kg m^2 s^{-1}]

The resolution of the EC-Earth model is 1.25 degrees, time step is 6 hours. Regional downscaling by KNMI to 0.5 degrees is possible, and smaller time steps up to 1 hour are also possible. Data can be delivered by KNMI at global, Western Europe or regional (modelling area) scale. Section 6.3.2 describes how we import and process these files.

6 Conceptual and Technical System design

6.1 Introduction

The chapter describes the design of the KKF-System based on the inventory of available models and the proposed (Delft-FEWS) infrastructure. The design is both conceptual and technical and based on the following principles:

- The system will use a step-wise zoom-in approach to achieve the desire level of detail. i.e. all initial runs will use the most simple (fastest running) model. The longer running high resolution models will be run only when more detail is required (during special conditions). This approach has been used successfully within GRADE.
- In the first setup only one-way connections will be made, no data exchanges per time step will be made in this setup. This approach fits within the Delft-FEWS database architecture in which all data is passed from one model to another via the database.
- The system will not be build among a fixed set-of models. It should (and will) be easy to replace parts of the system. As such, it can be used to deliver new input to ‘official systems’ such as the Data Model.

6.2 Design of the model system

6.2.1 Identifying periods of interest in the Climate scenarios

It is clear that detailed hydrodynamic models that are needed to determine water levels cannot be run for the whole 150-year period the KKF-System is designed to use. Therefore, we need to determine the periods for which extreme situations are expected using alternative methods. This will be done within Delft-FEWS using an automated procedure. This will also provide the operator with an overview of the contents of the Climate Scenarios which is otherwise hard to get from the raw data files. Delft-FEWS will present this in HTML reports.

Next, those periods can be examined with the more detailed models. Within GRADE a similar approach is used in which the hydrological model HBV is run first for the whole period and peaks are investigated in more detail separately using hydrodynamic models.

The following models are considered detailed models in the KKF-System:

- NHI (and maybe NHI-light)
- ZUNO, Kuststrook and more detailed models for the Dutch Coast (paragraph 4.6)
- WAQUA/SWAN models for Lake IJssel
- 2D WAQUA models for the rivers Rhine and Meuse in The Netherlands and the Northern Delta Basin

For the KKF-System periods of interest will be selected as follows. The selection below is preliminary and will be fine-tuned when implementing this in the pilot.

High flows

- Average precipitation in the Rhine/Meuse basin (10 day period) more than a certain amount
- Wind-speed and direction in combination with astronomical tide indicate possibility of (large) surge
- Wind-speed and direction indicate possible large surge in Lake IJssel
- Combinations of the above

Local Flooding

- Precipitation over any area (several to be determined area sizes) in NL higher than (to be determined) threshold for 3 hr, 1 day and 1 week.
- The above in combinations with high flows in the rivers and high coastal surge

Low flows/Drought

- Daily average discharge of Meuse at St. Pieter lower than 25 m^3/s (Rijkswaterstaat, 2010)
- Discharge of Rhine at Lobith lower than 1000 m^3/s, except for the months May, June, July and Augy when the threshold is 1400, 1300, 1200 and 1100 m^3/s respectively (Rijkswaterstaat, 2010).
- Combinations of the above
- Precipitation over any area (several to be determined area sizes) in NL lower than (to be determined) threshold for 10, 30, 60 day, and three months
- The above in combination with low flows in the rivers

6.2.2 How to incorporate different land-use scenario's

Recommendations for the socio-economical modelling are being formulated at the moment. However, it has become clear that the best way to link the results from such models to the physical system is via future land-use. This will impact both the Rhine/Meuse basin as a whole and the local water systems within The Netherlands.

6.3 Technical infrastructure and user interface

The KKF-System will be set-up in Delft-FEWS (Werner et al. 2004). The lasted version (>=2010-01) will be used in conjunction with a new interface that allows a higher degree of interaction with the underlying models with the use of modifiers.

The philosophy of Delft-FEWS is to provide an open shell for managing data and models. Delft-FEWS incorporates a wide range of general data handling utilities, while providing an open interface to any external calculation model. The modular and highly configurable nature of Delft-FEWS allows it to be used effectively both in simple systems and in highly complex systems utilising the full range of hydrological and hydraulic modelling. Delft-FEWS can either be deployed in a stand-alone, manually driven environment, or in a fully automated distributed client-server environment.

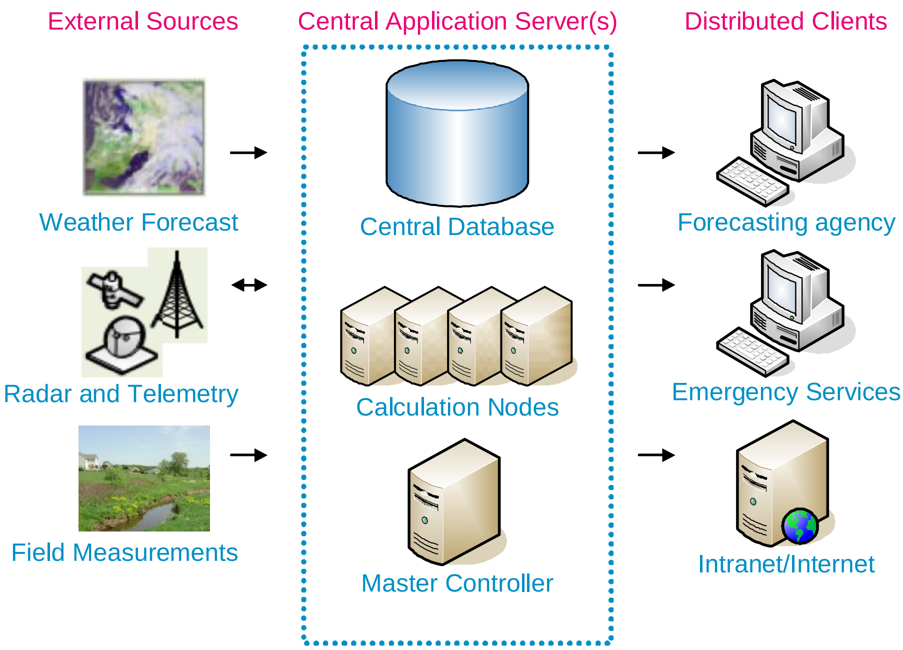


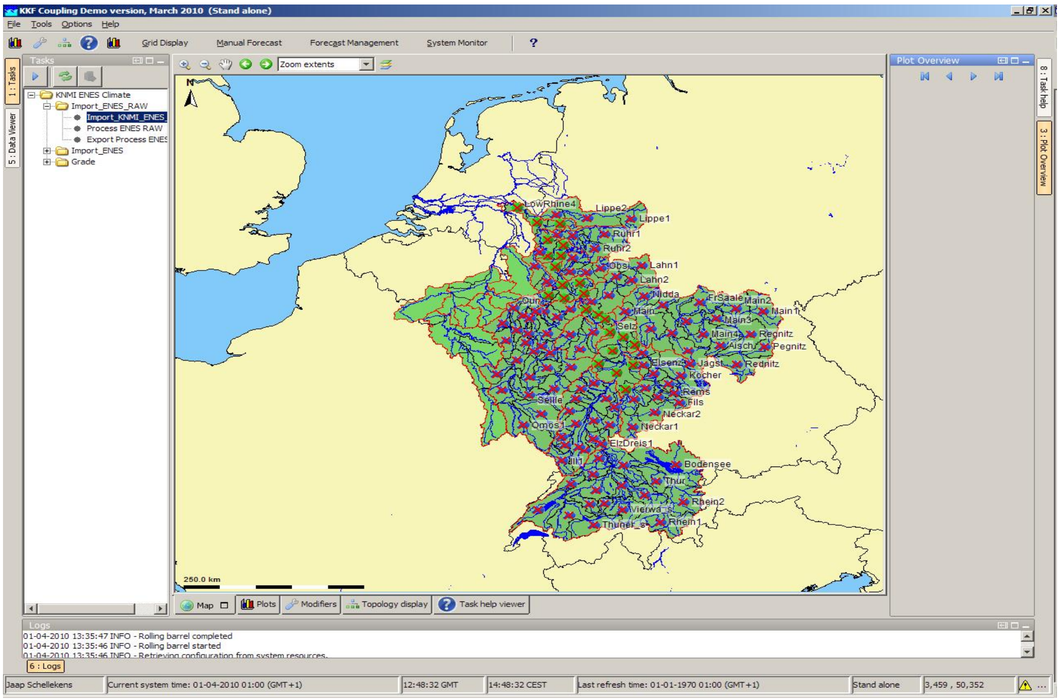
Figure 6.1 Components of Delft-FEWS in an operational setup

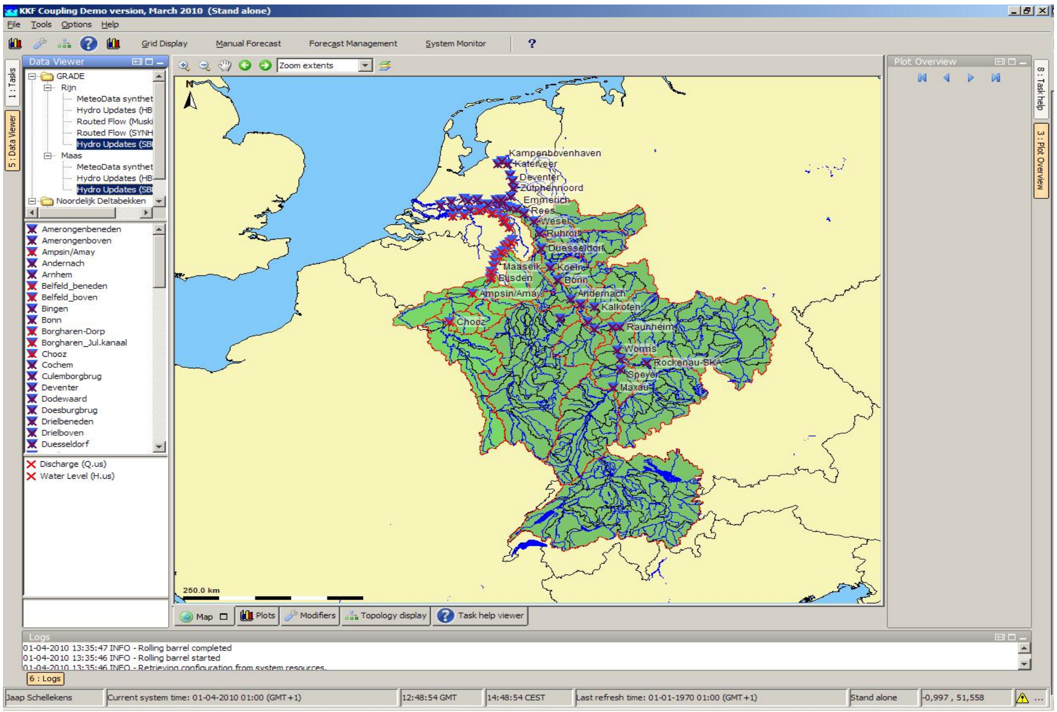
Originally designed for forecasting, Delft-FEWS has been extended over the years. At the moment it runs the National Groundwater Modelling System (FARRELL 2009) in the U.K and the NHI system in The Netherlands. In these setups it combines several models and ensures that different scenarios can be calculated easily using a consistent user interface.

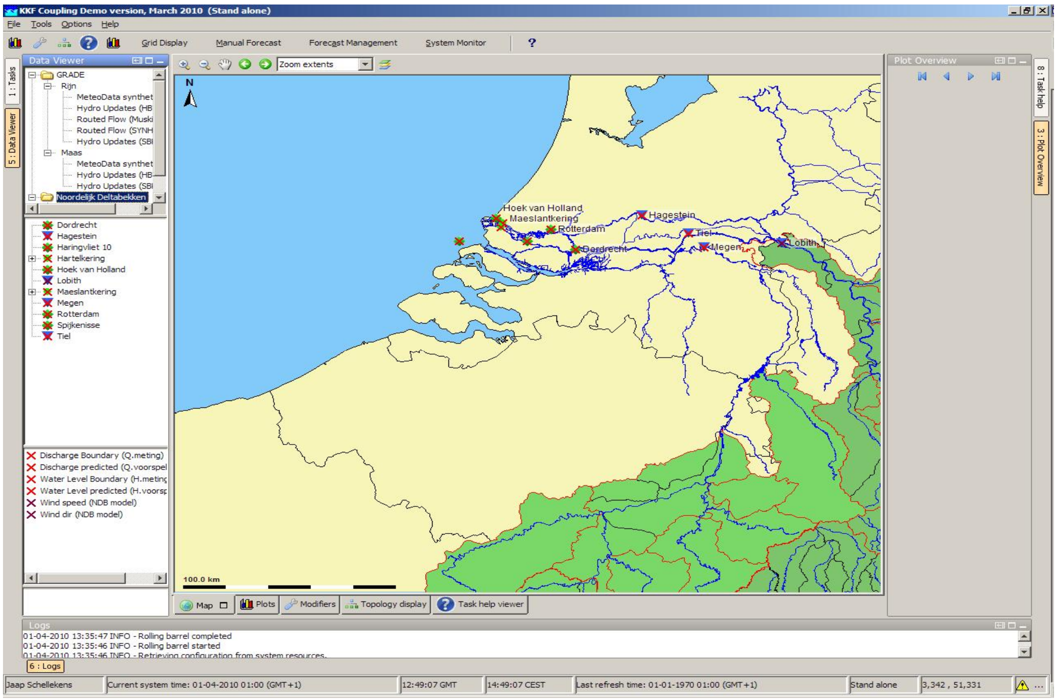
In order to feasibly run the models in the KKF-System, some specific hardware requirements must be met. Preferably, the full 150-year run is not performed on one physical computer, but is distributed over several computational cores. Especially when highly detailed models such as the WAQUA/SWAN combination for Lake IJssel need to be run, this will benefit from distribution of tasks. Delft-FEWS has the ability to run multiple models simultaneously and distribute the workload over several computers.

6.3.1 User Interface Based on Delft-FEWS

By placing all model under the control of Delft-FEWS a consistent user interface can be obtained. The interface allows detailed inspection of data in graphs and tables but also provides a graphical overview of the model domain and status of the system. In addition, reports can be configured to show key statistics of the results of a scenario run without needing to know the system in detail. The figures below show screenshots of the proposed UI build on Delft-FEWS:




KKF Coupling Demo version, March 2010 (Stand alone)
File Tools Options Help
Grid Display
Manual Forecast
Forecast Management
System Monitor
Data Viewer
Zoom extents
Plot Overview
GRADE
Rijn
MeteoData synthet
Hydro Updates (HB
Routed Flow (Muski
Routed Flow (SYNH
Hydro Updates (SBI
Maas
Noordelijk Deltabekken
Amerongenbeneden
Amerongenboven
Ampsin/Amay
Andernach
Arnhem
Belfeld_beneden
Belfeld_boven
Bingen
Bonn
Borgharen-Dorp
Borgharen_Jul.kanaal
Chooz
Cochem
Culemborgbrug
Deventer
Dodewaard
Doesburgbrug
Drielbeneden
Drielboven
Duesseldorf
Discharge (Q.us)
Water Level (H.us)
Kampenbovenhaven
Deventer
Emmerich
Rees
Wesel
Ruhrort
Duesseldorf
Maaseik
Koeln
Bonn
Ampsin/Amay
Andernach
Kalkofen
Chooz
Raunheim
Worms
Rockenau-SKA
Speyer
Maxau
250.0 km
Map
Plots
Modifiers
Topology display
Task help viewer
Logs
01-04-2010 13:35:47 INFO - Rolling barrel completed
01-04-2010 13:35:46 INFO - Rolling barrel started
6 : Logs
Jaap Schellekens
Current system time: 01-04-2010 01:00 (GMT+1)
12:48:54 GMT
14:48:54 CEST
Last refresh time: 01-01-1970 01:00 (GMT+1)
Stand alone
-0,997 , 51,558


KKF Coupling Demo version, March 2010 (Stand alone)
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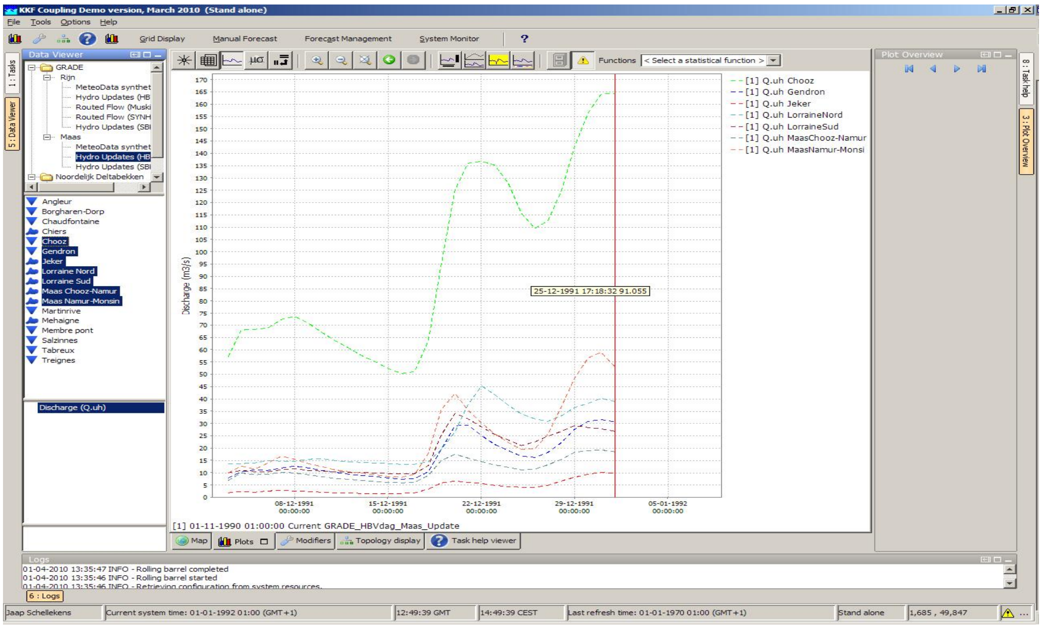
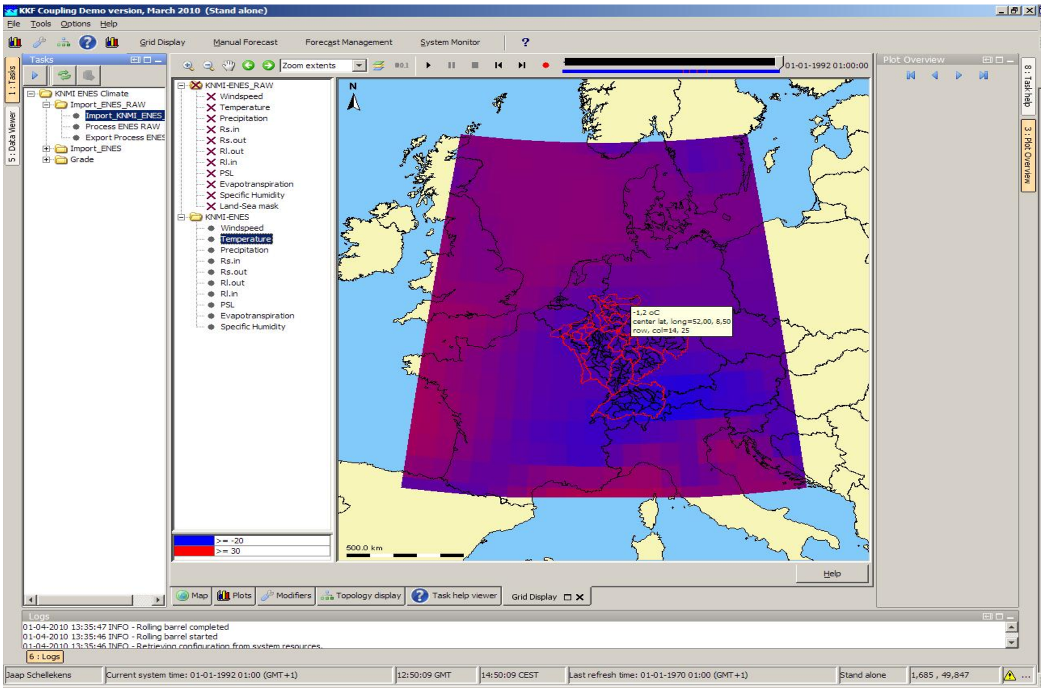
Plot Overview
GRADE
Rijn
Maas
Noordelijk Deltabekken
Dordrecht
Hagestein
Haringvliet 10
Hartelkering
Hoek van Holland
Lobith
Maeslantkering
Megen
Rotterdam
Spijkenisse
Tiel
Discharge Boundary (Q.meting)
Water Level Boundary (H.meting
Wind speed (NDB model)
Wind dir (NDB model)
Hoek van Holland
Maeslantkering
Rotterdam
Dordrecht
Hagestein
Tiel
Megen
Lobith
100.0 km
Map
Plots
Modifiers
Topology display
Task help viewer
Logs
01-04-2010 13:35:47 INFO - Rolling barrel completed
01-04-2010 13:35:46 INFO - Rolling barrel started
6 : Logs
Jaap Schellekens
Current system time: 01-04-2010 01:00 (GMT+1)
12:49:07 GMT
14:49:07 CEST
Last refresh time: 01-01-1970 01:00 (GMT+1)
Stand alone
3,342 , 51,331





6.3.2 Proposed setup and components of the KKF-System

The first setup of the KKF-system will be build upon the following existing models and systems:

1. The hydrological and hydrodynamic models from GRADE will be used to calculate flows and water levels for the Rhine and Meuse basin up to Lobith and Borgharen. The Delft-FEWS GRADE setup will also be used as the base to link to other models/systems.

2. For the Main Rivers GRADE (SOBEK) and SOBEK-NDB will be used. SOBEK-NDB is already coupled to GRADE in FEWS. It is also possible to run DM for the main rivers stand alone (not coupled to MOZART). In that case a file is needed that drives the water distribution at the DM nodes. For critical periods during the full 150 years of climate data 2D WAQUA models can be used if needed.
3. NHI Light or NHI repro is suited to model the Local Water Systems. DM which is part of NHI-light and NHI-repro has added value to the SOBEK models of the Main Rivers system because it deals with water allocation. For critical periods during the full 150 years of climate data NHI will be used.
4. DCSM covers the North- and Wadden Sea and will be coupled to SOBEK-NDB and SOBEK-Bekken. A coupling with DM is questionable because DM always assumes it can discharge to its boundary nodes (North Sea in the case of Northern Delta Basin). More detailed models like ZUNO, Kuststrook and even more detailed models will be used during critical periods within the full 150 years of climate data.
5. For Lake IJssel the SOBEK-Bekken model will be used. This model will be coupled to DSCM and DM. WAQUA/ SWAN models will be used for this system during critical period within the full 150 years of climate data.
6. Habitat will be linked (as a post operation) to the outputs of the IJsselmeer model to determine Habitat development over the whole simulation period

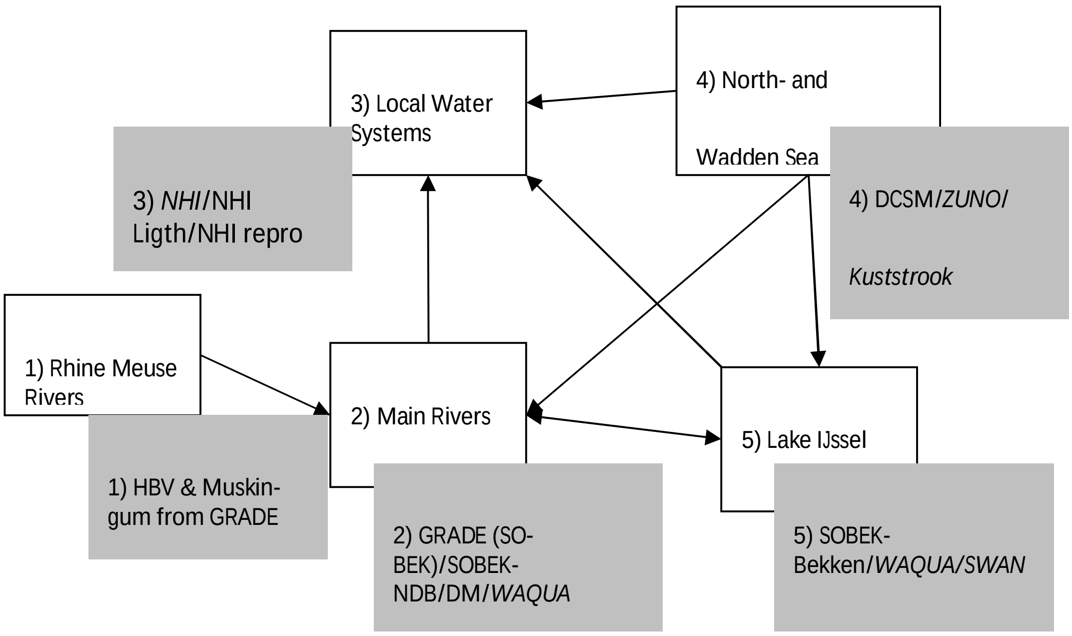


Figure 6.2 Schematical layout of the available systems (detailed models in italic)

When working with the system the following steps will be taken (NB this is not a complete list; it is based on the prototype, it does not yet include the socio-economical and nature steps):

1 Import and process the climate forcing date
1.1 Import raw data, make window and convert units
1.2 Export processed data
1.3 Delete local data cache
1.4 Import reduced dataset and process to provide input to:
   a. Hydrological and hydrodynamical models in Rhine and Meuse basin (also part in the Netherlands)
   b. DCSM for North- and Wadden Sea
   c. NHI-light or NHI-repro for the Local Water Systems/ Main Rivers
   d. SOBEK-Bekken for Lake IJssel
2 Run the following models (in this order):
   - GRADE
   - DCSM
   - SOBEK-NDB
   - NHI-light or NHI-repro
   - SOBEK-Bekken
3 Determine times of interest:
3.1 High flow
3.2 Low flow
4 Run more detailed models during times of interest

For the case studies HABITAl ans SOBEk-Bekken will also be run

6.3.3 Importing and processing KNMI ENES Forcing data

The data supplied by KNMI are available in netcdf 3 and netcdf 4 format. Delft-FEWS can import both formats. Importing one file (one month with 6 hourly timesteps, 282 MB in netcdf format) takes about one eigth minutes. Once stored in the Delft-FEWS database the data volume reduces to 90 Mb[3].

The supplied grid has a resolution of one degree and covers the entire globe. Date/time in the netcdf files is assumed to be GMT and the data is stored as such in the Delft-FEWS database. Error! Reference source not found. list the parameters that are imported from the KNMI ENES files while Error! Reference

[3] *This is achieved by applying run-length-encoding in combination with reducing the number of digits when storing the data.*

source not found. shows how external unit are converted to unit used in the KKF system.

Table 6.1 Parameters and units in the KNMI ENES files

internal-Parameter	internalLoca-tion	external-Parameter	externalLoca-tion	External unit	Internal unit
WS.u	ENES	uas	TEST	m/s	m/s
WS.v	ENES	vas	TEST	m/s	m/s
P.m	ENES	pr	TEST	kg/m^2/s	mm/6hr
T.m	ENES	tas	TEST	K	oC
PSL	ENES	psl	TEST	Pa	Pa
Rs.in	ENES	rsds	TEST	W/m^2	W/m^2
Rs.out	ENES	rsus	TEST	W/m^2	W/m^2
Rl.in	ENES	rlds	TEST	W/m^2	W/m^2
Rl.out	ENES	rlus	TEST	W/m^2	W/m^2
ET.m	ENES	evspsbl	TEST	kg/m^2/s	mm/6hr

SH	ENES	huss	TEST	-	-
lsm	ENES	lsm	TEST	-	-

Table 6.2 Unit conversions

inputUnitType	outputUnitType	multiplier	incrementer
K	oC	1	-273
kg/m2/s	mm	21600	0

7 Case studies

7.1 Introduction

In this pilot, we envisage not only, to make a coupling of several water-related models, but also to demonstrate the capabilities of such a system. This is done by developing several case studies, in which the unique capabilities of the instrument will come to use. The case studies are described in the remainder of this chapter.

7.2 Suitability of the NHI to run climate scenario's

In close co-operation with the NHI team we will look at how NHI may be linked to the KKF system and used to run climate scenarios. Given the timescale of the new NHI light version (that should be able to run 30 years of climate) we will only be able to run a subset of NHI based on the present operational system.

7.3 Co-variance of flood situations from the main river branches and from the North Sea

In this case study, we investigate the joint probability distribution of extreme discharges from the main rivers and extreme water levels at the North Sea. The joint occurrence of these two extreme conditions may impose a serious threat on Rotterdam. Imagine for instance what could happen if an extreme storm surge occurs that causes the Maeslant barrier to close. If at the same time an extreme discharge occurs from the main rivers, the Maeslant barrier may act like a dam will its upstream area may start acting like a reservoir. At this moment, there is no knowledge whether such situations are likely to occur. To simulate this joint occurrence and the associated joint probability distribution, a long continuous time series of climate data is required, and a model instrument, that jointly computes extremes from the main rivers and from the North sea. We can also compute, whether the water levels 'inside' the Maeslant barrier may become higher than the water levels 'outside' the Maeslant barrier. This is a force that the barrier has not been been designed for.

In this case study, the model instrument will be forced with the full 150 years of climate data resulting in 150-year long time series of water levels at Hoek van Holland and water levels and discharges in the port of Rotterdam. The decision rules for the Maeslant barrier can be used to estimate the water levels during closure of the barrier.

Expected outputs:

If 150 years of ENES data are available, the expected outputs of this case study are:

- Joint probability of occurrence of critical water levels both inside and outside the Maeslant barrier.
- Probability of occurrence (if any) of higher water levels inside the Maeslant barrier than outside during storm conditions when the barrier is closed.

The 150 years are a pre-condition to have a large enough sample. If a smaller sample is available we can still demonstrate the potential of joint simulation of water levels in and outside the barrier by a scenario simulation (e.g. is a critical situation such as described above likely to occur if higher precipitation would occur in the Rhine and Meuse basin? Or if the average wind velocity increases?).

7.4 Changing habitat conditions in Lake Marker and Lake IJssel

The Veerman committee suggested to raise the water level of Lake IJssel by 1.5 meters. Although this brings benefits for the supply of fresh water during dry situations, it may have a serious impact on habitat conditions in the lake. Maarse (2009) used the HABITAT software to estimate the effect of raising the water levels in Lake IJssel on its habitat conditions. The effects turned out to be positive (i.e. more species diversity) with a small change in water levels and negative for larger changes.

In the above-mentioned application, a pre-defined water level is imposed on all other variables. HABITAT then computes habitat suitabilities as a steady-state solution. In the KKF pilot system, we are able to generate long transient time series of water levels. This enables us to compute transient habitat suitability indices for different species. We will do this first of all by estimating a decadal averaged water level and compute habitat suitability indices for each 10-years of computations.

This experiment becomes much more exiting if we include the occurrence of extreme events in the cause-effect relationships and extract the occurrence of extreme events from each 10-year period. For instance, an extreme drought with persistent low water levels during one summer within the 10-year period may seriously affect the habitat suitability of certain species.

Within this pilot, the HABITAT models for Lake IJssel and Lake Marker will be coupled to the DM model. In tranche 2, we will investigate the effect of including extreme events in the cause-effect relationships.

Expected outputs:

- Decadal habitat suitability maps in a changing climate

8 Conclusions

The inventory of existing models revealed enough models that can be sensibly linked using the Delft-FEWS framework. The resulting data and model framework is capable of running the long timeseries that are required in climate modeling and can be fed with one consistent climate scenario. As such, the results should also be more consistent compared to running each model individually.

Run times for the chosen set of model are acceptable. However, several detailed models should only be run for specific periods of interest, a strategy that has successfully been used in earlier research (i.e. GRADE).

The set of models can be used to evaluate case studies such as the combined occurrence of high flows in the main rivers and a large storm surge at the coast. In addition, the future habitat development in Lake Ijssel may be determined by using a link to the Habitat model.

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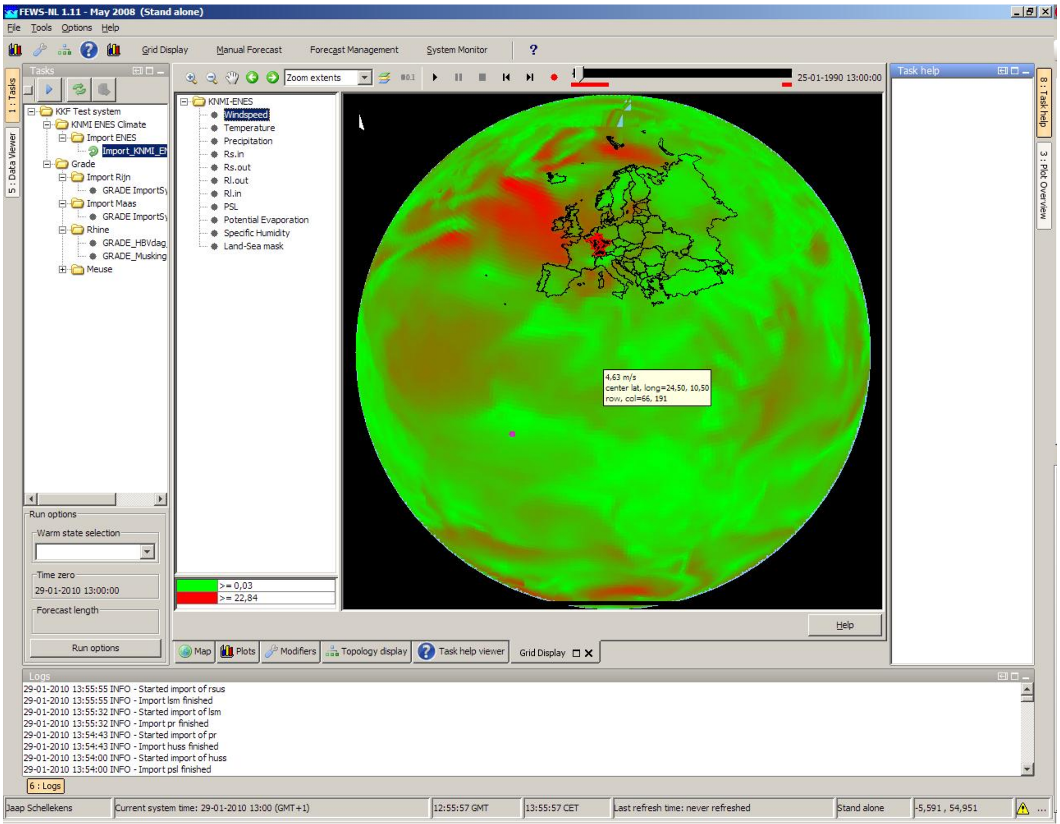
Bijlage A KNMI ENES Data description

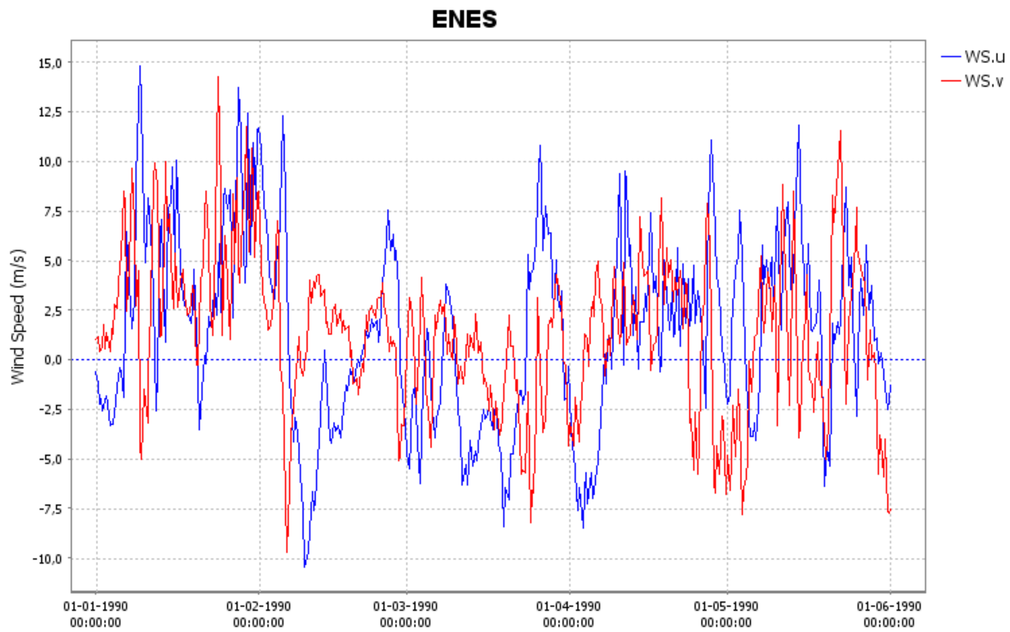
Introduction

This appendix graphically shows the KNMI ENES data as read and displayed by Delft-FEWS. All spatial displays show the whole grid while the graphs show the contents of a pixel in The Netherlands.

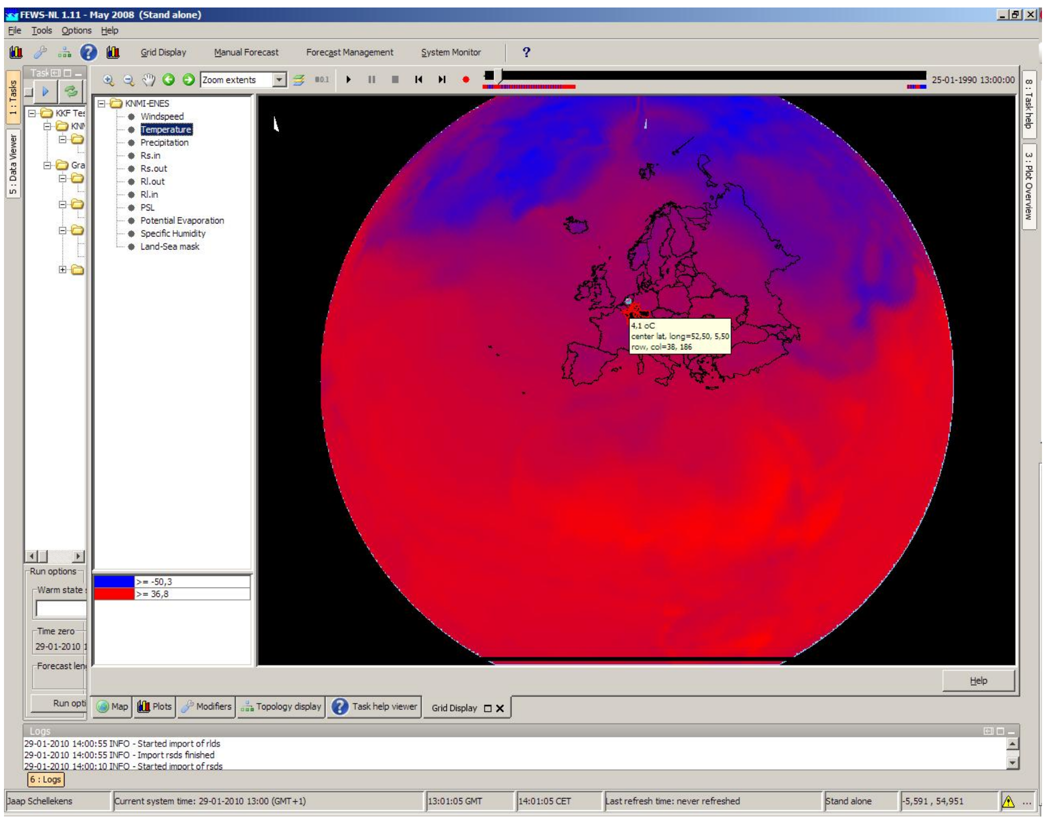
Wind speed (u and v)

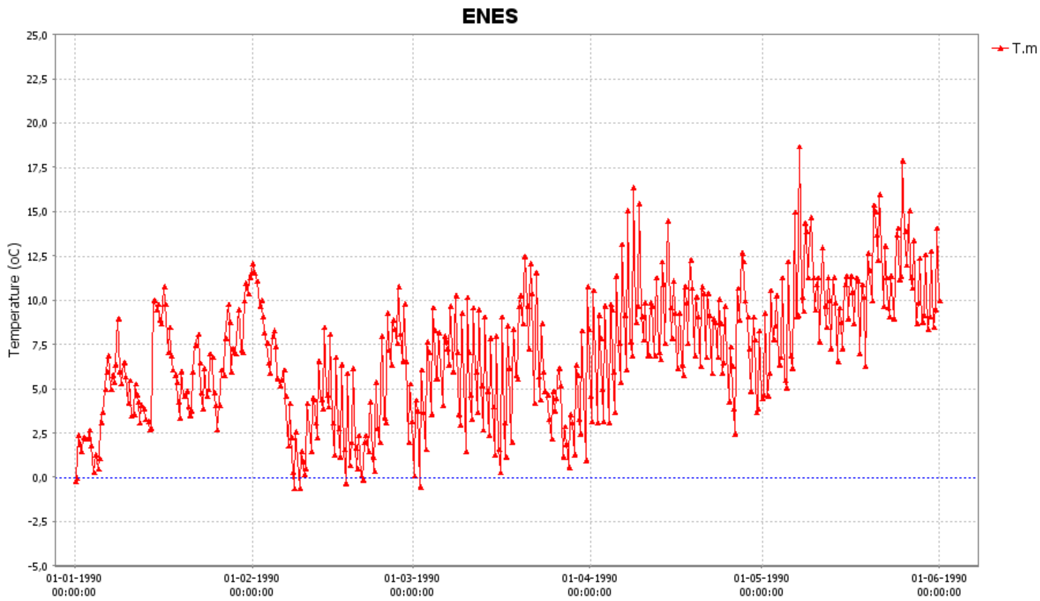
The spatial display shows the calculated speed (based on the u and v components) the graphs shows the two components separately.



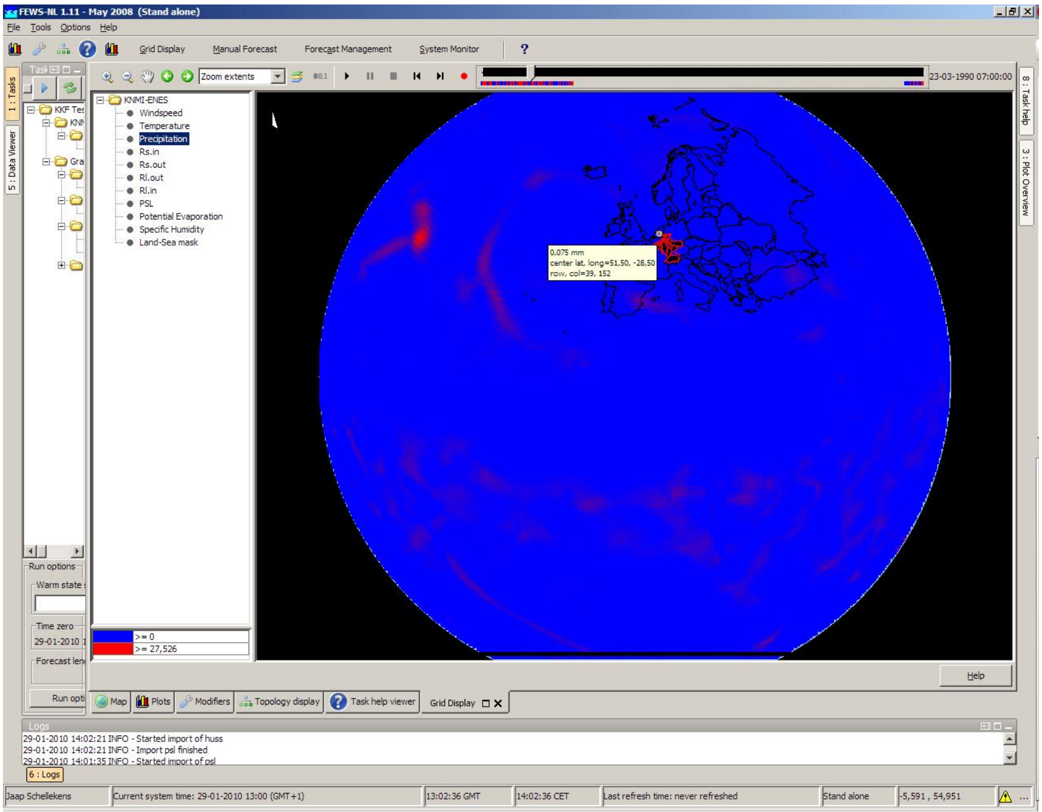


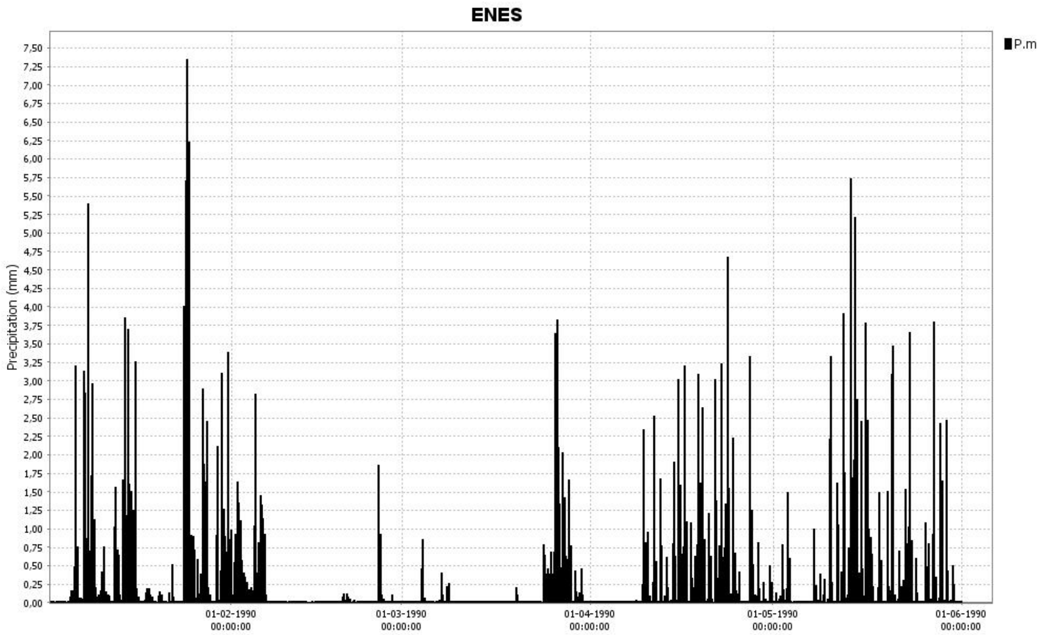
Temperature at 2 m



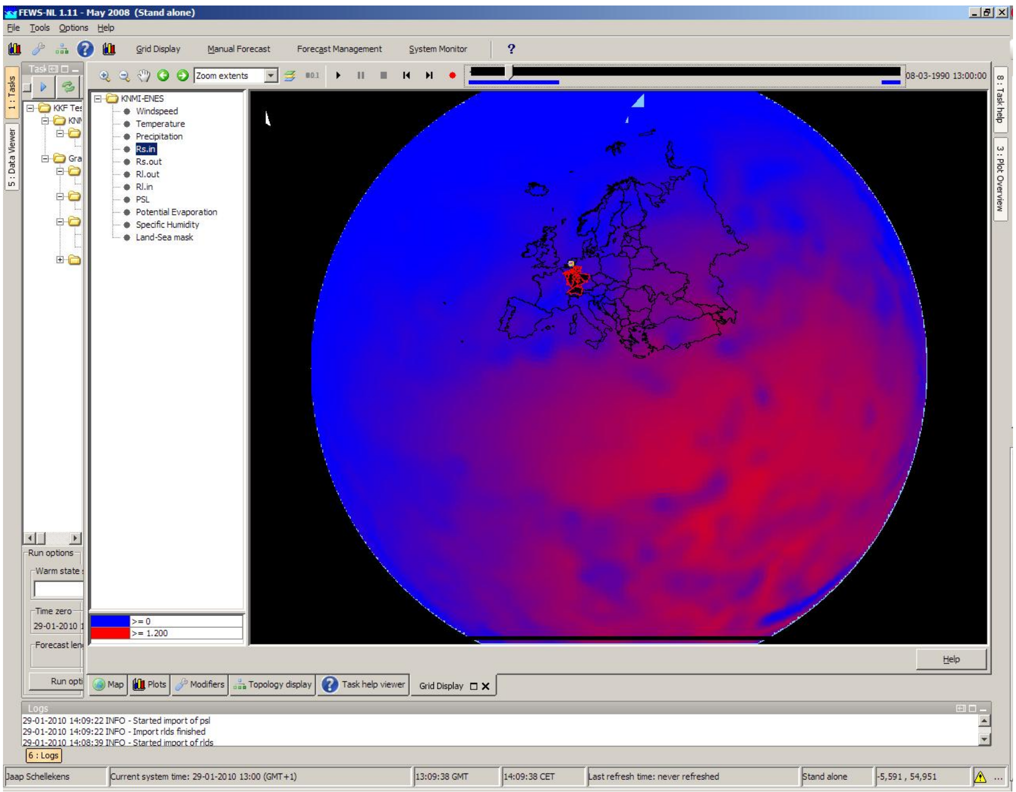


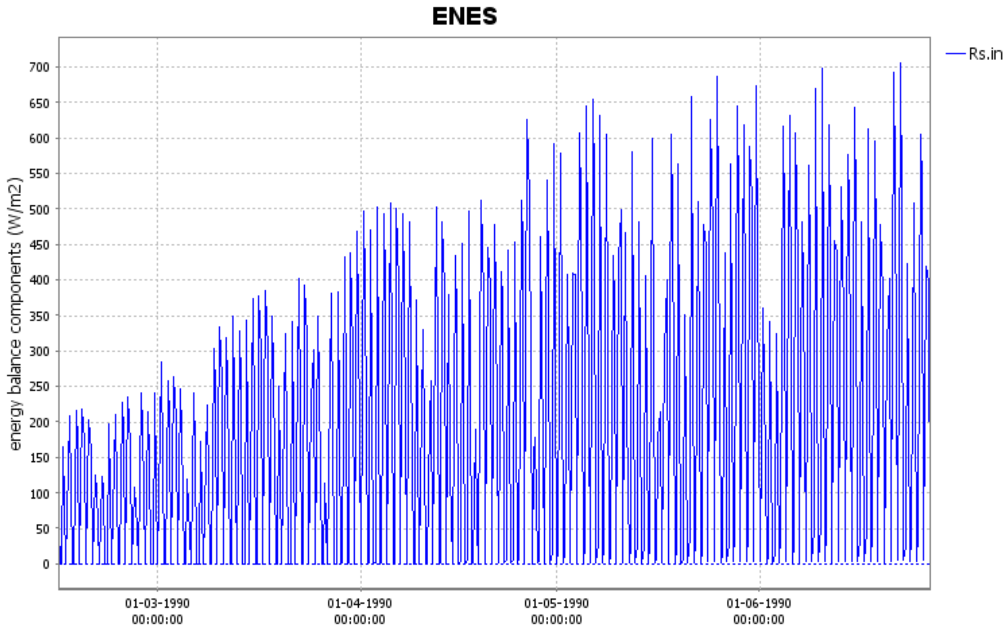
Precipitation



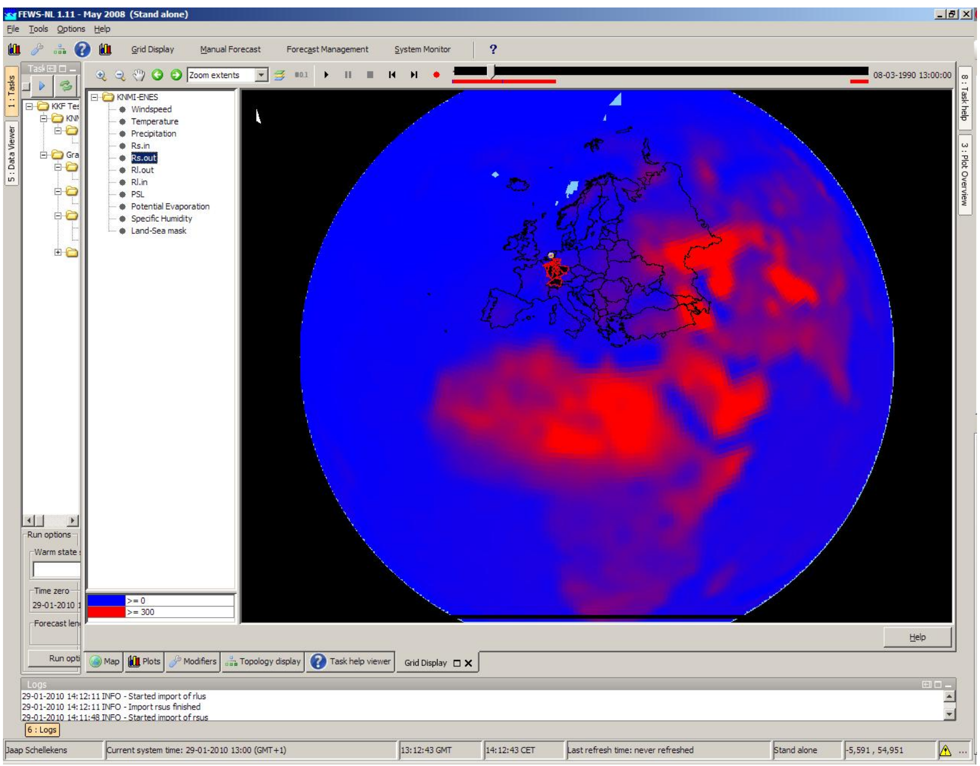


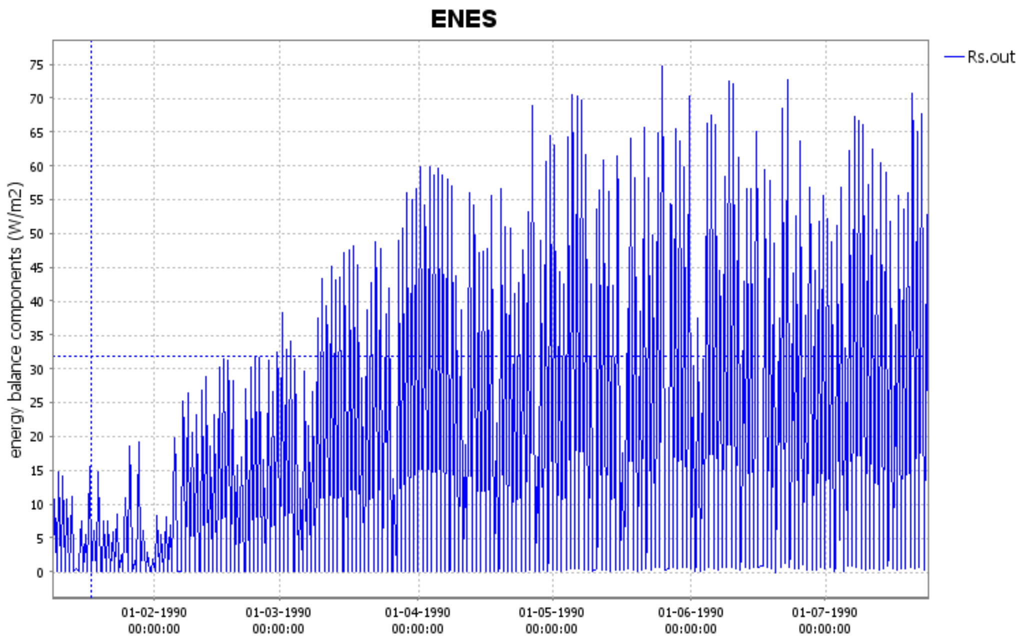
Incoming short-wave radiation



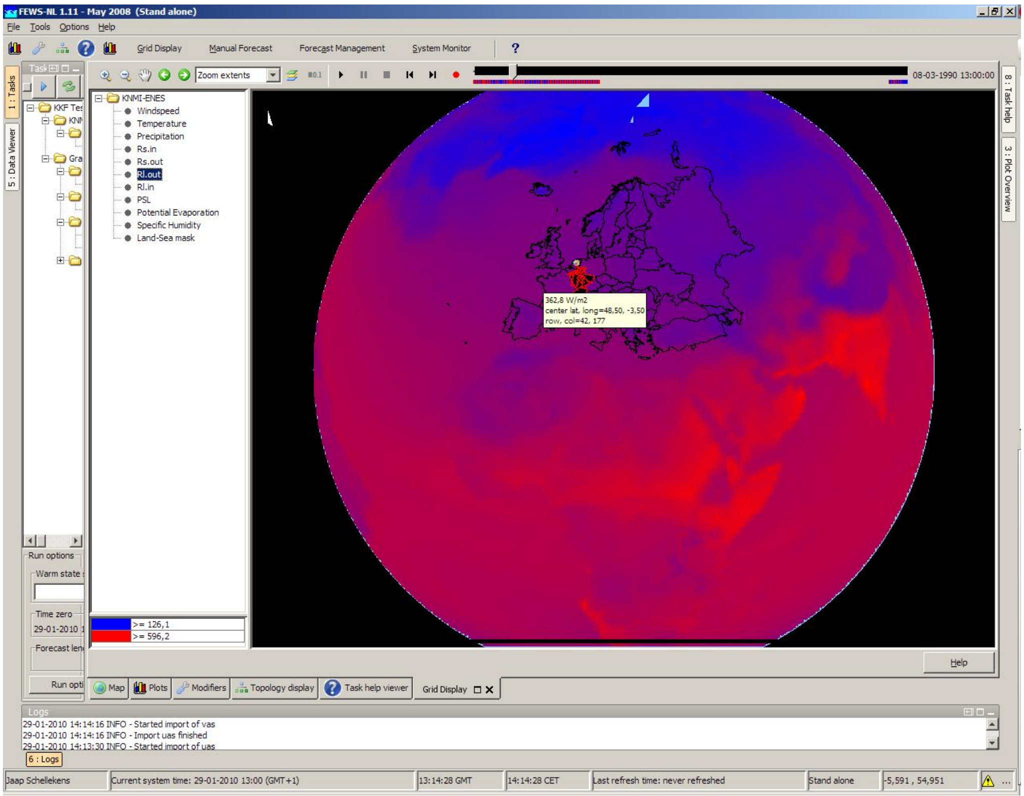


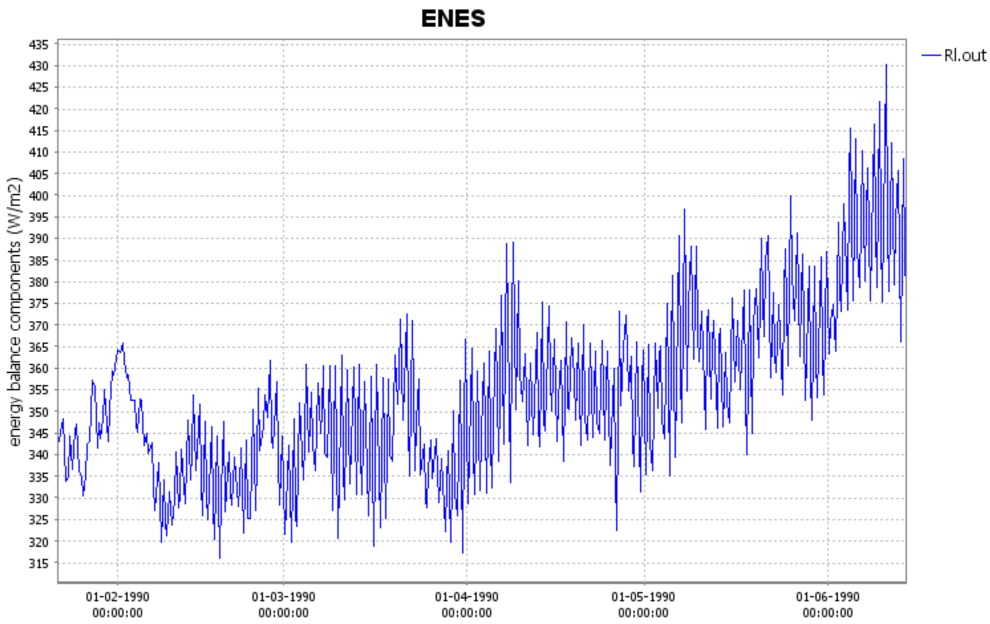
Outgoing short-wave radiation



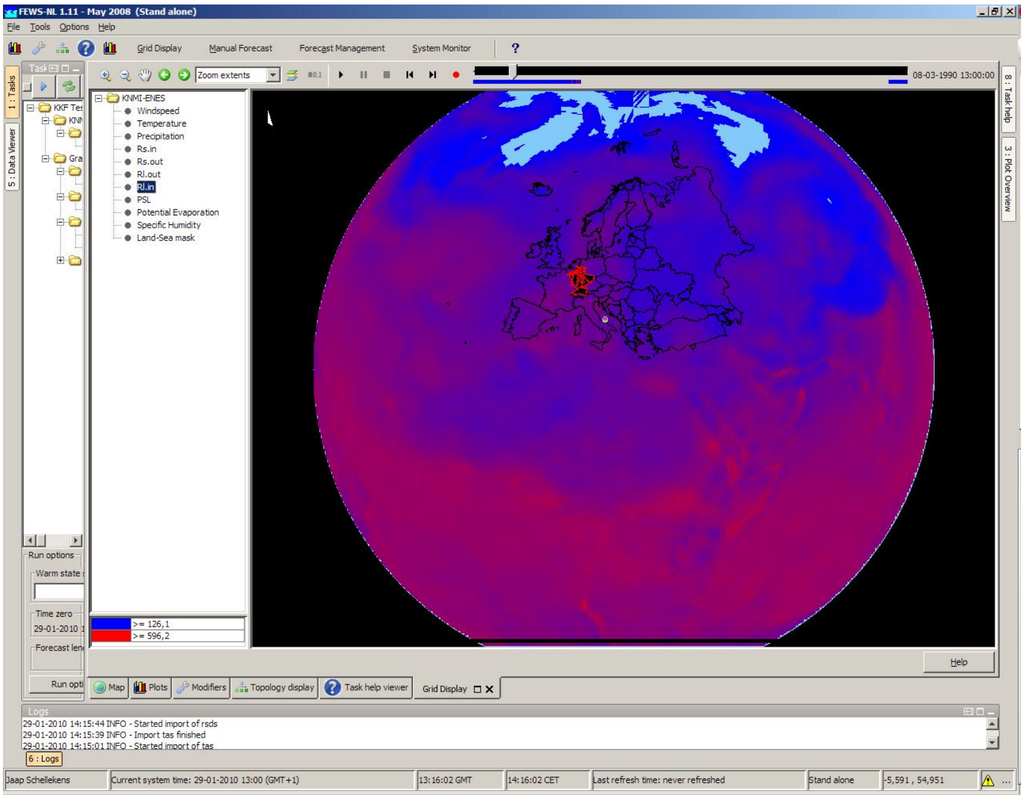


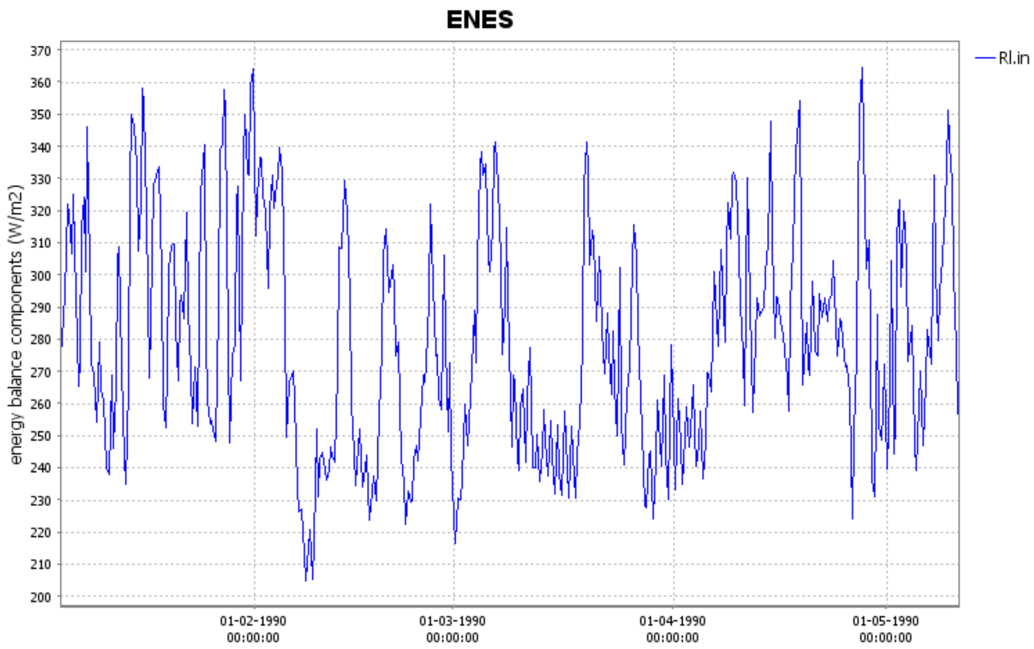
Outgoing long-wave radiation



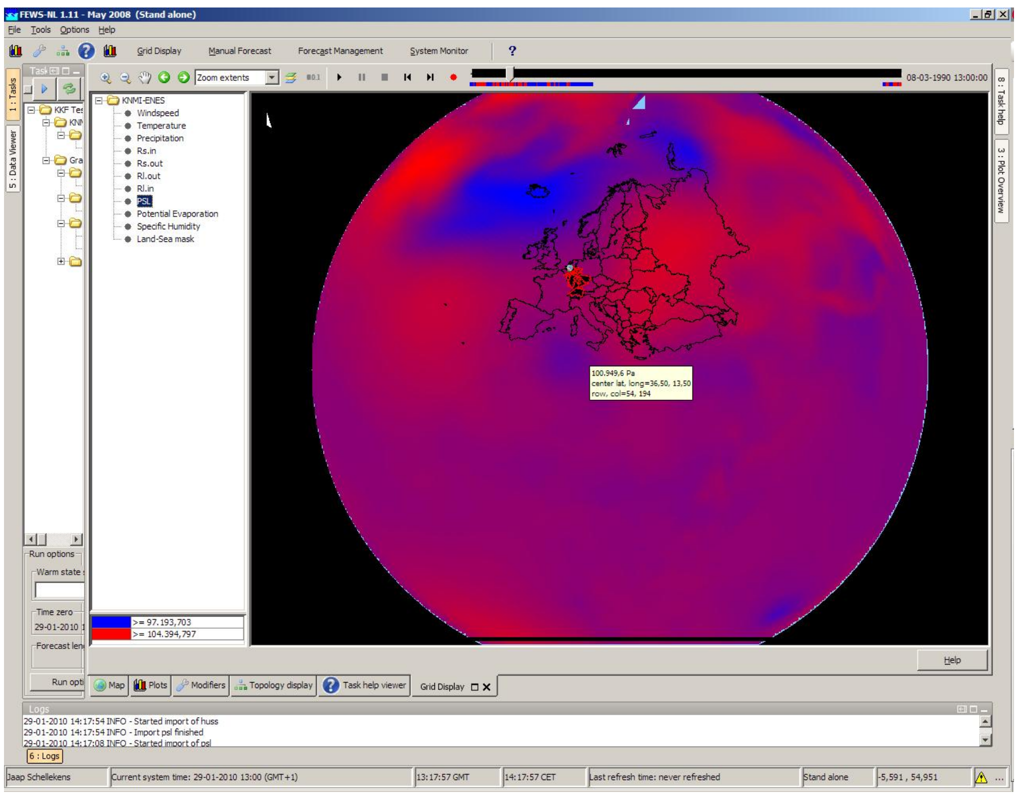


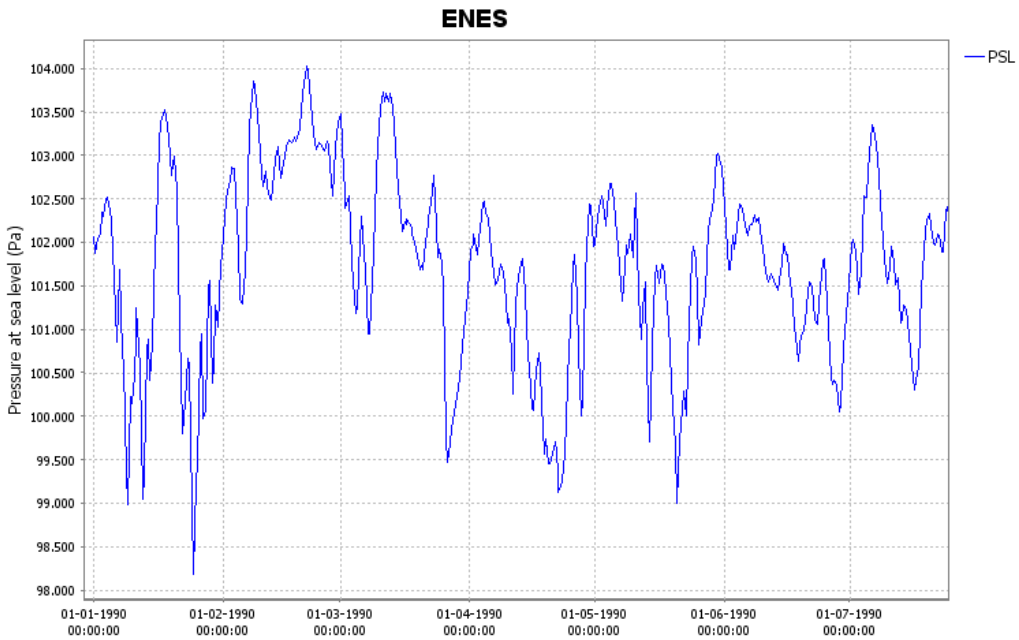
Incoming long-wave radiation



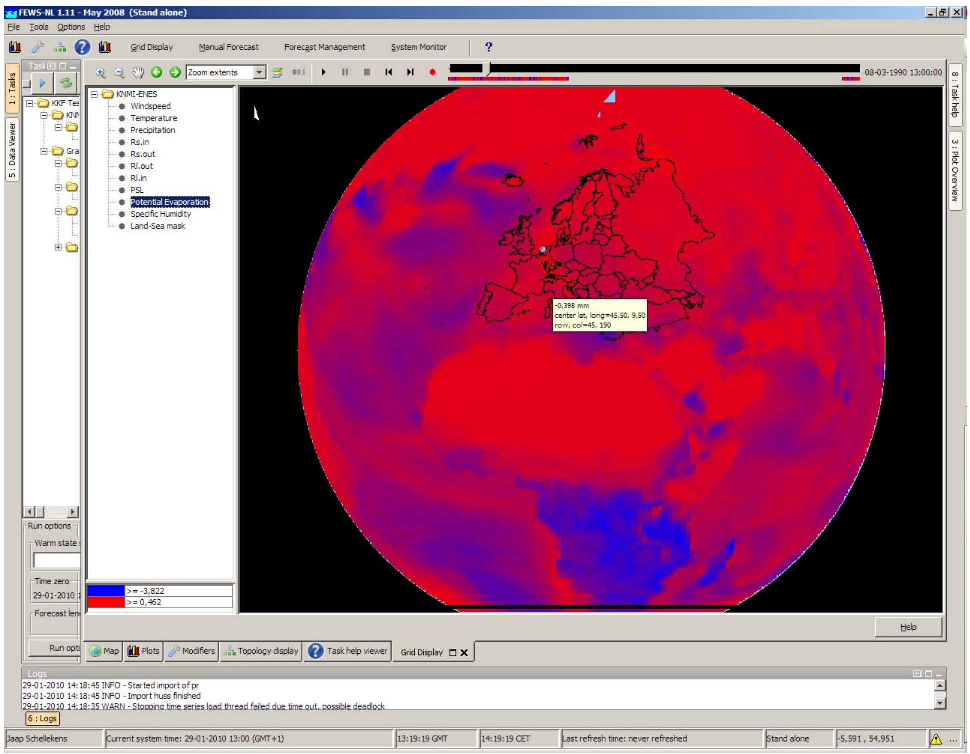


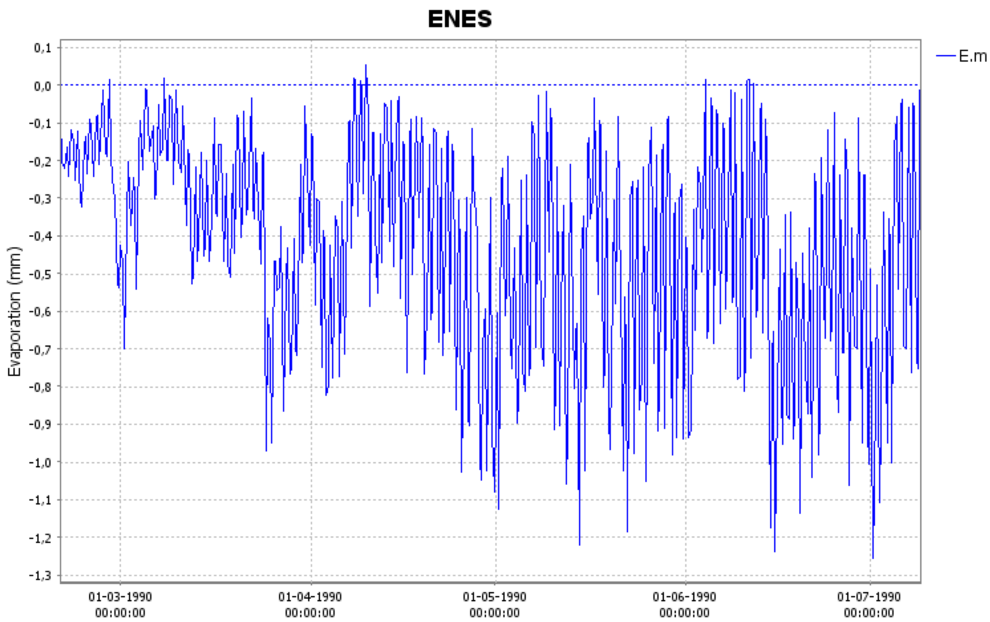
Pressure at sea level



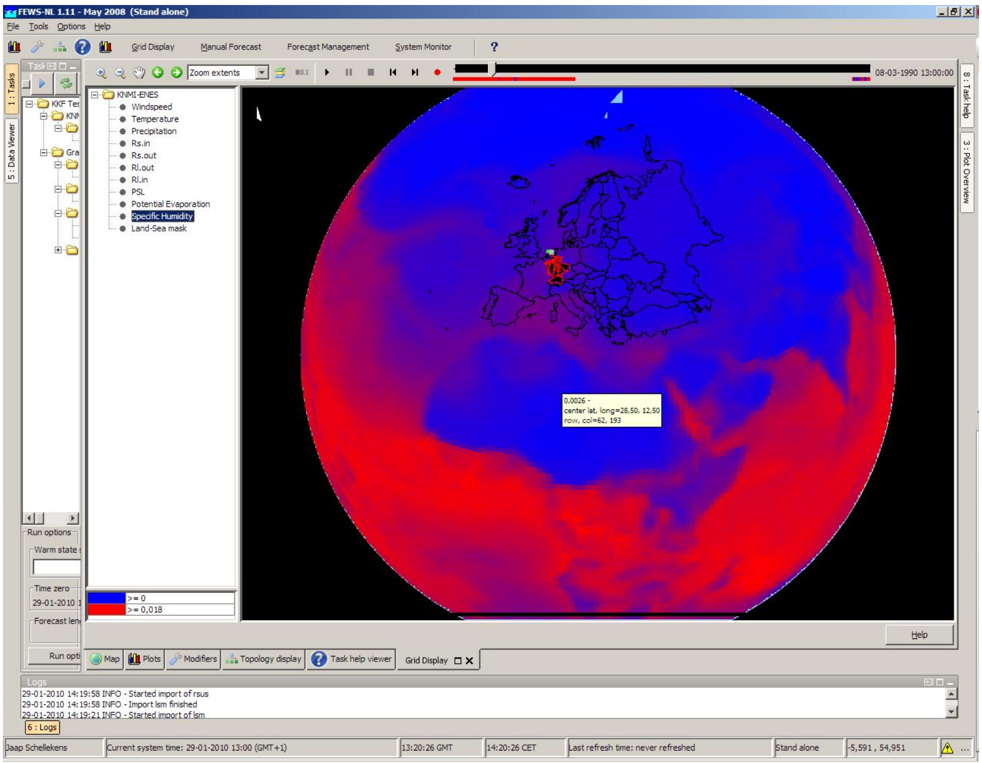


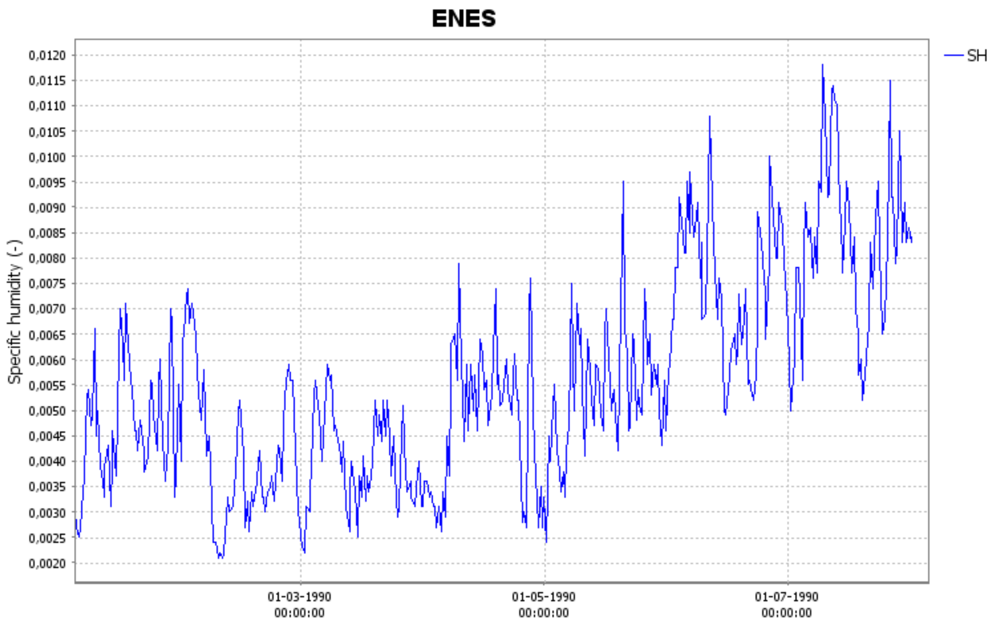
Evapotranspiration



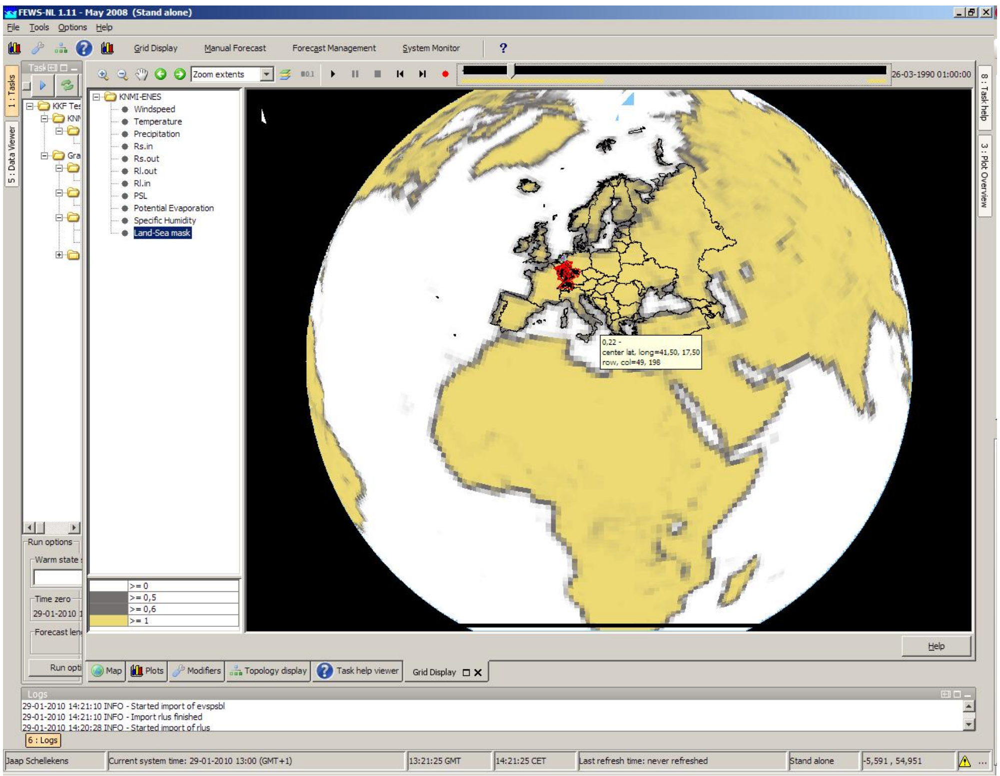


Specific Humidity





Land-Sea mask



Bijlage B: Minutes of the workshop

Verslag KKF-coupling workshop

Op 27 April 2010 is een workshop gehouden met als doel om belanghebbenden te informeren en te brainstormen over het project Klimaat Kennisfaciliteit Coupling. In dit project wordt beoogd een pilot modelsysteem neer te zetten wat onderzoek naar klimaateffecten faciliteert en vergemakkelijkt. De kern van het systeem gaat bestaan uit een aantal gekoppelde watermodellen (hydrologie en hydraulica) die gevoed worden door een lange tijdserie klimaatgegevens. Voor specifieke onderzoeksvraagstukken kunnen hier modelcomponenten aan toegevoegd worden, uitgeschakeld worden of aangepast worden om zo een flexibel effectanalyse instrument beschikbaar te hebben.

Hieronder volgt puntsgewijs een weergave van de besproken onderwerpen. De punten volgen de vastgestelde agenda.

10:30-10:45
Voorstellen Wat is het project. Doel, relatie tot andere projecten
Jaap Schellekens/Jaap Kwadijk
Wat onderscheidt dit project van het Deltamodel? • Deltamodel: model waarmee we *maatregelen* in Nederland doorreke-

nen om te beslissen wat we moeten doen om klimaatbestendig te blijven (*beleid*) • KKF: wat zijn de effecten van klimaatverandering op het natuurlijk systeem, dus in het uiterste geval bepaling van randvoorwaarden voor maatregelenstudies (*wetenschap*)

10:45 – 11:15
Presentatie model inventarisatie
Hessel Winsemius /Willem van Verseveld
Een belangrijke link mist in het schematisch overzicht van modellen: link tussen Regionaal water en IJsselmeer. Deze wordt toegevoegd. Benedenrivieren / Grote rivieren Ton Sponge: er lijkt sterke overlap tussen Deltamodel en KKF. Doen we niet precies hetzelfde? Discussiepunt: in KKF is het doel allereerst een kader voor onderzoek neer te zetten, waarbij modellen uitgewisseld kunnen worden. Interessante op te lossen vragen op den duur zijn bijvoorbeeld “heeft een beter model voor gebied *x* enige invloed op outputs van interesse (welke outputs wel/niet?)

11:15 – 11:30
Presentatie werk aan metaswap/NHI

Ab Veldhuizen
• Er is al een FEWS implementatie van NHI • Er is een NHI webportal • NHI voor al op droogte gericht (watervraag en water verdeling) • Ontwikkelingen: kijken naar vegetatie en bodem via SMART-SUMO-MOVE • Schade aan landbouw kan in principe wel berekend worden via AGRI-COM maar is (nog) niet gevalideerd

11:30 – 11:45
Landuse en klimaat
Philip Ward
Socio-economische modellen in KKF-platform Richten op landgebruik, waterveiligheid landbouw en natuur Belangrijke studie: WLO (veranderingen in komende 30 jaar), bestaat uit ca. 40 modellen, die samen een scenario voor landgebruik produceren. Verder dan 30 jaar vooruit is koffiedik kijken, dus gebeurt niet. Nieuwe ontwikkeling: WLO lite, lichtere versie van WLO. Koppeling kan op 2 manieren: • Landgebruik kan impact hebben op het water • Water heeft impact op landgebruik door schade (bv. Gewasschade bij droogte, overstromingsschade) Aandachtspunten: • Ruimtelijke/temporele resolutie (benodigdheid hangt af van vraag en

van de bijbehorende hydrologische modellen detailniveau!)
- Landgebruikklassen
- Output/input compatibiliteit (benodigdheid hangt af van vraag en van de bijbehorende hydrologische modellen detailniveau!)

Modellen:

CLUE: Europadekkend (specifiek ontwikkeld voor Europese vraagstukken

- Rijnbekken al gesimuleerd
- Landgebruik kan gekoppeld aan hydrologische modellen (bv. PhD Ruud Hurkmans)
- Risicomodel (dan toevoeging voor build-up area nodig)

Ruimtescanner:

- Gebruikt CLUE als randvoorwaarde
- Specifiek voor Nederland

Hoe koppelen?

a. landgebruikskaarten offline als input. Als risico's ook tot vraag behoren is aandacht nodig voor inundatie-schadekoppeling
b. online koppeling: inventarisatie van wat hydrologisch model echt nodig heeft (vertaalslag output CLUE naar input hydrologisch model).

Voor schade (damagescanner):

- volledige 2Dmodellering koppelen met landgebruik/schadekaart
- alternatief: hoe verandert de herhalingstijd, dit combineren met bekende overstromingspatronen horende bij 1/1250 jaar.
- Damagescanner is beschikbaar in matlab/PCRaster

11:45 – 12:00
Natuur en klimaat
Aat Barendrecht
Wat veranderd er voor natuur: - Wateraanvoer: wordt op peil gehouden dus verandert niet in West-Nederland, Oost wel. Droogvallen natte gebieden, is niet onder controle te houden dus kun je niets aan doen. - Getijden gebieden (zee niveau stijgt) - Rivieren (toename dynamiek) Dit resulteert in stress op stress: - Inlaat van water met verhoogde concentratie aan zout en nutrienten - Mineralisatie veen door verdroging - Hogere verdamping - Groeiseizoen verandert Modellen beschikbaar om hieraan te rekenen: - Modellering per soort (op basis van directe meting) - Expert judgment (Ellenberg) - Systeemgericht (ecotoopontwikkelingen/vegetatietypenontwikkeling) - Gedetailleerde modellen (met veel variabelen) - Multiple stress (klimaat, pH, zuurstof, koolstofdioxide, nutrienten,

zout)
Soorten reageren verschillend: wellicht kiezen voor alleen meest gevoelige soorten Om een idee te krijgen wat hier in Nederland staat te gebeuren met soorten-samenstelling, wellicht kijken naar andere landen waar het huidige klimaat vergelijkbaar is met wat ons te wachten staat (bv. Frankrijk).
Klimaatverandering wordt nu niet vertaald naar de vorm, nodig voor deze modellen
Wassen: Ecologen zitten aan het eind van de modelketen. Dus die hebben waarschijnlijk de meeste onzekerheid te verduren. Jaap: als we koppeling tot stand brengen, dan kun je juist onderzoeken wat die onzekerheid dan is en waar die door veroorzaakt wordt.

12:00 – 12:15
Air Quality and climate
Astrid Manders
Impact weer op luchtkwaliteit: • Transport

- Depositie
- Chemische reacties (afh. van temp. straling en luchtvochtigheid)

LOTOS-EUROS (heeft uur tot uur meteorology nodig en een tijdsprofiel van emissies uit een bestaande database)

Rekentijd is enorm. Er is wel een parallel versie beschikbaar

Wat voor koppelingen zijn er te bedenken?

- Effect van landgebruikverandering op emissies
- Effect van socio-economische scenario's op emissies

Discussie en vragen
Moderator Jaap Kwadijk
Hieronder per onderwerp gerangschikt 1. Zijn bestaande modellen functioneel aan elkaar te koppelen • Otto: Temperatuur is misschien een probleem omdat je watertempe-ratuur nodig hebt om een model te voeden, komt niet direct uit het klimaatmodel • Peter: in heel veel gevallen ga je eerst testen en kom je dan pas erach-ter wat voor problemen zijn met koppeling. Er is een testfase nodig. • Koppeling is goed realiseerbaar als er goede metadata over in-put/output van alle modellen (vooral waar koppeling gerealiseerd moet worden) • Is het niet beter om allereerst outputs uit verschillende modellen naast elkaar te zetten of offline outputs van de een als input voor de andere te gebruiken om te concluderen wat de dominante gevoeligheid is voordat een online koppeling tot stand gebracht wordt. • Jaap S. Bovenstaande klopt maar moet wel consistent blijven i.e. alle-

maal dezelfde climate inputs gebruiken.

- Complexiteit van koppeling is soms zo simpel dat een systeem zoals voorgesteld niet nodig is.

Conclusie: koppelen kan, maar eerst gevoeligheden toetsen, goede metadata van input/output organiseren zodat het duidelijk is wat de waarde hiervan is

2. Eenrichtingsverkeer. Maken we met zo'n simpele koppeling niet een fout?

- Marjolein: Vegetatieontwikkeling is 2-wegs gekoppeld met ruwheid → belangrijk voor hoogwater
- Marjolein: Watervraag in droge periodes. Droge zomer, meer water-vraag, dus lagere peilen, ook meerwegs koppeling
- Aline: terugkoppeling van bodemvocht en verdamping naar atmosfeer zit er niet in
- Erik Ruijgh: soort vragen wat je wilt oplossen bepaalt welke van boven-staande processen belangrijk is en of terugkoppeling belangrijk is.
- Jaap K. We behandelen de statistiek van stormen op noordzee en ri-vierafvoeren meestal apart aannemende dat deze onafhankelijk is. Dit systeem kan wel de co-variantie bepalen in het voorkomen van dit soort situaties. 150 jaar is relatief kort hiervoor, maar we kunnen mi-nimaal bepalen of deze situaties onafhankelijk zijn en of er aanwijsbare momenten zijn waarin dit voorkomt.
- Effect van vegetatiegroei op het bodemvocht in onverzadigde zone kan weer effect hebben op de hydrologie. Zou interessant zijn om te kijken wat de gevoeligheid hiervan is.
- Marjolein: belangrijk te inventariseren *welke* beperkingen er in dit sys-teem zit en wat hierdoor *niet* opgelost kan worden.
- Je kunt ook eerst een run doen, daarna de effecten daarvan interpre-teren in een nieuw scenario (bv. Hoe gaan we handelen als ergens de overstromingsfrequentie extreem toeneemt?).

Conclusie: we maken hier fouten mee, die met gevoeligheidsanalyses in kaart gebracht kunnen worden. Verder belangrijk te onderkennen waar de aannames en beperkingen zitten en wat er *niet* mee opgelost kan worden.

3. Bestaande modellen: kunnen we het hiermee doen?

- Martin: Benoemen wat de aannames achter bepaalde modellen zijn (bv. We weten niet zeker dat het model *climate-proof* is).
- Martin: Er is vaak een interpretatieslag nodig: bv. Wat voor water wordt aangeboden in welke verhouding in een ecologisch systeem

(hoeveelheid zeewater, neerslag, rivierwater, grondwater tijdens het groeiseizoen). Er wordt geconcludeerd dat dit in principe wel geleverd kan worden vanuit het NHI maar dat dit nu nog niet geïmplementeerd is.

- Belangrijk dat modellen uitwisselbaar blijven. Als een bepaalde studie vraagt wat de impact van verandering in gletsjerhydrologie in Zwitserland op rivierafvoeren in NL is, dan moeten daar uitwisselbare modellen voor ingezet kunnen worden.
- Peter: belangrijk om een aantal voorbeelden te laten zien zodat duidelijk wordt waarvoor je dit instrument kunt gebruiken.
- Vraag: Hoe open moet dit systeem zijn? Liefst zo open mogelijk. VU en Alterra willen graag dit systeem samen met Deltares gebruiken zodat het een community tool wordt.
- Risico hierbij: hoe ga je om met 2 verschillende antwoorden uit 2 modellen (bijvoorbeeld KKF en Deltamodel)? Belangrijke discussie die gevoerd moet worden als we erover gaan nadenken resultaten open te delen.

Conclusie: voor bepaalde vragen zijn minimaal aanpassingen nodig in bestaande modellen om fatsoenlijke koppeling te maken (bv. Zoutgehalte in grondwater/onverzadigde zone in NHI)

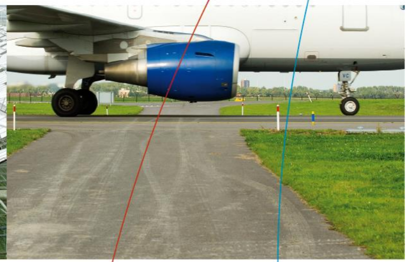
4. Pilot gaat draaien bij Deltares. Toegang van buiten mogelijk. Is dit voldoende? Wat gaan we ermee uitrekenen?

- We bouwen een systeem dat faciliteert dat modellen bij elkaar gebracht worden.
- Het is een samenwerkingsplatform dat verschillende onderzoeksinstituten in staat brengt om hun modellen bij elkaar te brengen en gezamenlijk klimaatsveranderingeffecten te bestuderen.
- Een onderzoeker kan zo effectief zijn vraag beantwoorden of zijn eigen modelletje ergens onder hangen wat al bestaat
- Metadata en beschrijvingen van modellen, waar het wel/niet geschikt voor is is belangrijk en moet gestructureerd beschikbaar worden gesteld.

5. Communicatie/planning:

- Jaap Schellekens is contactpersoon bij Deltares
- Eind mei: rapport af inclusief workshop verslag
- Daarna tot eind oktober pilot bouwen
-



To develop the scientific and applied knowledge required for Climate-proofing the Netherlands and to create a sustainable Knowledge infrastructure for managing climate change

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