Grant Agreement number: 266722
Project acronym: SUMO
Project title: Supermodeling by combining imperfect models
Funding Scheme:
Date of latest version of Annex I against which the assessment will be made:

Periodic report: □ 1st □ 2nd ■ 3rd □ 4th □

Period covered: from 01.10.2011 to 30.09.2012

Name, title and organisation of the scientific representative of the project's coordinator¹:
Prof. Ljupco Kocarev
Av. Krste Misirkov 2
1000 Skopje
Former Yugoslav Republic of Macedonia
Tel: +38923235400
Fax: +38923235501
E-mail:

Project website² address:

http://www.sumoproject.eu/

¹ Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.
² The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?page=logos). The area of activity of the project should also be mentioned.
Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;

- The project (dark box is used instead of tick as appropriate)³:
  - □ has fully achieved its objectives and technical goals for the period;
  - ■ has achieved most of its objectives and technical goals for the period with relatively minor deviations
  - □ has failed to achieve critical objectives and/or is not at all on schedule;

- The public website, if applicable
  - ■ is up to date
  - □ is not up to date

- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.

- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: Ljupco Kocarev

Date: 24/10/2012

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism.

³ If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.
1. Publishable summary

Summary: SUMO

Consensus formation among a small group of expert models of an objective process is challenging because the separate models have already been optimized in their own parameter spaces. In SUMO we address consensus formation in a connectionist framework, by introducing connections, with coefficients to be determined, between some restricted set of pairs of corresponding variables in the different expert models. By applying machine learning techniques, as well as methods from nonlinear dynamics, we can adapt the connection coefficients linking the corresponding variables in the different models. Using a recipe for extending synchronization between a pair of dynamical systems to adapt system parameters as well as states, for instance, we can adapt the connection coefficients linking the corresponding variables in the different models.

In the SUMO project we apply this procedure to the pressing problem of fusing different models of the Earth's climate system, which give different predictions regarding the details of climate change. The fusion scheme, which is referred to as supermodelling, is developed and validated in a hierarchy of increasingly complex model types, ranging from simple ODE's to models that are actually used for climate prediction.

This new computational approach to the simulation and prediction of complex, real systems can only be developed by bringing together experts from different disciplines: nonlinear dynamics, machine learning and, in this case, climate science, disciplines that are well represented in the SUMO project.

The extended SUMO project consists of the following 7 work packages:

- WP1 – General Theory of Supermodelling with ODEs
- WP2 – Learning of connection coefficients in ODEs
- WP3 – Learning of connection coefficients in PDE systems
- WP4 – Supermodelling with intermediate complexity climate models
- WP5 – Supermodeling with large climate models
- WP6 – Management
- WP7 – Learning complete supermodels

Most of the work in the first three work packages concerns relatively low-dimensional systems of up to a hundred dimensions and is extended to infinite dimensions in the work on partial differential equations in WP3. WP1 focuses on the possibility of synchronizing different models, given that the connections can be chosen manually, WP2 on strategies to learn the connections from observational data. WP4 is a step up in the hierarchy in that it uses the results from these work packages in the construction of a supermodel consisting of interconnected intermediate complexity climate models of order several thousand degrees of freedom. Results from this work package feed into the construction of a supermodel consisting of state-of-the-art climate models in WP5. Problems encountered in WP4 and WP5 are fed back to the other work packages that suggest solutions on the basis of additional work on lower dimensional systems or theoretical considerations. In the extended SUMO project, a new work package has been added (WP7), concerned with learning complete supermodels. The figure provides a graphical representation of the nature of and
interconnections between the work packages. The horizontal dimension of the ovals indicating each work package reflects the dimensionality of the model systems that are subject of research, the vertical dimension the amount of experimentation that is possible in that work package. The vertical ordering of the work package reflects the nature of the research from more fundamental at the bottom to more applied research to the top. The colors indicate the prevailing expertise needed in each work package. The arrows reflect the flow of information between the work packages. The overlap indicates the amount of joint work on the same model systems.

Figure 1 Graphical representation of the nature of and interconnections between the work packages.

Work performed for the period 1.10.2011 to 30.09.2012

The work performed and the main results achieved in the second year of the project can be summarized as follows.

WP1 (General theory of supermodeling with ODEs)

- We simulated supermodels composed of incomplete models. In these simulations, two 2-D models were constructed to model different aspects of the assumed 3-D Lorenz 63 ground truth. By coupling, either through connecting or weighting, the incomplete models were able to complement each other. Both supermodels provided a much better description of the assumed reality than any a posteriori average of the individual models could do. Both supermodels showed a rather complex chaotic butterfly shaped attractor, while the 2-D models only showed simple periodic orbits and point attractors. In the case where models and ground truth had all the same dimension, there seemed hardly any difference in the performance of connected and weighted supermodels. However, in the incomplete model case, the connected supermodel seemed to be able to better reproduce the butterfly shaped attractor of the assumed Lorenz 63 ground truth than the weighted supermodel. In particular,
the dynamics of the weighted supermodel seemed to be a bit less chaotic than the connected supermodel and the ground truth. A possible explanation could be that a weighted supermodel could be understood as a connected supermodel with infinite connections. This gives the weighted supermodel less flexibility because the models are in a way instantaneously synchronized and remain so over time. This may hinder transitions between different regimes in the attractor. In connected supermodels, where the connections have finite values, synchronization is not immediate, and models can deviate from synchronization. In other words, models are allowed to deviate from the consensus state and follow more their own dynamics for a while. By doing so, the model could make a transition to different other regimes, and by the couplings, other models may follow, which then results in a regime transition of the consensus state.

- We showed a proof-of-concept that a combination of different models of one dimensional scalar atmospheric quantity can be a better short-term predictor than any of them. The idea was tested on the Lorenz 96 toy model because it is simple enough, but also nontrivial and shares some basic properties with the real atmosphere. The atmosphere has (and always will) higher dimensionality than any model of it and so in this example we have taken that the models have less degrees of freedom than the truth. That causes the tendencies of the models and the truth to become different and possibly the largest factor that contributes to divergence of the prediction and the realization of the truth. Then a weighted combination of the tendencies of the individual models with weights learned by using the past observations can be used to construct an improved model for the short term prediction. As observations in the learning were used the tendencies, which are not available for any reality, and the atmosphere in particular. It should be estimated with appropriate techniques. To incorporate that limitation in this toy model we have added a noise. However, the noise that will inevitably emerge by using estimation of the tendency of the atmosphere can be even larger, and thus limit (or even eliminate) the improvement of short term forecast in this way.

WP2 (Learning of coefficients with ODEs)

- Supermodeling is about combining imperfect models to better approximate the truth. So-far we have considered mainly situations where the ground truth is represented by a model of the same model class as imperfect models. In reality, the atmosphere is of much higher complexity than any atmospheric model. We modelled this difference in low dimensional setting where we have modelled a driven Lorenz 63, that is, driven by another, hidden Lorenz 63 system. The latter resembles the unresolved scales. Two imperfect models, named model 1 and model 2, are assumed and both represented by a Lorenz 63 system with a constant forcing. These models have lower complexity. It is shown that supermodeling is still feasible, and that it improves weather prediction skill. However in this setting, the supermodel does not improve upon the long term model statistics, and a super model would actually be worse than a posteriori ensemble average.

- Weather prediction is the prediction of the state of a near future time, given the state at the current time and the vector field of the dynamical system. Climate prediction is the prediction of long term statistics of the system running free. Climate has to do with the attractor of the dynamical system. The supermodels so-far has been optimized for weather prediction, and the models discussed in this document clearly show that better weather prediction skill does not imply better climate prediction skill. We introduced a cost function for long term statistics based on the Wasserstein distance, and showed that a supermodel optimized for this cost function does indeed improve on the long term statistics.
WP3 (Learning coupling coefficients in PDE systems)

- The advantage of supermodeling over ex post facto averaging of outputs has been evaluated in regard to the index cycle in a simple quasigeostrophic channel model. Non-monotonic behavior as the forcing coefficient varies gives the supermodel a clear advantage if the individual models are defined with very large and very small forcings. (It appears that the weights or connections defining the supermodel could be readily learned from training data using methods previously articulated.) The advantage, however, is lost if the magnitude of the parameter differences among the individual models is arguably realistic.

- It is expected that the general conclusion will carry over to configurations of QG models created by varying other parameters, e.g. static stability, provided that the models are not close to bifurcations. Of course, the detailed attractor is reproduced better by the supermodel, and higher-order statistics, like the East-West covariances described in the first example, may be qualitatively improved. The overall conclusion is that the advantage of supermodeling is to be sought in situations where there are structural differences between the individual models, e.g. in the parametrizations of subgrid-scale processes (not realizable in the simple QG example), provided that they result in qualitative differences in large-scale quantities of interest.

WP4 (Supermodeling with intermediate complexity climate models)

- A prerequisite for the application of the connected super modeling concept is that the connected models are able to synchronize on a common solution that is closer to the truth than any of the separate imperfect model solutions. If the connections are not sufficient for synchronization, as is the case for connecting through the surface fluxes only, the supermodeling concept breaks down. We have shown that if the atmosphere models do not synchronize, the sea-surface temperature variability drops with a factor of $1/\sqrt{n}$ with $n$ the number of connected atmospheres. There is some degree of synchronization between the surface air temperatures, in the tropics and over all land masses, stronger on monthly than on daily time scales, but the synchronization does not extend into the free atmosphere in the regions outside of the tropics. The atmospheric heat-fluxes are anti-correlated over land areas leading to weakly anti-correlated precipitation fluxes over tropical land masses. We show in the context of a low-order climate model that upper level atmospheric variables need to be connected as well to enable the models to synchronize and make the connected SUMO approach feasible.

- We introduced perturbations in a number of parameters in the convection scheme of SPEEDO and found that the resulting errors in the climatological mean fields are of comparable magnitude as the errors in the current state-of-the-art models. What remains to be seen is that the range of climate sensitivities is also of similar magnitude as the range of climate sensitivities of current state-of-the-art climate models. If that is the case then we have a suitable experimental setting to investigate the ability of the super modeling approach to improve the climate sensitivity when trained only on past observations. This is planned for the third year of SUMO. To make this feasible, some additional technical work is needed to enable the exchange of upper level variables among the connected atmospheres.
WP5 (Supermodeling with large climate models)

- To test the super modeling strategy for climate prediction we coupled two atmospheric models with one ocean model. The atmospheric models differed in their convection scheme and climate-related parameters. As climate models show large sensitivity to convection schemes and parameterization, this approach may be a good basis for constructing a super model. We performed experiments with a small set of manually chosen coefficients and learning. The coupling strategy is able to synchronize atmospheric variability in the tropics, particularly over the western equatorial Pacific, and produce reasonable climate variability. Different coupling weights were shown to alter the simulated mean climate state. Some improvements were found that suggest a better strategy for choosing weighting coefficients could lead to a more improved simulation. Simulated variability was also affected by the different super modelling strategies, but little improvement was found.

WP7 (Learning complete supermodels)

- We adapt existing sampling approaches from the area of ensemble learning. The specificities of the task of sub-sampling an observed behavior of a dynamic system are taken into account. After different subsamples are generated, the base learner ProBMoT can be applied to learn different ODE models from them. The approaches adapted include sub-sampling the instance space and sub-sampling the feature space. Along the first dimension, we consider the selection of random sub-intervals of the observation period. We adapt bootstrap sampling and error-weighted sampling for the case of time-series data. Along the second dimension, we consider random sub-sampling of the variable space, as in random subspaces. We consider combining it with bootstrap sampling of the instance space. Moreover, we propose a generalized sub-sampling approach, which simultaneously subsamples both the instance and the feature space. Finally, we also suggest considering a procedure for sampling the template entities and processes from the library of background knowledge used by ProBMoT as a way to generate a set of diverse ODE models.

- We first attempt to define the notion of diversity for ODE models. While model diversity has been extensively studied in the context of ensemble models, the bulk of work has considered the task of classification. For regression, co-variance is used as a measure of similarity/diversity of constituent models of an ensemble. To the best of our knowledge, the notion of diversity has not been studied in the context of ensembles of ODE models. Our definition of diversity is based on similarity measures between dynamic system behaviors, i.e., multi-variate time series. These are based on similarity measures for single time-series. The similarities of corresponding time-series pairs in two behaviors are aggregated into an overall similarity. We consider a range of similarity measures for time-series, which we have collected and implemented. We explore their use in clustering of ODE models and observed behaviours of dynamic systems.

Expected results and potential impact

Upon completion, the project will have constructed at least a prototypical supermodel that will greatly reduce uncertainty regarding the details of expected climate change, including the magnitude of global warming and specific regional effects. The increased confidence in the projections will facilitate policy decisions at all levels and will increase public support for such
decisions, as the public becomes informed about expected changes in each locality, and not just global averages.

In the realm of computational science, there are other situations in which there are a handful of expert dynamical models of the same real-world process that could be efficaciously combined. One can envision applications to complex biological, social, economic, and environmental processes, in situations where there are a small number of competing models, e.g. created in academic institutions, or by a handful of leading business entities in a given field. The only requirement is that the constituent models be equipped with a methodology to incorporate new data from the objective process, as the model runs. In that situation, the models can also assimilate data from each other, as here, and an adaptation procedure for connection coefficients can be defined.

**Promotional activities**

A dedicated website has been set up for the main purpose of dissemination of the project results at the following web address: [http://www.sumoproject.eu/](http://www.sumoproject.eu/).

Other promotional activities have been conducted including:

- Presentation at the European Future Technologies Conference and Exhibition – FET11 held in Budapest, 4–6 May, 2011.
- A popular science article describing the objectives of the SUMO project has appeared in *research*eu focus magazine.
- Project flyer
- Broadcast of a TV documentary regarding the SUMO project on the Macedonian state TV
- Regular updates are provided on [http://www.sumoproject.eu/](http://www.sumoproject.eu/).
- The project flyer has been updated with the new partner and the new WP
- A facebook page dedicated to the SUMO project is open: [http://www.facebook.com/sumoproject](http://www.facebook.com/sumoproject)

**List of partners and contact details**

**Partner 1:** Macedonian Academy of Sciences and Arts (MASA) (Coordinator)

Country: Republic of Macedonia
Contact person: Ljupco Kocarev,
E-mail: [lkocarev@manu.edu.mk](mailto:lkocarev@manu.edu.mk),
Project entry/exit month: 1/36

**Partner 2:** Leibniz Institute of Marine Sciences (IFM-GEOMAR)

Country: Germany
Contact person: Noel Keenlyside
E-mail: [nkeenlyside@ifm-geomar.de](mailto:nkeenlyside@ifm-geomar.de)
Project entry/exit month: 1/9

**Partner 3:** Potsdam Institute for climate impact research (PIK)

Country: Germany
Contact person: Juergen Kurths
E-mail: [Juergen.Kurths@pik-potsdam.de](mailto:Juergen.Kurths@pik-potsdam.de)
Project entry/exit month: 1/36
**Partner 4:** Royal Netherlands Meteorological Institute (KNMI)
- Country: Netherlands
- Contact person: Frank M. Selten
- E-mail: selten@knmi.nl
- Project entry/exit month: 1/36

**Partner 5:** Radboud University Nijmegen (RU)
- Country: Netherlands
- Contact person: Wim Wiegerinck
- E-mail: w.wiegerinck@science.ru.nl
- Project entry/exit month: 1/36

**Partner 6:** Geophysical institute of the University of Bergen
- Country: Norway
- Contact person: Noel Keenlyside
- E-mail: nkeenlyside@ifm-geomar.de
- Project entry/exit month: 10/36

**Partner 7:** Jozef Stefan Institute (JSI)
- Country: Slovenia
- Contact person: Saso Dzeroski
- E-mail: Saso.Dzeroski@ijs.si
- Project entry/exit month: 10/36
2. Project objectives for the period

According to the Annex I – Description of work, the following describes the objectives of the project along the different work packages. Also, for each work package the tasks on which work should have started according to annex 1 are described.

WP1: General theory of supermodeling with ODEs

**Objectives** – The main objective of WP1 is to develop the general theory of a supermodel apart from the learning aspect, to specify how models with different structure should be connected and examine what are the conditions under which connecting variables among different models will lead to superior skill, and the form of those connections. Another goal of this WP is to determine limitations of the supermodeling strategy. In addition to machine learning we will develop a strategy on how to define connections based on insight and mathematical arguments that might lead to a useful supermodel. We do this because the automatic learning might be too complex or lead to suboptimal solutions and we spread the risk this way. Also, the developing of domain knowledge for machine learning of the structure of models and interconnections is considered in this WP. This material developed here will serve as input for WP 2-5, as well as WP7.

**Tasks** – The following tasks are foreseen in the WP1:

Task 1.2 Connection mechanisms: we will study how to connect models under different assumptions. This ranges from models that have the same structure and differ only in parameter values to models that have different structure and/or different spatial resolution. We will also study different formulations for the interactions in the supermodel and ways to limit the dimensionality and/or the degrees of freedom of the connection matrix. Another issue to be studied is whether and how connections and connection mechanisms should be constrained so that the supermodel obeys certain given symmetries, physical logics and balances.

Task 1.3 Manual optimization strategies: We will research and develop strategies how to define connections that lead to a useful supermodel. In this task we consider manual strategies from domain experts that are based on physical insights and mathematical arguments in relation of the imperfect models and what can be assumed to be known about the ground truth as well as considerations that make use of the prediction performances of the imperfect models in relation to the data generated by the assumed ground truth.

Task 1.6: The domain knowledge resulting from Tasks 1.1 and 1.2 will be formulated in a way suitable for use in computational scientific discovery. It will describe the basic processes typically captured in the models and typical alternative ODE templates used to model them. It will be represented in a process-based modelling formalism.

WP2: Learning of coefficients with ODEs

**Objectives** – The goal of work package two is to research and develop efficient, robust and scalable learning strategies to optimize connection coefficients for dynamical systems of low and intermediate size complexity (up to 1000 variables). The resulting learning strategies are to be used
to guide the development of methods in WP3 and WP4. A second objective is to assess performance of the obtained supermodeling learning strategies and research and develop methods to estimate model performance based on available data. The main research effort will be focused on exploring and improving existing learning strategies. Methods will be experimentally assessed by their performance on systems agreed upon in WP1 while keeping their scalability to the higher dimensional climate models of WP4 and WP5 in mind. Later in the project, feedback from WP3-5 will further guide the research directions in this WP. Issues that arise in those work packages will be referred back to WP1 and this WP for further analysis and improvement.

**Tasks** – The following task is foreseen in the WP2:

Task 2.2 Globally optimal learning In the presence of local optima, learning algorithms might lead to a solution that is suboptimal. This is addressed in the following subtasks:

- Local and global optima. Under what conditions are local optima acceptable? Can global methods help to find better optima?

- Global optimization methods. We will research the use of global optimization methods, such as simulated annealing, genetic algorithms and other meta-heuristic approaches, to escape local optima in favour of global ones.

**WP3: Learning of connection coefficients in PDE systems**

**Objectives** – This work package consists of two objectives. Firstly, to prescribe learning algorithms to determine optimal connection coefficients in a general PDE supermodel that will be applicable to large climate models and secondly to understand the importance of local vs. global optima in such coefficients, and to prescribe algorithms to avoid local optima if necessary. The goals of WP3 are to validate and refine the learning algorithms for a supermodel formed from several systems of partial differential equations that are imperfect counterparts of a single “true” system of PDE’s. General lessons from this investigation will be applied to climate models in WP4 and WP5. Issues that arise in those work packages will be referred back to WP2 for further exploration. To achieve this objectives work on the following two tasks should already have been started:

**Tasks** – The following task is foreseen in the WP3:

Task 3.3 Develop learning strategies for intermediate complexity climate supermodels: The work will be further continued on analysis of quasi-geostrophic (QS) channel model, which is a relatively simple geophysical model. MASA investigators have previously worked on this model showing that a single connection coefficient in a supermodel consisting of two QG channel models could be adapted using the incremental learning approach. It had been shown in previous work that two such models, one with a forcing jet in the Atlantic, and another with a jet in the Pacific, could be made to synchronize when connected, each model inducing the missing jet in the other. This model configuration in these studies was originally researched as to predict new types of Atlantic-Pacific teleconnections. But it is also a supermodel. It can be trained by connecting to a third “real” channel with two jets and provides an ideal test case to further develop an incremental learning approach. The QS channel investigation will form the basis for the subsequent study of the more realistic quasi-geostrophic model, the Ecbilt model, that will be studied in WP4.
WP4: Supermodelling with intermediate complexity climate models

Objectives – In this work package we develop and test the supermodelling approach using climate models of intermediate complexity. We follow the suggestions from WP1, WP2 and WP3 that developed and tested the approach in simpler systems guided by theoretical considerations and report back whether the approach needs rethinking and redesigning. The main objective is to develop a supermodelling approach that is applicable to the state-of-the-art climate models of WP5. In this work package we will create imperfect models by perturbing model parameters and formulations and regard the original model as a virtual truth. We will employ different climate model systems, starting from a relatively simple climate model and add to the complexity in small steps and address a specific issue at each step. We will assume a ground truth model at each step and create an ensemble of imperfect models by perturbing parameters and/or using different formulations for unresolved processes.

Tasks – The following task is foreseen in the WP4:

Task 4.3 Provide guidelines for a supermodel using state-of-the-art climate models
Based on the results obtained with the intermediate complexity models guidelines will be developed for the construction of a supermodel using state-of-the-art climate models.

WP5: Supermodelling with large climate models

Objectives – Work package five has 3 objectives. Firstly, to develop a super climate model by coupling three different climate models together using observations for the period 1870-1980 to train the model. Secondly to assess the benefits and drawbacks of the super climate modelling strategy against conventional approaches (i.e., multi-model mean) and the best model through simulating climate from 1980-2010 and retrospective-prediction of seasonal-to-decadal fluctuations during the same period. Finally, the third objective is to demonstrate that the super modelling strategy can be applied to make climate projections, by performing a scenario simulation for the 21st century with the super climate model and contrasting it with conventional multi-model scenario simulations. For the purpose of achieving these objectives three different climate models will be applied: ECHAM5/NEMO, ECHAM5/MPIOM, and IFS/NEMO coupled models; the first two will be provided by UiB and the last by KNMI. Two classes of simulations will be performed to assess the super climate model: externally forced (i.e., boundary value problem) and initialized (i.e., initial condition and boundary value problem).

Tasks – The following tasks are foreseen in the WP5:

Task 5.3 (month 13-20), construct a super climate model using a learning strategy: A first version of the super-climate model will be developed based on initial results of WP 1-4. The development will involve continued input from other WPs. Recommendations will be taken on the following:
• Whether to couple state variables or physical tendencies
• How to reduce of data dimensionality
• How to deal with fast atmospheric and slow ocean processes
• How to train the model on observational data

The supermodel will be trained over the period 1870-1980. [UiB, MASA, KNMI, RU, PIK]
Task 5.4 (month 19-24), test the super-climate model using independent data: Simulations will be made with the super climate model for the period 1980-2010 as well as a set of retrospective seasonal-to-decadal forecasts for the period 1980 till 2010. [UiB]

Task 5.5 (month 7-24), assess the super climate models constructed with connections chosen manually and using a learning strategy: The ability of the models to simulate the mean, variability, and global warming of climate over the independent period from 1980-2010 will be assessed. The skill of the trained super-model in predicting seasonal-to-decadal fluctuations (i.e., an initial condition and boundary value problem) will be quantified. Agreement and skill will be quantified using metrics developed in WP4 and compared to that of the individual models and their weighted average. [UiB, KNMI]

WP6: Management

Objectives – The objectives of the management work package are the following:

1. Efficiently manage the project.
2. Communication between the European Commission and SUMO, including all forms of reporting specified in the consortium contract agreement.
3. Provide the communication tools for the project: public and internal web sites.
4. Organize annual general assemblies and project meetings.
5. Organize a SUMO international dissemination Workshop.
6. Ensure promotion of clustering and cooperation with related projects (both in FP7 and other international and national projects).

Tasks – The following tasks are foreseen in the WP6:

Task 6.1 (Months 1-36): The coordinator supported by the project office and the administrative staff are in regular contact with the Management Board of SUMO and the European Commission. The project office prepares the necessary scientific and financial reports for the EC. The project office communicates all necessary information from the EC to the participants for the preparation of the due reports and for the financial aspects. The project maintains a public and an internal project website.

Task 6.2 (Months 1-36): Annual general assemblies and project meetings are being held. The project office prepares the general assemblies and project meetings. Together with the SSC, the project office produces the program of the meeting, invites the key scientists (guest speakers), and representatives from other related projects (FP7 projects and international projects).

Task 6.3 (Months 1-36): Contribution to portfolio and concentration activities at FET-Open level. The project office will actively promote dissemination activities. It will make sure that all scientific knowledge acquired in SUMO is freely available for external users. This will be done through promotion of the SUMO achievements, tools and data in meetings of national and international organizations and through a SUMO organized summer school in the 3th year for a wide scientific audience. The project office will produce a flyer and a brochure.
WP7: Learning complete supermodels

Objectives – The objective of this WP is to develop methods for computational scientific discovery that can learn complete supermodels (ensembles of ODE models) of dynamic systems. Its sub-objectives include the development of techniques for the (semi)automated generation of constituent models, for the selection of an appropriate subset of models, and for learning the form and coefficients of the interconnections among the models.

Tasks – The following tasks are foreseen in the WP7:

Task 7.1 Generate a diverse set of ODE models. To generate a diverse set of models, we will adapt existing approaches from the area of ensemble learning. These include taking different subsamples of the data, taking different projections of the data, and taking different learning algorithms (or randomized algorithms). Different subsets of domain knowledge may also be considered.

Task 7.2 Select a complementary set of ODE models. Given a set of models, we will use a measure of similarity between models to select models that are complementary. Different measures of similarity (or model performance/quality) will be considered. Besides the sum of squared errors and correlation, other measures might be considered such as weighted sum of squared errors or robust statistical estimators.
3. Work progress and achievements during the period

Progress and achievements: WP1 (General Theory of supermodelling with ODEs)

In WP1 we studied the networks of linearly coupled nonlinear Lorenz 63 oscillators in the limit of large connections. The motivation for this study was findings in the recently proposed supermodels. Supermodels are dynamically coupled ensembles of models. The connections are optimized, so that the supermodel fits to a data set of observations. Earlier work demonstrated the viability of this approach on low dimensional systems. The connections that were found with this procedure were typically quite large. This was the motivation to analyze its behaviour theoretically in the large connection limit. Similar to earlier results in coupled systems, it was theoretically argued that the models in a supermodel synchronize and that the dynamics of the synchronized state is a weighted average of the imperfect model dynamics. We verified numerically that the supermodel solutions are indeed well approximated by the weighted average approximation. With this analysis, the multiple local optima in connection space that has been found earlier can be better understood. Also the fact that the Lorenz 63 supermodel previously reported was able to correctly simulate the response to parameter change without the need of retraining of the connection coefficients has now a straightforward explanation.

One could consider doing weighted averages of model components from the start. This leads to the weighted supermodel. In practice, weighted supermodels seem to have several advantages. The most important one is the availability of scalable learning schemes. Other advantages are interpretability and transparency, the elimination of equivalent solutions, and possibly performance guarantees.

Inside our SUMO project, we assumed that all models have the same dimension and that each variable in each model is coupled to similar variables in other models. In reality, this may not hold. Partial coupling could be an option if models are too complex for a full coupling. For instance if real-world climate models are to be coupled, the additional overhead to have all variables exchange information will probably be infeasible. A second reason for partial coupling is that different models may have variables that have different interpretations. In this case, one may only want to couple variables with the same interpretation. In this work we argued that also in partially coupled models, large connections leads to averaging of the coupled variables. We verified with simulations in a network of ten partially coupled Lorenz 63 oscillators.

We also simulated supermodels composed of incomplete models. In these simulations, two 2-D models were constructed to model different aspects of the assumed 3-D Lorenz 63 ground truth. By coupling, either through connecting or weighting, the incomplete models were able to complement each other. Both supermodels provided a much better description of the assumed reality than any a posteriori average of the individual models could do. Both supermodels showed a rather complex chaotic butterfly shaped attractor, while the 2-D models only showed simple periodic orbits and point attractors.

In the case where models and ground truth had all the same dimension, there seemed hardly any difference in the performance of connected and weighted supermodels. However, in the incomplete model case, the connected supermodel seemed to be able to better reproduce the butterfly shaped attractor of the assumed Lorenz 63 ground truth than the weighted supermodel. In particular, the dynamics of the weighted supermodel seemed to be a bit less chaotic than the connected
supermodel and the ground truth. A possible explanation could be that a weighted supermodel could be understood as a connected supermodel with infinite connections. This gives the weighted supermodel less flexibility because the models are in a way instantaneously synchronized and remain so over time. This may hinder transitions between different regimes in the attractor. In connected supermodels, where the connections have finite values, synchronization is not immediate, and models can deviate from synchronization. In other words, models are allowed to deviate from the consensus state and follow more their own dynamics for a while. By doing so, the model could make a transition to different other regimes, and by the couplings, other models may follow, which then results in a regime transition of the consensus state.

In WP1 we showed a proof-of-concept that a combination of different models of one dimensional scalar atmospheric quantity can be a better short-term predictor than any of them. The idea was tested on the Lorenz 96 toy model because it is simple enough, but also nontrivial and shares some basic properties with the real atmosphere. The atmosphere has (and always will) higher dimensionality than any model of it and so in this example we have taken that the models have less degrees of freedom than the truth. That causes the tendencies of the models and the truth to become different and possibly the largest factor that contributes to divergence of the prediction and the realization of the truth. Then a weighted combination of the tendencies of the individual models with weights learned by using the past observations can be used to construct an improved model for the short term prediction. As observations in the learning were used the tendencies, which are not available for any reality, and the atmosphere in particular. It should be estimated with appropriate techniques. To incorporate that limitation in this toy model we have added a noise. However, the noise that will inevitably emerge by using estimation of the tendency of the atmosphere can be even larger, and thus limit (or even eliminate) the improvement of short term forecast in this way.

To our opinion there are two main lines of future research related to chapter~\ref{lorenz96}. The first one is towards searching of different techniques for combination of the individual models. One possible option is the coupling of the variables of state, or subset of them. For more complex atmospheric models exchange of fluxes is already in use - coupling of atmospheric and ocean models. However, coupling of different atmospheric models, to our knowledge is not applied yet. The interaction structure between the models will influence the strategies of searching of the best coupling parameters. Besides different techniques from machine learning, expert knowledge is welcomed also. The weights should not be constant in time, but time (e.g. seasonally) dependent instead. Or they can be adjusted and improved all the time because the measurement data is accumulating.

The second direction for further research is attempt to apply these results in more real atmospheric models, or even for those that are used for numerical weather prediction. The main obstacle can be the estimation of the tendency of the atmosphere. We think this kind of combination of state-of-the-art models is worth testing because it is of crucial importance for the weather prediction. In the worst case the weights can have unit values for the best member of the ensemble and thus there is at least one combination of weights that is as good as the best individual model. We expect that mixing the tendencies can lead to improvement of the numerical weather prediction. Another issue is improvement of the projections of the future climate. However, as our results have shown, maybe other techniques for optimization of the connection parameters should be applied to construct an interactive ensemble that will outperform the individual members.

Additionally, with regard to the question of how to connect models with different numerical grids, a promising approach is to do the connections on a grid at a resolution that can be represented by all considered models. This then involves projecting all model states onto this grid, calculate the
nudging terms (or average the tendencies for weighted SUMO) and project the results back onto the model grids.

Details on the results obtained have been thoroughly described in Deliverable D1.2.

**Highlight of clearly significant results:**

- Supermodels (both connected and weighted) composed of imperfect models (the reality is a 3 dimensional Lorenz 63, models are 2 dimensional dynamical systems) provide a much better description of the assumed reality than any a posteriori average of the individual models could do.
- A combination of different imperfect models of one dimensional scalar atmospheric quantity can be a better short-term predictor than any of them.

**There are no critical objectives missed. There is no significant deviation of the schedule.**

**Resources**

Resources for this work package have been used as was planned in Annex 1.

**Progress and achievements: WP2 (Learning coupling coefficients in ODEs)**

The issues addressed in WP2 are three-fold. The first issue is that sometimes, when learning algorithms have difficulty for the connections to converge to saturation, the resulting supermodels were found to behave suboptimal. In the first section, we studied the behaviour of connected systems as function of the connection strength. We found that for intermediate size connection strength, the behaviour of the system can be completely different due to a spurious damping effect. This could be an explanation of the sometimes suboptimal behaviour of the learned supermodels when the connections did not saturate. The findings of this section indicate that synchronization may be a crucial criterion for converge. This could be used to provide guidelines for learning algorithms.

The second issue is model complexity. Supermodeling is about combining imperfect models to better approximate the truth. So-far we have considered mainly situations where the ground truth is represented by a model of the same model class as imperfect models. In reality, the atmosphere is of much higher complexity than any atmospheric model. We modelled this difference in low dimensional setting where we have modelled a driven Lorenz 63, that is, driven by another, hidden Lorenz 63 system. The latter resembles the unresolved scales. Two imperfect models, named model 1 and model 2, are assumed and both represented by a Lorenz 63 system with a constant forcing. These models have lower complexity. It is shown that supermodeling is still feasible, and that it improves weather prediction skill. However in this setting, the supermodel does not improve upon the long term model statistics, and a super model would actually be worse than a posteriori ensemble average.

The third issue is about the difference between weather prediction skill and climate prediction skill. Weather prediction is the prediction of the state of a near future time, given the state at the current time and the vector field of the dynamical system. Climate prediction is the prediction of long term statistics of the system running free. Climate has to do with the attractor of the dynamical system.
The supermodels so-far has been optimized for weather prediction, and the models discussed in this document clearly show that better weather prediction skill does not imply better climate prediction skill. We introduced a cost function for long term statistics based on the Wasserstein distance, and showed that a supermodel optimized for this cost function does indeed improve on the long term statistics. We further demonstrated that the supermodeling concept incorporates a natural regularization so that over fitting on long term statistics is avoided and still reasonably good vector fields are retained.

There are still a number of important issues. One is that long term statistics learning is expensive. Further investigation to find more efficient ways to optimize the supermodel is needed. Another, related issue is the question how relevant the issue of weather prediction versus climate prediction is. In many earlier toy examples improved weather prediction indeed leads to improved climate prediction. If this is also the case in real climate models, the optimization of supermodels can be done using the much cheaper vector-field optimization algorithms. The example in this document showed however that one has to be careful with this assumption. It would therefore be interesting to investigate if criteria for the validity of this assumption can be formulated.

Details on the results obtained have been thoroughly described in Deliverable D2.2.

Highlight of clearly significant results:

- Assuming that the reality is a driven Lorenz 63 and two imperfect models are Lorenz 63 system with a constant forcing, it is shown that super-modelling is still feasible and improves short term (weather) prediction.
- A cost function for long term statistics based on the Wasserstein distance is introduced and it is shown that a supermodel optimized for this cost function improves the long term statistics.

There are no critical objectives missed. There is no significant deviation of the schedule.

Resources

Resources for this work package have been used as was planned in Annex 1.

Progress and achievements: WP3 (Learning coupling coefficients in PDE systems)

In WP3 we studied in a simple quasigeostrophic channel model. The achievements in the work package can be summarized as follows. The advantage of supermodeling over ex post facto averaging of outputs has been evaluated in regard to the index cycle in a simple quasigeostrophic channel model. Non-monotonic behaviour as the forcing coefficient varies gives the supermodel a clear advantage if the individual models are defined with very large and very small forcing. (It appears that the weights or connections defining the supermodel could be readily learned from training data using methods previously articulated.) The advantage, however, is lost if the magnitude of the parameter differences among the individual models is arguably realistic.
It is expected that the general conclusion will carry over to configurations of QG models created by varying other parameters, e.g. static stability, provided that the models are not close to bifurcations. Of course, the detailed attractor is reproduced better by the supermodel, and higher-order statistics, like the East-West covariances described in the first example, may be qualitatively improved. The overall conclusion is that the advantage of supermodeling is to be sought in situations where there are structural differences between the individual models, e.g. in the parametrizations of subgrid-scale processes (not realizable in the simple QG example), provided that they result in qualitative differences in large-scale quantities of interest.

Details on the results obtained have been thoroughly described in Deliverable D3.2.

**Highlights of significant results**

- It is shown that the super-modelling is feasible in quasigeostrophic channel models when the individual models are defined with very large and very small forcing.
- Possible advantage of supermodeling is to be sought in situations where there are structural differences between the individual models, e.g. in the parametrizations of sub-grid scale processes, provided that they result in qualitative differences in large-scale quantities of interest.

There are no critical objectives missed. There is no significant deviation of the schedule.

**Resources**

Resources for this work package have been used as was planned in Annex 1.

**Progress and achievements: WP4 (Supermodeling with intermediate complexity climate models)**

Two aspects of super-modelling with intermediate complexity climate models are investigated in WP4: synchronisation of two identical atmospheres and sensitivity of SPEEDO to convection parameters. The results are summarized below.

A prerequisite for the application of the connected super modeling concept is that the connected models are able to synchronize on a common solution that is closer to the truth than any of the separate imperfect model solutions. If the connections are not sufficient for synchronization, as is the case for connecting through the surface fluxes only, than the super modeling concept breaks down. We have shown that if the atmosphere models do not synchronize, the sea-surface temperature variability drops with a factor of \(1/\sqrt{n}\) with \(n\) the number of connected atmospheres. There is some degree of synchronization between the surface air temperatures, in the tropics and over all land masses, stronger on monthly than on daily time scales, but the synchronization does not extend into the free atmosphere in the regions outside of the tropics. The atmospheric heat-fluxes are anti-correlated over land areas leading to weakly anti-correlated precipitation fluxes over tropical land masses. We show in the context of a low-order climate model that upper level atmospheric variables need to be connected as well to enable the models to synchronize and make the connected SUMO approach feasible.

We introduced perturbations in a number of parameters in the convection scheme of SPEEDO and found that the resulting errors in the climatological mean fields are of comparable magnitude as the
errors in the current state-of-the-art models. What remains to be seen is that the range of climate sensitivities is also of similar magnitude as the range of climate sensitivities of current state-of-the-art climate models. If that is the case then we have a suitable experimental setting to investigate the ability of the super modelling approach to improve the climate sensitivity when trained only on past observations. This is planned for the third year of SUMO. To make this feasible, some additional technical work is needed to enable the exchange of upper level variables among the connected atmospheres.

Details on the results obtained have been thoroughly described in Deliverable D4.2.

**Highlights of significant results**

- In the context of a low-order climate model it is shown that upper level atmospheric variables need to be connected as well to enable the models to synchronize and make the connected SUMO approach feasible.
- Perturbations in a number of parameters in the convection scheme of SPEEDO are introduced and it is found that the resulting errors in the climatological mean fields are of comparable magnitude as the errors in the current state-of-the-art models.

There are no critical objectives missed. There is no significant deviation of the schedule.

**Resources**

Resources for this work package have been used as was planned in Annex 1.

**Progress and achievements: WP5 (Supermodeling with large climate models)**

In WP5 to test the super modeling strategy for climate prediction we coupled two atmospheric models with one ocean model. The atmospheric models differed in their convection scheme and climate-related parameters. As climate models show large sensitivity to convection schemes and parameterization, this approach may be a good basis for constructing a super model. We performed experiments with a small set of manually chosen coefficients and learning. The coupling strategy is able to synchronize atmospheric variability in the tropics, particularly over the western equatorial Pacific, and produce reasonable climate variability. Different coupling weights were shown to alter the simulated mean climate state. Some improvements were found that suggest a better strategy for choosing weighting coefficients could lead to a more improved simulation. Simulated variability was also affected by the different super modelling strategies, but little improvement was found.

In order to summarise the results of all the simulations, we compute a performance index that quantifies the model error considering a number of observed quantities together. The performance index is formed by taking mean over the normalized error variances of all observables. The seven observables related to ocean-atmosphere coupling were considered here. In general, when considering latent and sensible heat flux and 2m and surface temperature, and 10m zonal and meridional wind the best model is the well tuned COSMOS(N). It has good performance in heat flux, temperature and surface wind velocities. It is also the best model when considering all these quantities together.
The performance metric is very sensitive to the inclusion of convective precipitation, which is heavily influenced by the convection scheme and cloud parameters. COSMOS(N) prefers precipitating over the ocean in the tropical region, whereas in the NCEP/NCAR reanalysis there is preference for precipitating over land. The large sensitivity to precipitation means that the performance index determined by the seven observables is dominated by the convective precipitation, because it contributes most of the uncertainty. It should be noted that the convective precipitation in the NCEP/NCAR reanalysis is essentially a product of the model.

Details on the results obtained have been thoroughly described in Deliverable D5.2.

**Highlights of significant results:**

- Two atmospheric models are coupled with one ocean model. The atmospheric models differed in their convection scheme and climate-related parameters. The coupling strategy is able to synchronize atmospheric variability in the tropics, particularly over the western equatorial Pacific, and produce reasonable climate variability.
- Different coupling weights were shown to alter the simulated mean climate state. Some improvements were shown that suggest a better strategy for choosing weighting coefficients could lead to a more improved simulation.

**There are no critical objectives missed. There is no significant deviation of the schedule.**

**Resources**

Resources for this work package have been used as was planned in Annex 1.

**Progress and achievements: WP7 (Learning complete supermodels)**

The objective of WP7 is to develop methods for computational scientific discovery that can learn complete supermodels (ensembles of ODE models) of dynamical systems. The supermodels are expected to be built in three phases: generate diverse models, select a set of complementary models, and learn the interconnections between the constituent models of an ensemble. While this decomposition allows for independent development of the different components of the approaches to learning ensembles of ODE models, we can evaluate their performance only when we integrate them into complete approaches to learning ensembles. Thus, the issues related to finding working combinations of the methods developed and proposed within D7.1 and D7.2 are still open and are to be resolved within the task T7.3.

Task 7.1 is concerned with generating a diverse set of ODE models. To generate a diverse set of models, we adapt existing sampling approaches from the area of ensemble learning. The specificities of the task of subsampling an observed behavior of a dynamic system are taken into account. After different subsamples are generated, the base learner ProBMoT can be applied to learn different ODE models from them. The approaches adapted include subsampling the instance space and subsampling the feature space. Along the first dimension, we consider the selection of random sub-intervals of the observation period. We adapt bootstrap sampling and error-weighted sampling for the case of time-series data. Preliminary experiments with learning ODE models (same structure, different parameters) have been conducted with some of these adaptations within Task 7.3.
Along the second dimension, we consider random sub-sampling of the variable space, as in random subspaces. We consider combining it with bootstrap sampling of the instance space. Moreover, we propose a generalized sub-sampling approach, which simultaneously subsamples both the instance and the feature space. Finally, we also suggest considering a procedure for sampling the template entities and processes from the library of background knowledge used by ProBMoT as a way to generate a set of diverse ODE models. Further experiments within Task 7.3 are needed to evaluate the performance of these methods in the context of learning supermodels.

Task 7.2 is concerned with selecting a set of complementary ODE models. To address this task, we first attempt to define the notion of diversity for ODE models. While model diversity has been extensively studied in the context of ensemble models, the bulk of work has considered the task of classification. For regression, co-variance is used as a measure of similarity/diversity of constituent models of an ensemble. To the best of our knowledge, the notion of diversity has not been studied in the context of ensembles of ODE models.

Our definition of diversity is based on similarity measures between dynamic system behaviors, i.e., multi-variate time series. These are based on similarity measures for single time-series. The similarities of corresponding time-series pairs in two behaviors are aggregated into an overall similarity. We consider a range of similarity measures for time-series, which we have collected and implemented. We explore their use in clustering of ODE models and observed behaviours of dynamic systems. These clustering experiments are important in the context of further work within Task 7.3, where a set of appropriate models has to be chosen for inclusion in the ensemble. After clustering a larger set of models, representative models from each cluster could be chosen for combination, for example.

Details on the results obtained have been thoroughly described in Deliverable D7.2.

**Highlights of significant results:**

- The selection of random sub-intervals of the observation period and bootstrap sampling and error-weighted sampling for the case of time-series data are adopted. We consider combining it with bootstrap sampling of the instance space. A generalized sub-sampling approach, which simultaneously subsamples both the instance and the feature space, is proposed.
- Since the notion of diversity has not been studied in the context of ensembles of ODE models, it was suggested that diversity is based on similarity measures between dynamic system behaviors, i.e., multi-variate time series.

**There are no critical objectives missed. There is no significant deviation of the schedule.**

**Resources**

Resources for this work package have been used as was planned in Annex 1.
Published work

Journal papers (including submitted)

2011


G. S. Duane, Synchronicity from synchronized chaos\textsuperscript{4}, submitted, 2011.


2012


\textsuperscript{4} arxiv.org/abs/1101.2213
P. Hiemstra, N. Fujiwara, F.M. Selten, J. Kurths, “Complete synchronization of chaotic atmospheric models by connecting only a subset of state space”, Nonlin. Proc. in Geosciences (2012) (accepted for publication)


Book chapters

2012


Conference proceedings

2011


W. Wiegerinck, F.M. Selten, Supermodeling: Combining Imperfect Models through Learning
In: Machine Learning for Sustainability at NIPS 2011, On-line:

2012

In: The Second International Workshop on Climate Informatics, On-line:


4. Project management during the period

Progress and achievements: WP6 (Management)

- Task 6.1: The coordinator supported by the project office and the administrative staff are in regular contact with the Management Board of SUMO and the European Commission. The project office prepares the necessary scientific and financial reports for the EC. The project office communicates all necessary information from the EC to the participants for the preparation of the due reports and for the financial aspects. The project maintains a public and an internal project website.
- Task 6.2: Annual general assemblies and project meetings are being held (see list below)
- Task 6.3: The project office produced a flyer for the project and promotes the project in national and international environment.

Meetings:
According to the Consortium Agreement for SUMO, the General Assembly should meet at least once a year, whereas the Management Board should meet at least semi-annually.

2011

- The General Assembly met for the first time on the third of November 2010 in Skopje, Republic of Macedonia. This was considered as the SUMO’s kick off meeting. It was chaired by Ljupco Kocarev from Macedonian Academy of Sciences and Arts (MASA), presentations were made by Frank Selten from Royal Netherlands Meteorology Institute (KNMI), Jurgen Kurths from Potsdam Institute (PIK), Noel Keenlyside from Leibniz Institute, University of Kiel (IFM –GEOMAR), Ralf Hand from Leibniz Institute, University of Kiel (FM –GEOMAR), Wim Wiegerinck from Radboud University (RU), Willem Burgers from Radboud University, Greg Duane from Macedonian Academy of Sciences and Arts (MASA), Naoya Fujiwara from Potsdam Institute (PIK), Saso Dzeroski from Josef Stefan Institute (JSI), and was attended by Igor Tomovski, Anastasios Tsonis, Daniel Trpevski, Igor Trpevski, Daniel Smilkov, Angel Stanoev, Miroslav Mirchev, Lasko Basnarkov, Igor Mishkovski, Dimitar Solev and Vanja Askapova.

- The Management Board met on the 03.11.2010 in Skopje Macedonia, and it was attended by Ljupco Kocarev from Macedonian Academy of Sciences and Arts (MASA), Frank Selten from Royal Netherlands Meteorology Institute (KNMI), Jurgen Kurths from Potsdam Institute (PIK), Noel Keenlyside from Leibniz Institute, University of Kiel (IFM – GEOMAR), Ralf Hand from Leibniz Institute, University of Kiel (FM –GEOMAR), Wim Wiegerinck from Radboud University (RU), Willem Burgers from Radboud University and Naoya Fujiwara from Potsdam Institute (PIK).

- The second Management Board was held on fourth of May 2011 in Budapest, Hungary. This meeting was also attended by Ljupco Kocarev from Macedonian Academy of Sciences and Arts (MASA), Frank Selten from Royal Netherlands Meteorology Institute (KNMI), Jurgen Kurths from Potsdam Institute (PIK) and Wim Wiegerinck from Radboud University (RU).
The General Assembly met for the second time on the twenty-third of November 2011 in Skopje, Republic of Macedonia. The assembly was chaired by Ljupco Kocarev from the Macedonian Academy of Sciences and Arts (MASA), presentations were made by Ljupco Kocarev and Gregory Duane from Macedonian Academy of Sciences and Arts (MASA), Jurgen Kurths and Naoya Fujiwara from Potsdam Institute (PIK), Wim Wiegerinck from Radboud University (RU), Frank Selten and Paul Hiemstra from Royal Netherlands Meteorology Institute (KNMI), Noel Keenlyside from University of Bergen (UiB) and Saso Dzeroski from Jozef Stefan Institute (JSI). The meeting was also attended by Igor Tomovski, Daniel Trpevski, Igor Trpevski, Daniel Smilkov, Angel Stanoev, Miroslav Mirchev, Lasko Basnarkov and Vanja Askapova.

The third Management Board was held on the twenty-third of November 2011 in Skopje, Macedonia. This meeting was attended by Ljupco Kocarev from Macedonian Academy of Sciences and Arts (MASA), Frank Selten from Royal Netherlands Meteorology Institute (KNMI), Jurgen Kurths from Potsdam Institute (PIK) and Wim Wiegerinck from Radboud University (RU), Noel Keenlyside from the University of Bergen (UiB) and Saso Dzeroski from Jozef Stefan Institute (JSI).

The first review meeting was held on the twenty-fourth of November 2011 in Skopje, Republic of Macedonia. The review board consisted of prof. dr. Klaus Hasselmann, prof. dr. Michael Ghil and prof .dr. Witold Dzwinsel. The meeting was attended by Aymard.De-Touzalin, project officer. On the meeting presentations were made by Ljupco Kocarev and Gregory Duane from Macedonian Academy of Sciences and Arts (MASA), Jurgen Kurths and Naoya Fujiwara from Potsdam Institute (PIK), Wim Wiegerinck from Radboud University (RU), Frank Selten and Paul Hiemstra from Royal Netherlands Meteorology Institute (KNMI), Noel Keenlyside from University of Bergen (UiB) and Saso Dzeroski from Jozef Stefan Institute (JSI). The meeting was also attended by Mao-Lin Shen, Darko Cerepnalkovski, Nikola Simidjievski, Jovan Tanevski, Igor Tomovski, Daniel Trpevski, Igor Trpevski, Daniel Smilkov, Angel Stanoev, Miroslav Mirchev, Lasko Basnarkov, and Vanja Askapova.

2012

The General Assembly met for the third time on 22-24 May 2012 in Bergen, Norway. It was chaired by Ljupco Kocarev from Macedonian Academy of Sciences and Arts (MASA), presentations were made by Ljupco Kocarev from Macedonian Academy of Sciences and Arts (MASA), Wim Wiegerinck from Radboud University (RU), Paul Hiemstra from Royal Netherlands Meteorology Institute (KNMI), Noel Keenlyside from University of Bergen (UiB), Greg Duane from Macedonian Academy of Sciences and Arts (MASA), Saso Dzeroski from Josef Stefan Institute (JSI), and was attended by Mao-Lin Shen, Carsten Grabow, Nikola Simidjievski, and Lasko Basnarkov.

The fourth Management Board was held on the twenty-third of May 2012 in Bergen, Norway. This meeting was attended by Ljupco Kocarev from Macedonian Academy of Sciences and Arts (MASA), Wim Wiegerinck from Radboud University (RU), Paul Hiemstra from Royal Netherlands Meteorology Institute (KNMI), Noel Keenlyside from University of Bergen (UiB) and Saso Dzeroski from Josef Stefan Institute (JSI),
Conferences:

2011

- From the fourth to the sixth of May 2011 the European Research Consortium for Informatics and Mathematics held the FET11 Conference. This conference was attended by Ljupco Kocarev (MASA), Gregory Duane (MASA) Frank Selten from Royal Netherlands Meteorology Institute (KNMI), Jurgen Kurths from Potsdam Institute (PIK) and Wim Wiegerinck from Radboud University (RU).

- From the second to the seventh of October 2010 the European Science Foundation held ESF Reserach Conference on Future Internet and Society. This conference was attended by Naoya Fujiwara (PIK).

- From the third to the eighths of April 2011 the European Geosciences Union held the General Assembly. This conference was attended by Jurgen Kurths (PIK) and Naoya Fujiwara (PIK).

- From the fourth to the eighths of July 2011 the conference Engineering of Chemical Complexity was held. This conference was attended by Naoya Fujiwara (PIK).

- From the twelfth to the sixteenth of September 2011 the conference Dynamics Days Europe 2011 was held. This conference was attended by Naoya Fujiwara (PIK).

- From the nineteeth to the twenty fifth of September 2011 the 9th International Conference on Numerical Analysis and Applied Mathematics was held. This conference was attended by Naoya Fujiwara (PIK).

- From 3-4 November 2011 at the BNAIC 2011, The 23rd Benelux Conference on Artificial Intelligence, in Ghent, Belgium, W. Wiegerinck presented a poster.

- At the American Geophysical Society Fall Meeting, 5-9 December, 2011, San Francisco, CA, USA, Greg Duane organized a session on super-modeling, oral presentation and 2 poster presentations (together with Frank Selten).

2012


- Mao-Lin Shen delivered an oral presentation on 2-3 April 2012 at Origins of the Kuroshio and Mindanao Currents OKMC workshop, Kaohsiung, Taiwan.

- Wim Wiegerinck attended a seminar on Uncertainty Quantification for Climate and Environmental Models, 29 June 2012, UCL, London, UK.


- Mao-Lin Shen presented a poster at Bjerknes Centre 10-Year Anniversary Conference: Climate Change in High Latitudes in Bergen, Norway, 3-6 September 2012.

- Wim Wiegerinck and Frank Selten presented a poster at the Climate, Informatics Workshop, 18-19 September 2012, NCAR, Boulder, Colorado, US.

- Carsten Grabow presented a poster at the DAMES conference - Data analysis and modelling in Earth sciences, 8-10 October 2012, Potsdam, Germany.

Consultative meetings:

2011

- From the sixteenth to the twentieth of November 2010, Gregory Duane from MASA was in Potsdam, Germany to work on SUMO with PIFK.
- From the nineteenth to the twenty-first of January 2011, Gregory Duane from MASA was in Potsdam, Germany to work on SUMO with PIFK.
- From the sixth to twelfth of February 2011, Naoya Fujiwara from PIK was in Barcelona, Spain, at University of Barcelona for a consultation about SUMO.
- On the fourteenth of March 2011, Gregory Duane from MASA was in Potsdam, to discuss about SUMO with PIFK.
- In March 2011, Gregory Duane from MASA was in Kiel, Germany, for discussions about SUMO with IFM-GEOMAR.
At 24 March 2011, Gregory Duane from MASA was in Utrecht and Nijmegen, Netherlands, to work on SUMO with KNMI and RU.

On the twenty-eighth of March 2011 Greg Duane from MASA, Paul Hiemstra, and Frank Selten from KNMI were in Nijmegen, Netherlands, at Radboud University (RU) for a consultation about SUMO.

On sixteenth and seventeenth of June and from twenty seventh of June to the first of July 2011, Naoya Fujiwara from PIK was in DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

From the nineteenth to twenty fifth of June 2011, Naoya Fujiwara from PIK was in Nijmegen, Netherlands, at Radboud University (RU) for a consultation about SUMO.

From the sixteenth and seventeenth of June and from twenty seventh of June to the first of July 2011, Naoya Fujiwara from PIK was in DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

From the twenty-sixth of June to the first of July 2011, Lasko Basnarkov from MASA was in DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

On the twenty-first of June 2011 Frank Selten from KNMI was in Nijmegen, Netherlands, at Radboud University (RU) for a consultation about SUMO.

From the twenty-sixth of June to the first of July 2011, Lasko Basnarkov, as a representative from MASA was in Nijmegen, Netherlands, at Radboud University (RU) for a consultation about SUMO.

On the thirtieth of June 2011 Wim Wiegerinck and Willem Burgersen from RU were in DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

On the twenty-eighth of August 2011 Paul Hiemstra from KNMI visited NCAR (Boulder, Colorado) for the purpose of consultation about SUMO.

In August 2011, Frank Selten from KNMI visited NCAR (Boulder, Colorado) for the purpose of consultation about SUMO.

From the twenty-fifth to the twenty-ninth of October 2011, Gregory Duane as a representative of MASA was in Ljubljana, Slovenia at the Josef Stefan Institute (JSI) for the purpose of consultation about SUMO.

From the twenty-fourth to the twenty-ninth of October 2011, Ljupco Kocarev as a representative of MASA was in Ljubljana, Slovenia at the Josef Stefan Institute (JSI) for the purpose of consultation about SUMO.

On the twenty-fourth of November 2011, the first annual review meeting was held in Skopje, Macedonia. The review board consisted of prof. dr. Klaus Hasselmann, prof. dr. Michael Ghil and prof .dr. Witold Dzwinel, The meeting was attended by Aymard.De-Touzalin, project officer.

From 20-23th December, 2011 Gregory Duane as a representative of MASA was in Miami, Florida, USA at the University of Miami for the purpose of consultation about SUMO.

2012

On the 3th of February 2012, Wim Wiegerinck, as a representative from RU was in DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

From the 13-17th of February 2012, Mao-Lin Shen, as a representative from UiB was in DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

From the 11-16th of March 2012, Ljupco Kocarev, as a representative from MASA was in Ljubljana, Slovenia at the Josef Stefan Institute (JSI) for the purpose of consultation about SUMO.
• From the 2-6th of April 2012, Saso Dzerovski and Nikola Simidjievski, as a representatives from JSI were in DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

• From the 13-18th of May 2012, Miroslav Mirchev, as a representative from MASA was in Gottingen, Germany at the Max Plank Institute for the purpose of consultation about SUMO.


• From the 2-6th of July 2012, Carsten Grabow, as a representative from PIK was in DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

• On the 4th July 2012, Wiegerinck, Burgers, Duane, Grabow were in DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

• From the 5-7th of September 2012, Gregory Duane as a representative of MASA was in Potsdam Germany at Potsdam Institute for climate impact research (PIK) for the purpose of consultation about SUMO.

• From 10-14 September, 2012, Gregory Duane as a representative of MASA was DeBilt, Netherlands at the Royal Netherlands Meteorology Institute (KNMI) for the purpose of consultation about SUMO.

Web-meetings are held on a regular basis (total of 5 in period October 2011 – October 2012), where different aspects and issues about the project are discussed.
Deliverables and milestones tables

Deliverables

The deliverables due in this reporting period, as indicated in Annex I to the Grant Agreement have to be uploaded by the responsible participants (as indicated in Annex I), and then approved and submitted by the Coordinator. Deliverables are of a nature other than periodic or final reports (ex: "prototypes", "demonstrators" or "others"). If the deliverables are not well explained in the periodic and/or final reports, then, a short descriptive report should be submitted, so that the Commission has a record of their existence.

If a deliverable has been cancelled or regrouped with another one, please indicate this in the column "Comments". If a new deliverable is proposed, please indicate this in the column "Comments".

This table is cumulative, that is, it should always show all deliverables from the beginning of the project.
<table>
<thead>
<tr>
<th>Del. no.</th>
<th>Deliverable name</th>
<th>Versi on</th>
<th>WP no.</th>
<th>Lead beneficiary</th>
<th>Nature</th>
<th>Dissemination level⁵</th>
<th>Delivery date from Annex I (proj month)</th>
<th>Actual / Forecast delivery date Dd/mm/yyyy</th>
<th>Status</th>
<th>Contractual</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>D 5.1</td>
<td>Report on super climate model with manually chosen connections</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>R</td>
<td>PU</td>
<td>12</td>
<td>02/05/2012</td>
<td>Submitted</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>D7.1</td>
<td>Report on generation of a diverse set of ODE models</td>
<td>7</td>
<td>6</td>
<td>R</td>
<td>PU</td>
<td>18</td>
<td>01/08/2012</td>
<td>Submitted</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1.2</td>
<td>Report on connectivity and optimization</td>
<td>1</td>
<td>4</td>
<td>R</td>
<td>PU</td>
<td>24</td>
<td>24/10/2012</td>
<td>Submitted</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1.4</td>
<td>Report on domain knowledge for the automated construction/ revision of climate models</td>
<td>1</td>
<td>6</td>
<td>R</td>
<td>PU</td>
<td>24</td>
<td>24/10/2012</td>
<td>Submitted</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2.2</td>
<td>Report on quality of local optima and global optimization methods</td>
<td>2</td>
<td>5</td>
<td>R</td>
<td>PU</td>
<td>24</td>
<td>24/10/2012</td>
<td>Submitted</td>
<td>No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

⁵ PU = Public  
PP = Restricted to other programme participants (including the Commission Services).  
RE = Restricted to a group specified by the consortium (including the Commission Services).  
CO = Confidential, only for members of the consortium (including the Commission Services).  
Make sure that you are using the correct following label when your project has classified deliverables.  
EU restricted = Classified with the mention of the classification level restricted "EU Restricted"  
EU confidential = Classified with the mention of the classification level confidential " EU Confidential "  
EU secret = Classified with the mention of the classification level secret "EU Secret "
<table>
<thead>
<tr>
<th>D3.2</th>
<th>Report on different learning approaches for QG channel models</th>
<th>3</th>
<th>1</th>
<th>R</th>
<th>PU</th>
<th>24</th>
<th>24/10/2012</th>
<th>Submitted</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>D4.2</td>
<td>Report with guidelines for a climate super model</td>
<td>4</td>
<td>3</td>
<td>R</td>
<td>PU</td>
<td>24</td>
<td>24/10/2012</td>
<td>Submitted</td>
<td>No</td>
</tr>
<tr>
<td>D5.2</td>
<td>Report on super climate model behaviour after learning</td>
<td>5</td>
<td>7</td>
<td>R</td>
<td>PU</td>
<td>24</td>
<td>24/10/2012</td>
<td>Submitted</td>
<td>No</td>
</tr>
<tr>
<td>D6.4</td>
<td>Project periodic report 2</td>
<td>6</td>
<td>1</td>
<td>R</td>
<td>PU</td>
<td>24</td>
<td>24/10/2012</td>
<td>Submitted</td>
<td>No</td>
</tr>
</tbody>
</table>
Milestones

Please complete this table if milestones are specified in Annex I to the Grant Agreement. Milestones will be assessed against the specific criteria and performance indicators as defined in Annex I.

This table is cumulative, which means that it should always show all milestones from the beginning of the project.

<table>
<thead>
<tr>
<th>Milestone no.</th>
<th>Milestone name</th>
<th>Work package no</th>
<th>Lead beneficiary</th>
<th>Delivery date from Annex I dd/mm/yyyy</th>
<th>Achieved Yes/No</th>
<th>Actual / Forecast achievement date dd/mm/yyyy</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS1</td>
<td>Decision on model classes</td>
<td>WP1, WP2, WP3, WP4, WP5</td>
<td>4</td>
<td>12</td>
<td>Yes</td>
<td>30/09/2011</td>
<td>Deliverables D1.1 and D2.1</td>
</tr>
<tr>
<td>MS2</td>
<td>Decision on initial super modeling strategy for climate super models</td>
<td>WP1, WP2, WP3, WP4, WP5</td>
<td>1</td>
<td>12</td>
<td>Yes</td>
<td>30/09/2011</td>
<td>Deliverables D3.1, D4.1, D4.2 and D5.1</td>
</tr>
<tr>
<td>MS3</td>
<td>Evaluate the initial super model experience with climate super models</td>
<td>WP1, WP2, WP3, WP4, WP5</td>
<td>3</td>
<td>24</td>
<td>Yes</td>
<td>01/10/2012</td>
<td>Deliverables D4.2 and D5.2</td>
</tr>
<tr>
<td>MS4</td>
<td>Decision on an updated strategy for climate super models</td>
<td>WP1, WP2, WP3, WP4, WP5</td>
<td>5</td>
<td>24</td>
<td>Yes</td>
<td>01/10/2012</td>
<td>Deliverables D1.2, D2.2, D3.2 and D4.2</td>
</tr>
<tr>
<td>MS5</td>
<td>Showcase for intermediate and complex climate super models</td>
<td>WP4, WP5</td>
<td>2</td>
<td>36</td>
<td></td>
<td></td>
<td>Deliverables D4.3 and D5.3</td>
</tr>
<tr>
<td>MS6</td>
<td>Domain knowledge and methods for generating diverse models developed</td>
<td>WP1, WP7</td>
<td>6</td>
<td>18</td>
<td>Deliverables D1.4 and D7.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS7</td>
<td>Methods for selecting a set of complementary models developed</td>
<td>WP7</td>
<td>6</td>
<td>27</td>
<td>Deliverables D7.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS8</td>
<td>Methods for learning functional form and coefficients of interconnections developed</td>
<td>WP7</td>
<td>6</td>
<td>36</td>
<td>Deliverables D7.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>