NCCR Climate III: Scientific Results

1 EURO4M - A Gridded Alpine Daily Precipitation Data Set

1.1 The project EURO4M

Data collection for a trans-Alpine precipitation analysis
EU FP7 Project EURO4M (external Project Webpage)
Internal project webpage (bitte verlinken mit der neuen Seite von EURO4M unter den abgeschlossenen Projekten, im Moment ist es diese hier:
http://www.meteoswiss.admin.ch/web/en/research/current_projects/climate/euro4m.html)

2 Preclim - Future Climate and Decadal Forecasts

2.1 The project Preclim

The reality of a changing climate is expected to affect society at many levels, requiring the development of strategies to effectively manage the risks and chances due to changing climatologic conditions. However, for such strategies to be effective, reliable climate change scenarios are needed so that magnitude and uncertainty of the future climate development can be estimated.

Given these societal needs, the project Preclim aims at improving and updating the existing climate scenarios for Switzerland and the Alpine region on the basis of a new generation of climate models as well as sophisticated statistical methods. The resulting climate change information will be provided in a format which allows their direct use for various applications in sectors such as hydrology, agriculture, infrastructure, tourism and energy.

Methods and data
The climate projections will be based on a new suite of state-of-the-art global climate models as well as high-resolution regional models stemming from the European ENSEMBLES project. The focus will be on the expected climate conditions by mid of this century under the assumption of IPCC Emission Scenario A1B. The individual climate models will thereby be jointly evaluated and their information content combined such that optimum projections are obtained and the model uncertainties are appropriately quantified. Additionally, modern statistical methods (downscaling) will be applied to enhance the spatial and temporal resolution of the climate projections to meet the end users' need.

Decadal forecasts
Between the target period of the PreClim climate scenarios (2030-2050) and the already well-established seasonal forecasts, there is a prediction gap on the time-scale of 1-10 years. While this time-scale is of particular socioeconomic interest since it represents the planning horizon for many economic and political decisions, the field of decadal forecasting is still in its infancy due to the high computational demands. However, recent developments in model technology indicate that decadal forecasting may now start to become feasible to some degree. To shed more light on this upcoming research field, PreClim will also analyze the potential of decadal forecasts for Europe and particularly Switzerland. The required data will be provided from international projects like ENSEMBLES. The long time cooperation with Swiss Re and thus the link to the application side will be continued in this part of the project.

2.2 Risks of model weighting in multimodel climate projections

Should climate projections stemming from different models be weighted?
One of the key questions in the construction of multi-model climate projections is whether each climate

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model is equally credible, or whether the information stemming from different models should be weighted according to some criteria of model performance. At the moment, there is no consensus in the scientific community on how such performance-based weights should be obtained. Many methods have been proposed in literature, but due to the long time-scales involved it is not possible to prove which method is the best. Consequently, there is an inherent risk that "wrong" weights are applied, not truly reflecting model quality. This is a rather unsatisfying condition, since the choice of weighting scheme can have a big impact on the results of climate projections.

To tackle this problem and obtain some decision guidance on this issue, we have "put the cart before the horse" and asked: Assuming we knew how good the models are, what could be potentially gained by optimum weighting, and what could potentially be lost by wrong weighting? On the basis of an entirely conceptual approach, which also includes experience from seasonal forecasting, the following interesting result has been obtained:

If model weights are applied which do not reflect the true model uncertainties, then the weighted multimodel may have much lower skill than the unweighted one. In many cases, more information may be lost due to inappropriate weights than could potentially be gained by optimum weights (see Fig. 1).

In other words: if it is not clear how model weights should be obtained, then equal weighting may well be the safer way to go. This finding has direct consequences for the regional climate projections calculated within the Preclim project, in that all available information are considered in our analysis without a-priori weighting.

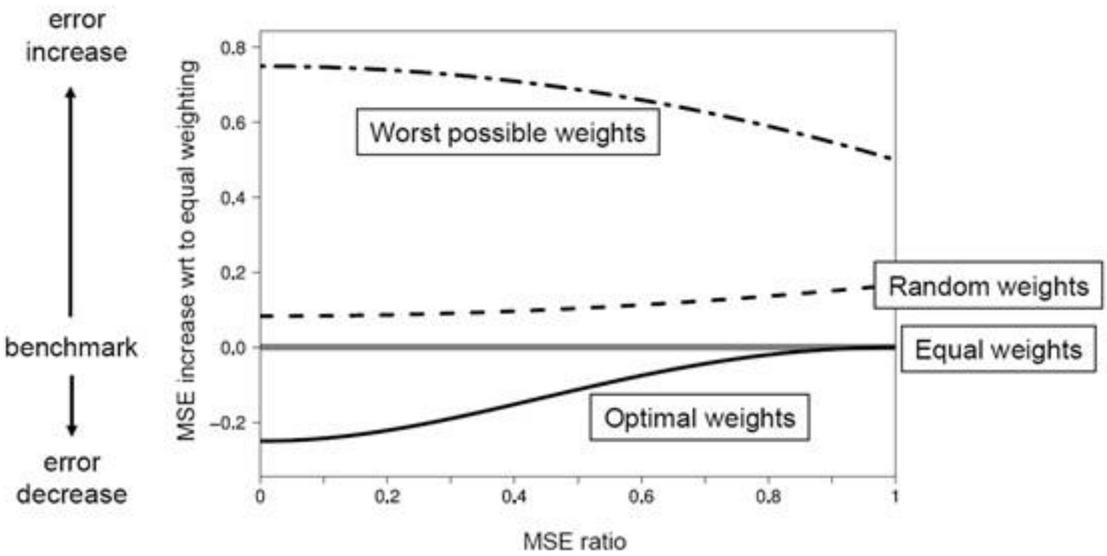

Fig. 1: Increase/decrease of the expected mean squared error (MSE) of weighted averages of two single models (solid black: optimum weights; dot-dashed: worst possible weights; dashed: random weights) with respect to the benchmark of equal weighting. The results are plotted as a function of the MSE ratio of the two single models to be combined. The combination experiments are based on the conceptual model of Weigel et al. (2010).

This study was supported by the Swiss National Science Foundation through the National Centre for Competence in Research (NCCR) Climate and by the ENSEMBLES project (EU FP6, Contract GOCE-CT-2003-505539).

Reference:

Weigel, A. P., Knutti, R., Liniger, M. A. and Appenzeller, C. (2010): Risks of model weighting in multimodel climate projections. Journal of Climate, Vol. 23, 4175-4191

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Contact:
For further information please contact Andreas Fischer.

2.3 Revisiting Swiss temperature trends 1959-2008

Temperature is a key variable for monitoring global climate change. Here we perform a trend analysis of Swiss temperatures from 1959 to 2008, using a new 2 × 2 km gridded data-set based on carefully homogenized ground observations from MeteoSwiss. The aim of this study is twofold: first, to discuss the spatial and altitudinal temperature trend characteristics in detail, and second, to quantify the contribution of changes in atmospheric circulation and local effects to these trends.

The seasonal trends are all positive and mostly significant with an annual average warming rate of 0.35 °C/decade (~1.6 times the northern hemispheric warming rate), ranging from 0.17 in autumn to 0.48 °C/decade in summer. Altitude dependent trends are found in autumn and early winter where the trends are stronger at low altitudes (<800 m asl), and in spring where slightly stronger trends are found at altitudes close to the snow line.

Part of the trends can be explained by changes in atmospheric circulation, but with substantial differences from season to season. In winter, circulation effects account for more than half the trends, while this contribution is much smaller in other seasons. After removing the effect of circulation, the trends still show seasonal variations with higher values in spring and summer. The circulation-corrected trends are closer to the values simulated by a set of ENSEMBLES regional climate models, with the models still tending towards a trend underestimation in spring and summer.

Our results suggest that both circulation changes and more local effects are important to explain part of recent warming in spring, summer, and autumn. Snow-albedo feedback effects could be responsible for the stronger spring trends at altitudes close to the snow line, but the overall effect is small. In autumn, the observed decrease in fog frequency might be a key process in explaining the stronger temperature trends at low altitudes.

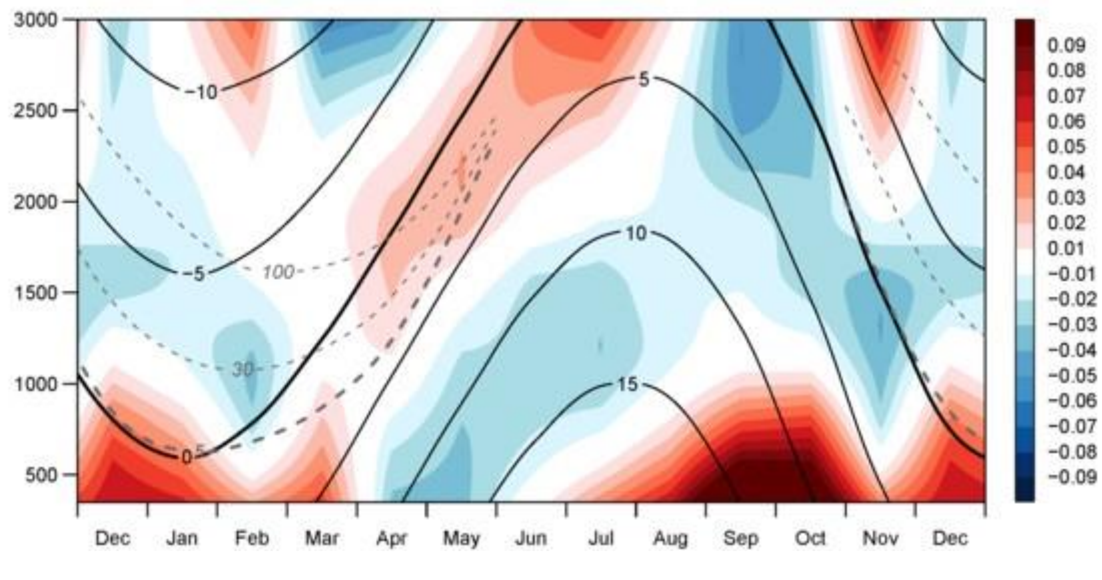

Figure 1: Vertical anomalies of the observed monthly temperature trends 1959-2008 in °C/10 years. The solid black lines denote estimated temperature isotherms (°C), while the dashed yellow lines represent isolines of 5, 30, and 100 cm snow depth.

This study was supported by the Swiss National Science Foundation through the National Centre for Competence in Research (NCCR) Climate.

Reference:
Ceppi, P., Scherrer, S.C., Fischer, A.M. and Appenzeller, C. (2012). Revisiting Swiss temperature trends 1959-2008. Int. Journal of Climatology, 32: 203-213.

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Contact:
For further information please contact Simon Scherrer.

2.4 Snow-albedo feedback and Swiss spring temperature trends

The snow-albedo feedback (SAF) is an important positive feedback effect in the climate system. If a snow-covered area warms and the snow melts, the surface albedo decreases, more solar energy is absorbed, and the local temperature tends to increase. A shortening of the snow season will result in a lower surface albedo during the transition seasons and could potentially amplify a warming signal and thereby increase temperature trends.

The SAF effect is well-known in theory and it has been shown that northern hemispheric land warming in spring is likely to have been significantly enhanced by the SAF. On the more local scale, it was found that temperature trends are most rapid near the annual 0°C isotherm and that warming is weaker when snow cover is present. However, none of these studies do actually quantify the SAF effect on local 2 m temperature in the snow melt period. Here, we quantify the effect of the SAF on Swiss spring temperature trends using daily temperature and snow depth measurements from six station pairs for the period 1961-2011.

We show that the daily mean 2 m temperature of a spring day without snow cover is on average 0.4°C warmer than one with snow cover at the same location (cf. Figure 1). Comparisons with regional climate model simulations show that this value lies rather at the lower end of the estimations in literature.

Caused by the decreases in snow pack, the snow-albedo feedback amplifies observed temperature trends in spring. The influence is small and confined to areas around the upward moving snow line in spring and early summer. For the 1961-2011 period, the related temperature trend increases are in the order of 0.01 to 0.03°C/10 years or 3-7% of the total observed trend. This estimate was possible since no long-term trend in relevant weather types was observed.

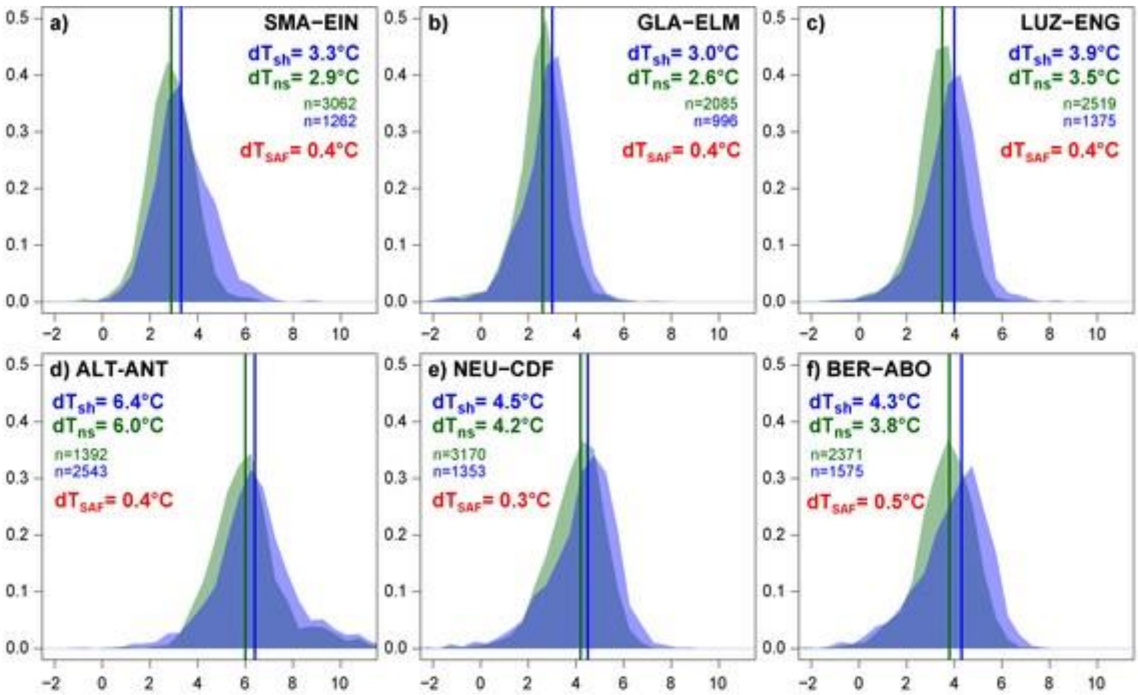

Figure 1: Distributions (colored areas) and medians (vertical lines) of temperature differences (°C) between the low- and high-altitude stations for "days with snow only at the high-altitude station only" (dTsh, blue area, line and numbers) and for "days without snow at both stations" (dTns, green area, line and numbers). Shown are available spring data (MAM) between 1961 and 2011 for the station pairs Zürich / Fluntern - Einsiedeln (SMA-EIN, panel a), Glarus - Elm (GLA-ELM, panel b), Luzern - Engelberg (LUZ-ENG, panel c), Altdorf - Andermatt (ALT-ANT, panel d), Neuchâtel - La Chaux-de-Fonds (NEU-CDF, panel e) and Bern / Zollikofen - Adelboden (BER-ABO, panel f). The bin width used

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to construct the distributions is 0.5°C. Also shown for all station pairs is the number of days (n=?) used to construct the distributions and statistics. The estimated value of the snow-albedo feedback effect dTSAF is given in red.

This study was supported by the Swiss National Science Foundation through the National Centre for Competence in Research (NCCR) Climate.

Reference:

Scherrer, S.C., Ceppi, P., Croci-Maspoli, M. and Appenzeller, C. (2012). Snow-albedo feedback and Swiss spring temperature trends. Theoretical and Applied Climatology. doi:10.1007/s00704-012-0712-0.

Contact:

For further information please contact Simon Scherrer.

2.5 Climate change projections for Switzerland based on a Bayesian multi-model approach

Regional projections of future climate with associated uncertainty estimates are increasingly being demanded. Generally, such scenarios rely on a finite number of model projections and are accompanied by considerable uncertainties which cannot be fully quantified. Consequently, probabilistic climate projections are conditioned on several subjective assumptions which can be treated in a Bayesian framework.

In this study, a recently developed Bayesian multi-model combination algorithm is applied to regional climate model simulations from the ENSEMBLES project to generate probabilistic projections for Switzerland. The seasonal temperature and precipitation scenarios are calculated relative to 1980-2009 for three 30-year scenario periods (centered at 2035, 2060, and 2085), three regions, and the A1B emission scenario. Projections for two further emission scenarios are obtained by pattern scaling. Key to the Bayesian algorithm is the determination of prior distributions about climatic parameters. It is shown that the prior choice of model projection uncertainty ultimately determines the uncertainty in the climate change signal. Here, we assume that model uncertainty is fully sampled by the climate models available. We have extended the algorithm such that internal decadal variability is also included in all scenario calculations. Fig. 1 gives an overview of the methodological chain applied to generate probabilistic regional scenarios.

For Switzerland, the A1B scenarios show a significant rise in temperature increasing from 0.9-1.4 °C by 2035 (depending upon region and season), to 2.0-2.9 °C by 2060, and to 2.7-4.1 °C by 2085. Mean precipitation changes are subject to large uncertainties with median changes close to zero. As an illustration, the change signals for the northeastern region of Switzerland are displayed in Fig. 2. Significant signals are seen towards the end of the century with a summer drying of 18-24% depending on region, and a likely increase of winter precipitation in Switzerland south of the Alps. The A2 scenario implies a warming of 3.2-4.8°C, and a summer drying of 21-28% by 2085, while in case of the mitigation scenario RCP3PD, climate change could be stabilized to 1.2-1.8 °C of warming and 8-10% of drying.

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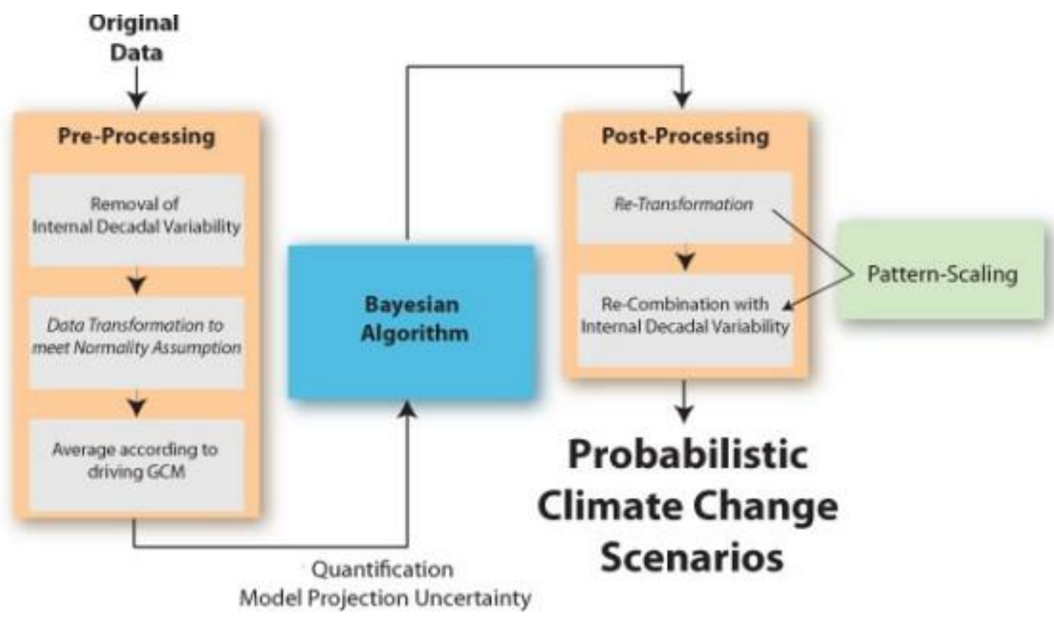

Fig. 1: Schematic overview of the applied methodology to generate regional climate change scenarios for Switzerland. The steps denoted in italics only apply to precipitation data.

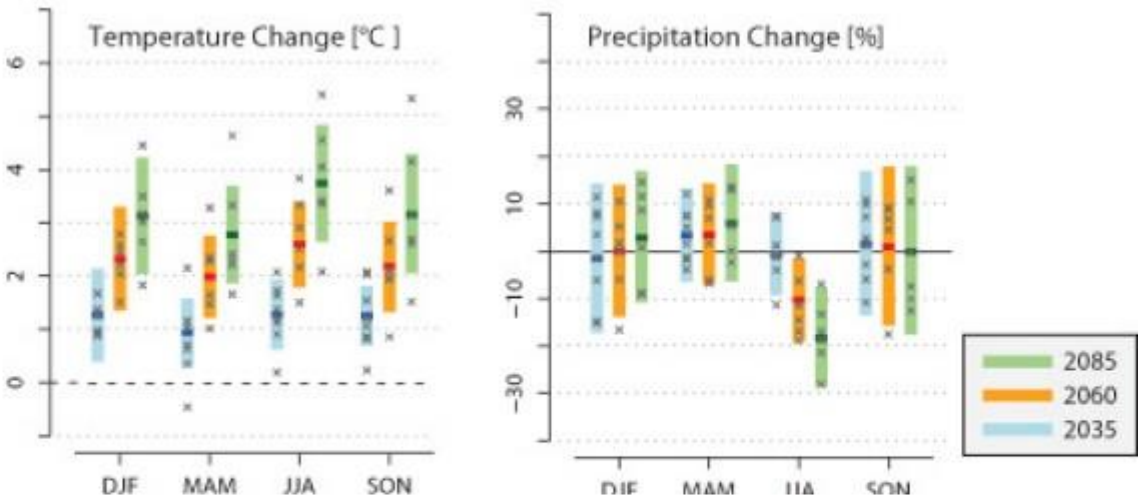

Fig. 2: Probabilistic temperature and precipitation change scenarios (in °C) for the northeastern region of Switzerland assuming the A1B emission scenario. The seasonal changes are with respect to the reference period 1980-2009. The colored bars represent the 95% confidence interval in the climate shift parameter (including internal decadal variability) with the median as bold horizontal line. The crosses are the raw model projections from ENSEMBLES (averaged according to driving GCM).

This research was partly funded by the Swiss National Science Foundation through the National Centre for Competence in Research (NCCR) Climate, the Center for Climate Systems Modelling (C2SM) at ETH Zurich, and by the ENSEMBLES project (EU FP6, Contract GOCE-CT- 2003-505539).

Reference:

Fischer, A. M., Weigel, A. P., Buser, C. M., Knutti, R., Künsch, H. R., Liniger, M. A., Schär, C. and Appenzeller, C. (2011), Climate change projections for Switzerland based on a Bayesian multi-model approach. Int. J. Climatology, doi: 10.1002/joc.3396

Contact:

For further information please contact Andreas Fischer.

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3 BiotoP - Pest and Disease Forecasts for Agriculture

3.1 The project BiotoP

Current and projected climate change will affect agriculture due to changed temperature and precipitation patterns. In addition to such direct climate change effects, also agricultural pest and disease populations will largely be influenced, and thus plant health and productivity will be affected.

The outcome of the project will enable us to estimate risks of climate change for present pest and disease management scenarios, and to adapt plant protection strategies, such as early warning systems, to maintain their sustainability. The general results and methodologies may thereby easily be adapted in further pest and disease combinations as well as in other agricultural systems.

Methods

The project BiotoP aims at improving the meteorological input to plant pest modeling. Timing, location and speed of plant disease development are largely dependent on local meteorological conditions. As examples the life cycle of codling moth, as well as fire blight infection, i.e. two major pest and disease threats to apple will be investigated. In collaboration with Agroscope Changins - Wädenswil ACW, where forecast models for the timing of codling moth / fire blight are available, but with too simple meteorology, downscaling methodologies will be evaluated and applied to make best use of large-scale available meteorological information.

In a first step, climate change scenarios are downscaled to temporally high-resolution weather series with a statistical model, a so-called weather generator. This synthetic hourly weather is then used as input for the pest models of ACW to investigate the potential threat of plant diseases in a changed climate. In a second step, the procedure will be extended for sub-seasonal pest predictions in combination with probabilistic monthly weather forecasts.

3.2 Downscaling climate change scenarios for apple pest and disease modeling in Switzerland

As a consequence of current and projected climate change in temperate regions of Europe, agricultural pests and diseases are expected to occur more frequently and possibly to extend to previously non-affected regions. Given their economic and ecological relevance, detailed forecasting tools for various pests and diseases have been developed. Assessing the future risk of pest-related damages requires future weather data at high temporal and spatial resolution.

Here, we use a combined stochastic weather generator and re-sampling procedure for producing site-specific hourly weather series representing present and future (1980-2009 and 2045-2074 time periods) climate conditions in Switzerland. The climate change scenarios originate from the ENSEMBLES multi-model projections and were calculated in the subproject Preclim. They provide probabilistic information on future regional changes in temperature and precipitation. Hourly weather series are produced by first generating daily weather data for these climate scenarios and then using a nearest neighbor re-sampling approach for creating realistic diurnal cycles. These hourly weather series are then used for modeling the impact of climate change on important life phases of the codling moth.

Results for the codling moth indicate a shift in the occurrence and duration of life phases relevant for pest control. In southern Switzerland, a 3rd generation per season occurs only very rarely under today's climate conditions but is projected to become normal in the 2045-2074 time period. While the potential risk for a 3rd generation is also significantly increasing in northern Switzerland, the actual risk

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will critically depend on the pace of the adaptation of the codling moth with respect to the critical photoperiod. As a consequence, this would require an intensification and prolongation of control measures (e.g., insecticides), implying also an increased risk of pesticide resistances.

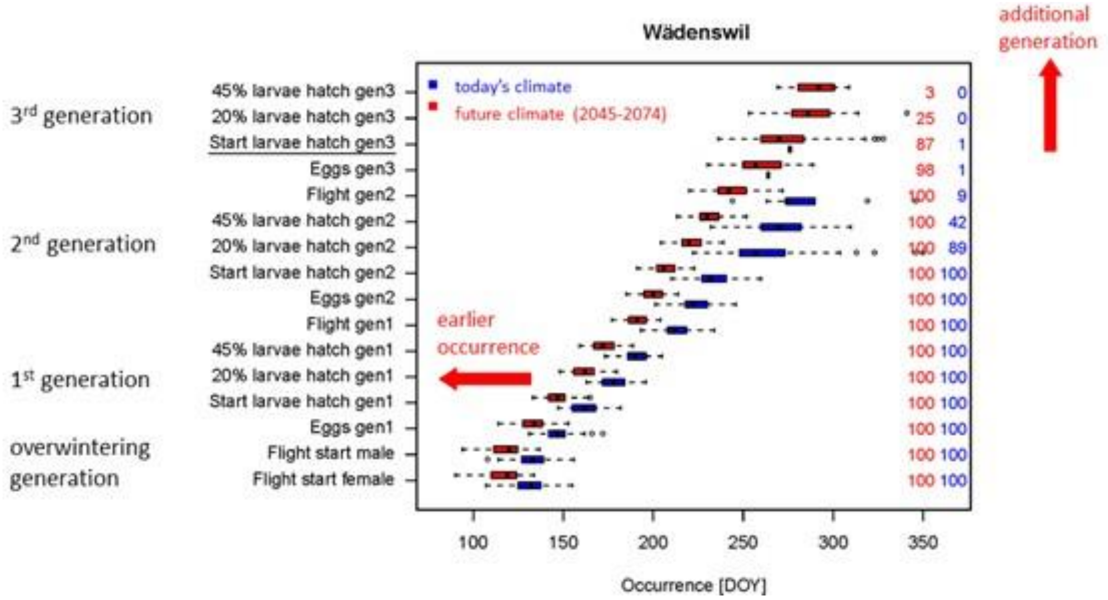

Figure 1: Occurrences (as day of year, DOY) of important codling moth life phases in the course of the year for present and future climate. The y-axes display the life phases for three generations (denoted "gen1-3") over one year, starting with the flight start in spring. The boxplots were derived from synthetic weather data representing 100 years in the present and future climate. The numbers on the right of the panels denote the percentage of years when the respective phase was reached based on the respective climate.

This study was supported by the Swiss National Science Foundation through the National Centre for Competence in Research (NCCR) Climate, and by the State Secretariat for Education and Research in the framework of the European COST Action 734.

Reference:

Hirschi, M., Stöckli, S., Dubrovsky, M., Spirig, C., Calanca, P., Rotach, M.W., Fischer, A.M., Duffy, B. and Samietz, J. (2012). Downscaling climate change scenarios for apple pest and disease modeling in Switzerland. Earth System Dynamics, 3, 33-47.
http://www.earth-syst-dynam.net/3/33/2012/esd-3-33-2012.pdf

Contact:

For further information please contact Christoph Spirig.

3.3 Monthly weather forecasts in a pest forecasting framework

Downscaling, recalibration and skill improvement

Monthly weather forecasts (MOFCs) were shown to have skill in extra-tropical continental regions for lead times up to three weeks, particularly for temperature and if weekly averaged. This skill could be exploited in practical applications, for implementations exhibiting some degree of memory or inertia towards meteorological drivers potentially even for longer lead times. Many agricultural applications fall into this category due to the temperature dependent development of biological organisms, allowing simulations based on temperature sums. However, most of such agricultural models require local weather information at daily or even hourly temporal resolution, preventing a direct use of the spatially and temporally aggregated information of MOFCs, which may furthermore include significant biases.

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At the example of forecasting life phases of codling moth, the major insect pest in apple orchards worldwide, we investigate the application of downscaled weekly temperature anomalies of MOFCs for use in an impact model requiring hourly input. The downscaling and post-processing included the use of a daily weather generator and a re-sampling procedure for creating hourly weather series, and the application of a climate conserving recalibration technique (Weigel et al. 2009) on the forecasted occurrences of codling moth life phases.

Results show a clear skill improvement over the full forecast range when incorporating MOFCs as compared to deterministic forecasts using climatology. This is true both in terms of root mean squared errors (RMSE) and of the continuous rank probability scores (CRPS) of the ensemble forecasts vs. the mean absolute errors of the climatological benchmark forecasts.

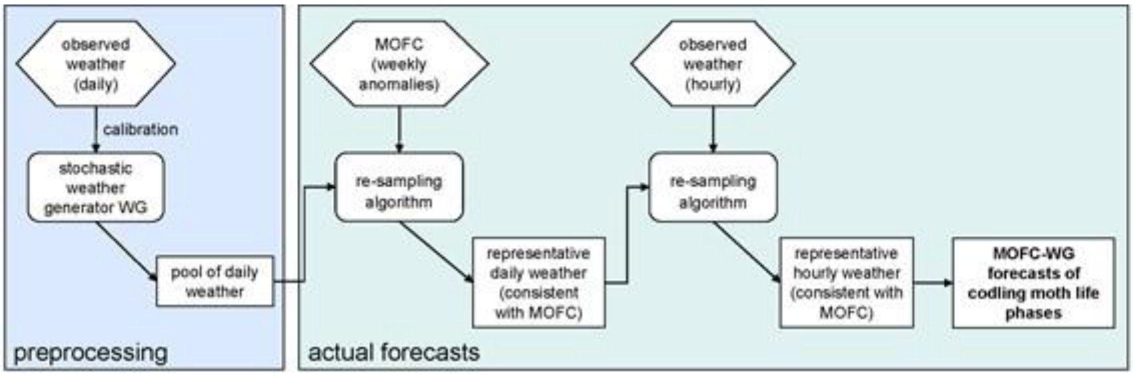

Figure 1: Weather generator/re-sampling downscaling scheme

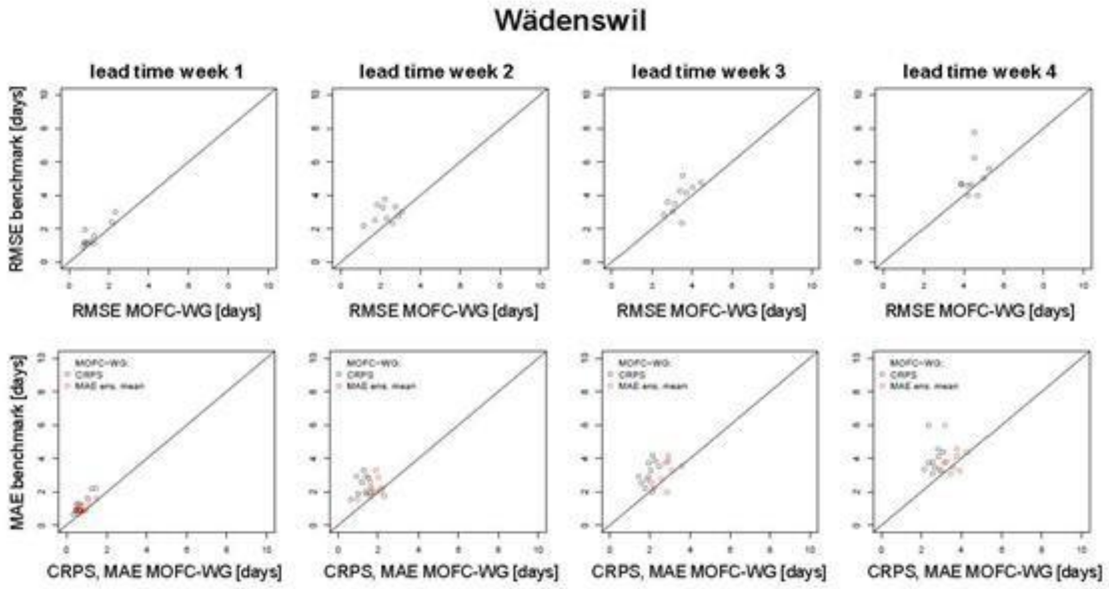

Figure 2: Improvement in the skill of the forecasted occurrence of codling moth life phases in the 5-member hindcasts for lead time 1-4: (top) RMSE of the MOFC-WG ensemble mean vs. RMSE of the climatological benchmark forecasts, (bottom) CRPS of the MOFC-WG ensemble forecasts (red) and MAE of the MOFC-WG ensemble mean (black) vs. MAE of the climatological benchmark forecasts.

This study was supported by the Swiss National Science Foundation through the National Centre for Competence in Research (NCCR) Climate.

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Reference:

Hirschi, M., Spirig, C., Weigel, A. P., Calanca, P., Samietz, J. and Rotach, M. W. 2012. Monthly weather forecasts in a pest forecasting context: Downscaling, recalibration, and skill improvement. Journal of Applied Meteorology and Climatology, 51(9):1633-1638, doi:10.1175/JAMC-D-12-082.1.

Contact:

For further information please contact Christoph Spirig.

4 CombiPrecip - High Resolution Precipitation Data Over Switzerland

4.1 The project CombiPrecip

Flood forecasts, avalanche warnings, agricultural planning and many more sectors rely, nowadays, on models that estimate effects of weather and climate numerically. Such models need accurate meteorological input at a spatial resolution much finer than what direct measurements at weather stations can provide. This challenge is particularly pronounced for rain and snowfall because of the fine-scale nature of these weather elements. This project aims at generating area-covering precipitation analyses at high temporal and spatial resolution, suitable for use in application models and for warnings.

Methods

The idea behind CombiPrecip is to combine information from the two classical rainfall measurement devices, namely radar and weather-station measurements. The combination shall be accomplished by advanced statistical methods, which can take advantage of the relative merits of each of the devices. That is, fine resolution of radar and high accuracy of station measurements. The method shall be applicable for deriving precipitation fields in near real time and continuously for recent years. A particular challenge of the project is the Alpine topography with its complex precipitation processes and with its difficulties for precipitation measurement.

4.2 Geostatistical radar-raingauge combination with nonparametric correlograms

Methodological considerations and application in Switzerland

Modelling spatial covariance is an essential part of all geostatistical methods. Traditionally, parametric semivariogram models are fit from available data. More recently, it has been suggested to use nonparametric correlograms obtained from spatially complete data fields. Here, both estimation techniques are compared. Nonparametric correlograms are shown to have a substantial negative bias. Nonetheless, when combined with the sample variance of the spatial field under consideration, they yield an estimate of the semivariogram that is unbiased for small lag distances. This justifies the use of this estimation technique in geostatistical applications.

Various formulations of geostatistical combination (Kriging) methods are used here for the construction of hourly precipitation grids for Switzerland based on data from a sparse realtime network of raingauges and from a spatially complete radar composite. Two variants of Ordinary Kriging (OK) are used to interpolate the sparse gauge observations. In both OK variants, the radar data are only used to determine the semivariogram model. One variant relies on a traditional parametric semivariogram estimate, whereas the other variant uses the nonparametric correlogram. The variants are tested for three cases and the impact of the semivariogram model on the Kriging prediction is illustrated (fig.1).

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For the three test cases, the method using nonparametric correlograms performs equally well or better than the traditional method, and at the same time offers great practical advantages.

Furthermore, two variants of Kriging with external drift (KED) are tested, both of which use the radar data to estimate nonparametric correlograms, and as the external drift variable. The first KED variant has been used previously for geostatistical radarraingauge merging in Catalonia (Spain). The second variant is newly proposed here and is an extension of the first. Both variants are evaluated for the three test cases as well as an extended evaluation period. It is found that both methods yield merged fields of better quality than the original radar field or fields obtained by OK of gauge data. The newly suggested KED formulation is shown to be beneficial, in particular in mountainous regions where the quality of the Swiss radar composite is comparatively low.

An analysis of the Kriging variances shows that none of the methods tested here provides a satisfactory uncertainty estimate. A suitable variable transformation is expected to improve this.

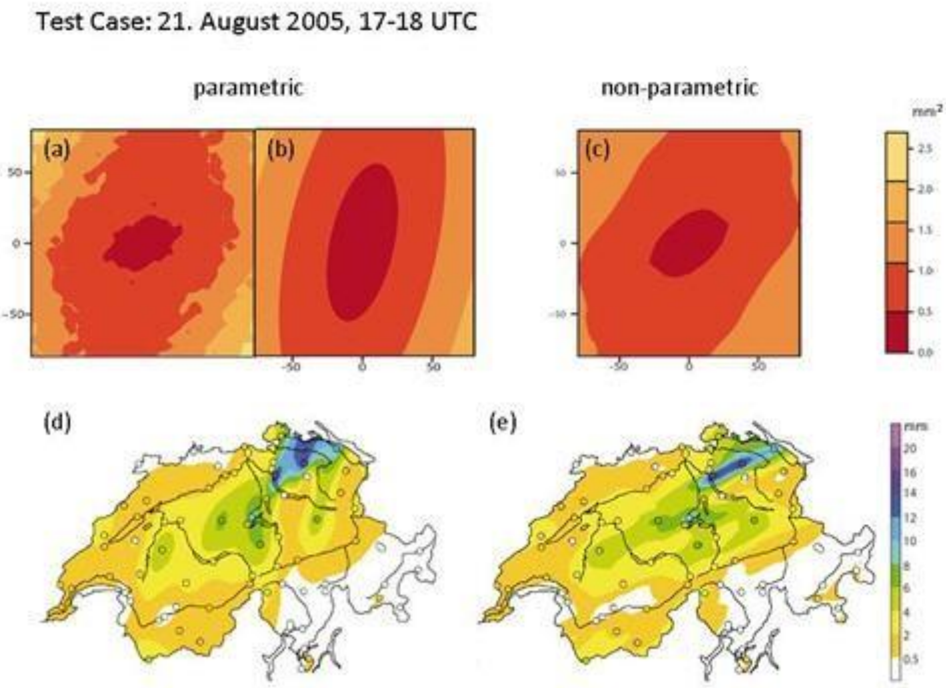

Fig. 1.: Spatial analysis of hourly rainfall (21. August 2005, 17-18 UTC), by Ordinary Kriging with parametric and non-parametric semivariogram estimation (left and right panels respectively). (a) Empirical semivariogram from subsampled radar field (mm2), (b) exponential anisotropic semivariogram fitted to (a), (c) nonparametric semivariogram derived from complete radar field, (d) Ordinary Kriging with semivariogram from (b), (e) Ordinary Kriging with semivariogram from (c).

This study was also supported by the COST Action 731.

Reference:

Schiemann, R., Erdin, R., Willi, M., Frei, C., Berenguer, M. and Sempere-Torres, D. 2010: Geostatistical radar rain-raingauge combination with nonparametric correlograms: methodological considerations and application in Switzerland. Hydrology and Earth System Science Discussion, Vol. 7, 6925-6979.

Contact:

For further information please contact Christoph Frei.

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4.3 Data transformation and uncertainty in geostatistical combination of radar and rain gauges

Geostatistics provides a popular framework for deriving high-resolution quantitative precipitation estimates (QPE) by combining radar and rain gauge data. At present, this framework is investigated at MeteoSwiss for the development of a QPE procedure for hourly precipitation in real time. One potential caveat of this methodology is, however, that the skewed and heteroscedastic nature of precipitation is in contradiction to assumptions of classical geostatistics.

This study examines the potential of trans-Gaussian kriging to overcome this contradiction. Combination experiments are undertaken with kriging with external drift (KED) using several settings of the Box-Cox transformation. Hourly precipitation data in Switzerland for the year 2008 serve as testbed to compare KED with and without transformation. The impact of transformation is examined with regard to compliance with model assumptions, accuracy of the point estimate and reliability of the probabilistic estimate.

Data transformation improves the compliance with model assumptions, but some level of contradiction remains in situations with many dry gauges. Very similar point estimates are found for KED with untransformed and appropriately transformed data. However, care is needed to avoid excessive transformation (close to log), because this can introduce a positive bias. Strong benefits from transformation are found for the probabilistic estimate, which is rendered positively skewed, sensitive to precipitation amount, and quantitatively more reliable. Without transformation, 44% of all precipitation observations larger than 5 mm per hour are considered as extremely unlikely by the probabilistic estimate in our test application. Transformation reduces this rate to 4%. Although transformation cannot fully remedy the complications for geostatistics in radar gauge combination, it seems a useful procedure if realistic and reliable estimation uncertainties are desired, such as for the stochastic simulation of QPE ensembles.

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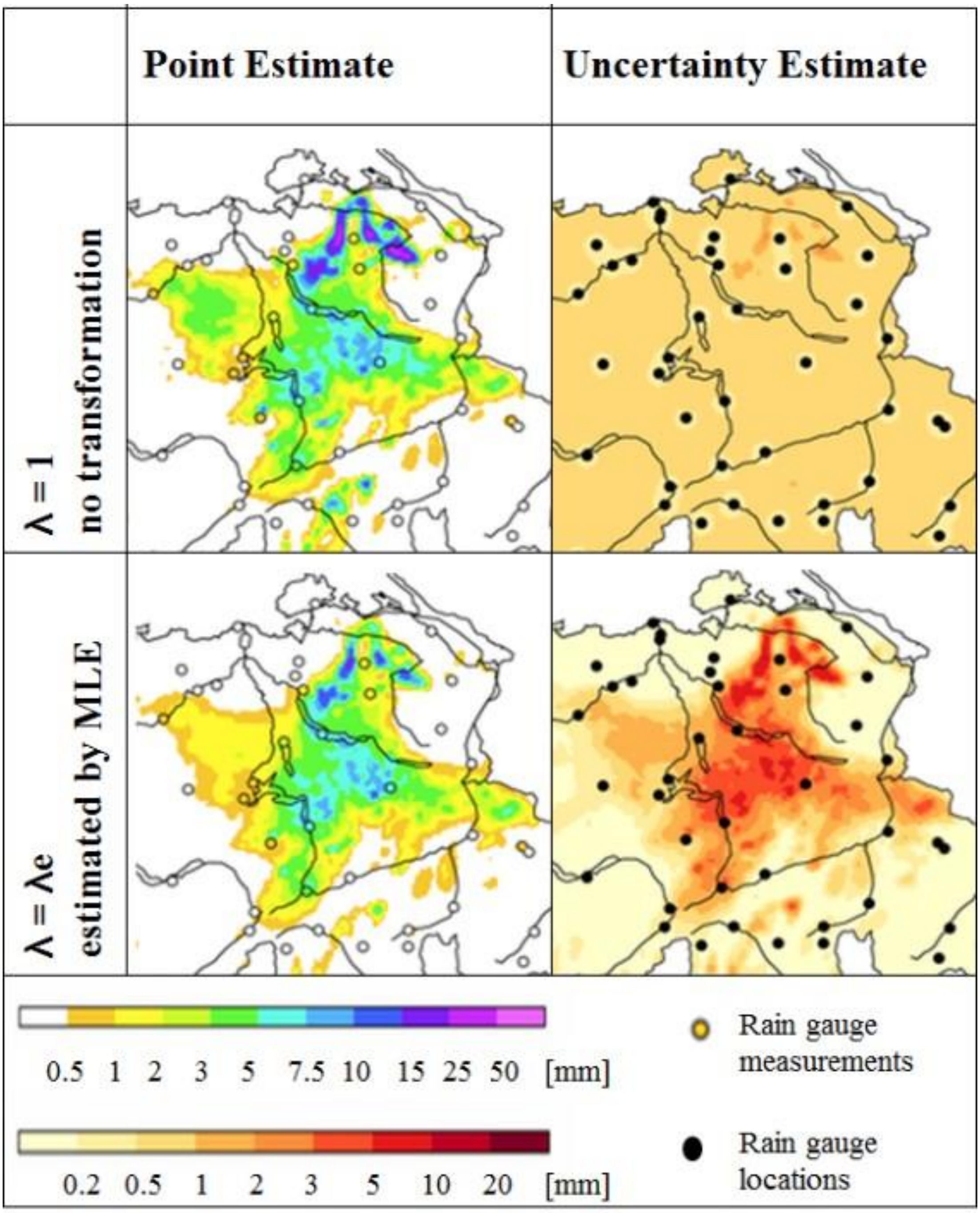

Figure 1.: Example results from experiments with geostatistical radar rain-gauge combination (KED) for a case of intense summer-time thunderstorms in Switzerland (10.6.2008 18:00-19:00 UTC). Left hand panels: point estimate (in mm per hour). Right hand panels: probabilistic estimate (in mm, a measure of the standard error of the analysis). The first / second rows depict results without / withe Box-Cox data transformation.

Reference:

Erdin, R., Frei, C. and Kuensch, H.R., 2012: Data Transformation and Uncertainty in Geostatistical Combination of Radar and Rain Gauges. *J. Hydrometeor*, **13**, 1332–1346. doi: http://dx.doi.org/10.1175/JHM-D-11-096.1

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Contact:
For further information please contact Mark Liniger.

4.4 Real-time operational implementation of raingauge-radar combination in Switzerland

Although both raingauges and radars have been operating for a series of years in Switzerland, one naturally desires to merge them into a single precipitation-estimation scheme, where their advantages combine to provide improved, in terms of accuracy, rainfall fields. The main approach has been to employ complex statistical techniques suitable for this kind of problems. Such techniques have been used in several contexts since the eighties , but only in the last decade they began emerging as operational tools for providing real-time rainfall estimates. Prominent among them stand the geostatistical techniques which aim in zeroing the bias of the error between the estimator and the actual value of precipitation but simultaneously minimizing the variance of this error. In Switzerland, the geostatistical radar-raingauge combination stands as a logical next step in a long series of research efforts spent to produce in real-time quantitative radar estimates of precipitation at ground with high spatial and temporal resolution over the whole Swiss territory including border regions.
We have devised a spatiotemporal version of kriging, the co-kriging with external drift (CED) which takes into account hourly-aggregated point raingauge measurements, and their corresponding radar fields from both present and previous time-states of the precipitation stochastic process in order to produce a merged rainfall map. The primary variable is always taken to be the raingauge measurements, and in this sense the radar field is adjusted locally so to be consistent with raingauge data, while conserving the general structure and outline of the radar precipitation map.

The performance of the CED algorithm has been examined in terms of (a) accuracy, (b) stability, (c) computational speed, and (d) flexibility:
Regarding **accuracy** several skill scores have demonstrated a consistent and significant improvement over the corresponding scores of the radar field alone. The strength of CED can be particularly demonstrated in the overall bias which typically improves considerably, remedying the underestimations or overestimations of precipitation fields often observed in radar fields.
In terms of **stability** it can be shown that CED, due to its spatiotemporal structure, succeeds providing reasonable estimates even in cases where robustness of input data is doubtful In particular, CED was tested for input as low as 10-minutes aggregated data and still succeeded to perform reasonably well in terms of skill-scores.
Regarding **computational speed** the radar-raingauge merging process can be achieved in less than 10 minutes using the computational resources of MeteoSwiss. The expectation is to produce hourly-aggregated precipitation maps of Switzerland every 10 minutes, with the hourly aggregations being motivated by the necessity for sufficiently robust input.
In terms of **flexibility**, we give special focus on the needs of potential clients. For instance, the fact that the produced hourly maps only cover the area of Switzerland may make it impractical for nowcasting needs which require a shorter temporal resolution input. Moreover, geostatistical interpolation (as is commonly true for other interpolation schemes) gradually deteriorates as distance increases from the monitored terrain (in our case away from the Swiss borders). Currently we are in the process of developing tools to provide solutions for these kind of issues. As, for example, a scheme which produces five-minute precipitation maps employing the hourly radar-raingauge combination maps as an input. The goal is to provide a raingauge-adjusted raster spatiotemporally equivalent to that of the radar product.

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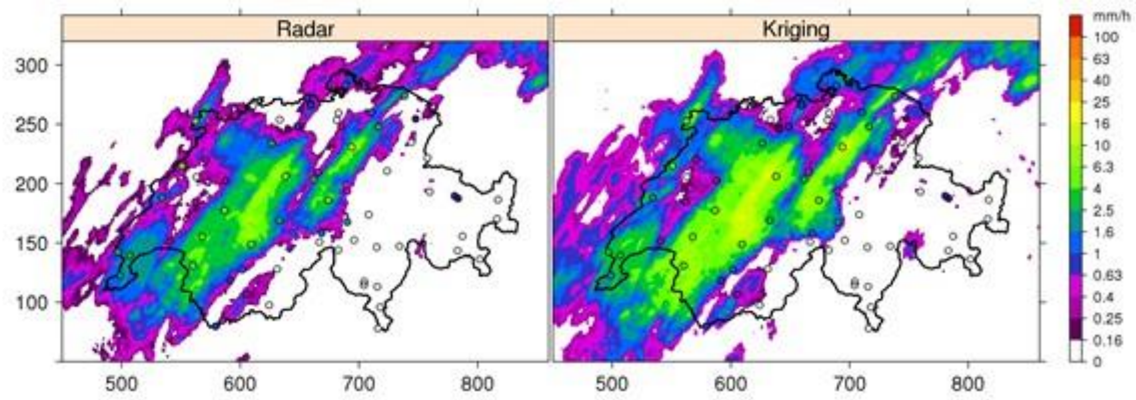

Fig. 1: Comparison of radar measurement (left) and the statistical combination of radar and rain gauge measurement (right) on 22. Aug. 2005, 5:10 - 6:00. The gauges are represented by dots.

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Contact:

For further information please contact Ioannis Sideris.

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