Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Precipitation changes associated with shifts in North Atlantic teleconnectivity

Flavio Lehner (1,2), Christoph C. Raible (1,2)

(1) Climate and Environmetnal Physics, University of Bern, Bern, Switzerland
(2) Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland

Corresponding author's e-mail address: lehner@climate.unibe.ch

Session: Global aspects

The relatively short observational record of winter atmospheric circulation in the North Atlantic region is dominated by the well-known North Atlantic Oscillation (NAO) pattern. Temporally extended reanalysis products, such as the Twentieth Century Reanalysis, provide new evidence that this pattern and the associated atmospheric teleconnections are not necessary stable over time.

We use a running window pattern correlation of teleconnectivity to investigate the temporal stability of the classical NAO teleconnection pattern in reanalysis data. Centers of teleconnectivity are found to shift during the twentieth century with corresponding changes in temperature and precipitation. This has important implications for the reconstruction of atmospheric circulation patterns as these reconstruction concepts often assume a stationary relation between a proxy location and the atmospheric circulation. Investigating a number of temperature and precipitation proxies identifies locations that are susceptible to changes in their relation to the atmospheric circulation.

Applying the analysis to CMIP5 historical and RCP simulations reveals a qualitative change in future teleconnectivity in the North Atlantic region with weaker correlations to the classical NAO pattern. We investigate the changes in the hydrological cycle associated with these altered teleconnections and discuss their importance for regional precipitation projections.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Title: Impact of cloud microphysics on climate sensitivity and the hydrological cycle

Ulrike Lohmann (1) and Sylvaine Ferrachat (1)

(1) Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

Corresponding author's e-mail address: ulrike.lohmann@env.ethz.ch

Session: Global aspects

Clouds are important for climate and climate change by interacting with radiation and being part of the hydrological cycle. They constitute a large uncertainty in global climate modeling and climate change projections as cloud processes occur on the subgrid-scale and need to be parameterized. In order to investigate the importance of cloud microphysics on the hydrological cycle and on climate sensitivity, we will use different versions of the ECHAM6 general circulation model.
The standard version ECHAM6-std (Stevens et al., 2013) only has a one-moment cloud microphysics scheme, which solves prognostic equations for the liquid and ice water mass mixing ratios. In ECHAM6-HAM, a two-moment cloud microphysics scheme (Lohmann and Ferrachat, 2010) is coupled to the Hamburg Aerosol Model HAM (Stier et al., 2005). In this version the chemical composition of the aerosols for acting as cloud condensation and ice nuclei is taken into account. In addition to these two versions, we will conduct simulations with an intermediate level of complexity. In ECHAM6-CCN, the two-moment cloud microphysics scheme is used, but in order to obtain the number of activated cloud droplets, the number of cloud condensation nuclei (CCN) is prescribed as monthly means, i.e. the aerosol module HAM is not needed. We compare two ways of obtaining monthly means of CCN. In ECHAM6-CCN-obs, a CCN climatology is used that has been derived from observations of aerosol optical depth and a suite of climate models to obtain the anthropogenic fraction of CCN (Kinne, pers. comm.). In ECHAM6-CCN-HAM, we use monthly mean CCN values that have been saved from a multi-year ECHAM6-HAM simulation.
By coupling these different ECHAM versions to a mixed-layer ocean model and running these simulations to an equilibrium climate, we will investigate how the different degrees of complexity in cloud microphysics impact climate sensitivity and the hydrological cycle in a 2xCO2 climate and in a climate with pre-industrial aerosol emissions.

References:

Lohmann, U. and Ferrachat, S., Atmos. Chem. Phys., 10, 11373-11383, 2010.
Stier, P., et al., Atmos. Chem. Phys., 5, 1125-1156, 2005.
Stevens, B., et al., J. Adv. Model. Earth Syst. 5, 1-27, 2013.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Tropical precipitation anomalies following the 1991 Pinatubo eruption

Angela Meyer (1, 2), Ulrike Lohmann (1), Thomas Peter (1)

(1) Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland
(2) Center for Climate Systems Modeling (C2SM), ETH Zurich, Switzerland

Corresponding author's e-mail address: angela.meyer@env.ethz.ch

Session: Global aspects

We have evaluated the tropical land surface temperature and precipitation responses following the eruptions of Mount Pinatubo and El Chichón as present in 6 global observational datasets and CMIP5 simulations of 18 global climate models with prescribed sea-surface temperatures. Our aim was to assess the performances of the CMIP5 models in capturing precipitation anomalies upon strong perturbations of the stratospheric aerosol optical depth, as would be expected from stratospheric sulfuric acid aerosol geoengineering.

After removing the impact of the El Niño Southern Oscillation (ENSO) on tropical land surface temperature and precipitation, we found that both observations and CMIP5 models show a significant decrease in tropical land surface temperatures and precipitation after the Pinatubo eruption ($p<0.001$). With the ENSO contributions removed, observed detrended tropical land surface temperature and precipitation show a drop by about 0.45 K and 0.2 mm/day, respectively. In contrast, for the 1982 eruption of El Chichón, observations show a significant decrease in tropical land surface temperature ($p<0.001$) but not in precipitation. Models are ambivalent in simulating the precipitation response to El Chichón: For $p<0.05$, one third of the models simulate a significant decrease in tropical land precipitation. If the Nino3.4 index is chosen for removing the ENSO impact on precipitation, about half of the models simulate a significant decrease even at $p<0.001$. Thus even with prescribed sea-surface temperatures, many CMIP5 models simulate false positives for a sulfur injection of 3.5 Mt.

Stratospheric geoengineering scenarios typically assume injections of 2 to 8 Mt of sulfur per year, compared to about 3.5 Mt by El Chichón and 10 Mt by Mt. Pinatubo. In view of our results, it appears questionable whether a majority of the models would be able to simulate tropical precipitation responses of the right order of magnitude in stratospheric geoengineering simulations.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Elusive drought: Uncertainty of short- and long-term CMIP5 drought projections

Boris Orlowsky (1), Sonia I. Seneviratne (1)

(1) Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland

Corresponding author's e-mail address: boris.orlowsky@env.ethz.ch

Session: Global aspects

Recent years have seen a number of severe droughts in different regions around the world, causing agricultural and economic losses, famines and migration. However, classical drought indicators such as the Standardized Precipitation Index or Soil Moisture Anomalies show large uncertainties in observations, hampering reliable event detection. Based the historical simulations of the 5th phase of the Coupled Model Intercomparison Project (CMIP5) as a proxy for natural variability, these observational drought indicators fall within the natural variability range. For the future, drought projections in CMIP5 display a large uncertainty over all time frames, generally impeding trend detection. Analogue analyses of the frequencies rather than magnitudes of drought show better signal-to-noise ratios with detectable trends towards increasing drought in a few regions, e.g. the Mediterranean and Amazonia. A separation of different sources of uncertainty in drought projections reveals that for the near term, natural variability is the dominant source, while GCM formulation generally becomes dominant by the end of the 21st century, especially for agricultural drought. In comparison, the uncertainty in emissions scenarios is negligible for most regions. These findings stand in contrast to respective analyses for a heat wave indicator, for which emissions scenarios constitute the main source of uncertainty. Our results highlight the inherent ambiguity of drought quantification and the uncertainty of drought projections. However, high uncertainty should not be equated with low drought risk, since potential scenarios include large drought increases in key agricultural and ecosystem regions.

Predicting the Water Cycle in a Changing Climate. A Vision for the Future based on a Seamless and Stochastic Perspective

T. N. Palmer

Department of Physics, University of Oxford, UK

Corresponding author's e-mail address: T.N.Palmer@atm.ox.ac.uk

There is hardly a more urgent problem for society than that of predicting reliably the regional changes in precipitation we can expect from increasing greenhouse gas concentrations in the atmosphere. CMIP multi-model ensembles provide probabilistic predictions of climate change, and for some regions the predicted changes in probability are substantial. But are these predictions sufficiently reliable to be used to inform policy on mitigation or adaptation? Evidence from seasonal prediction studies suggest that many of these regional predictions are not fully reliable, partly because of the dominance of model bias and partly because we do not yet have a completely satisfactory way of representing model uncertainty in forecast ensembles. There is evidence that some of these biases can be alleviated by increasing model resolution. However, we struggle to find the computational resources to make such high-resolution integrations. In this presentation I will discuss some new ideas on strategies to develop ultra-high resolution dynamical cores for global climate models. These strategies are based on the notion that because our sub-grid closure schemes should be considered stochastic rather than deterministic, we have over-engineered our current (bit-reproducible double-precision) dynamical cores and this will prevent us from making efficient use of future resources available for high-performance computing. I conclude that predicting the water cycle in a changing climate reliably may require the development of efficient ultra-high resolution Earth-System Models in which both the parametrisations and dynamical cores are stochastic.

The water cycle in a changing climate: recent projections of large-scale changes

Christoph Schär (1), Reto Knutti (1) and Jan Sedlacek (1)

(1) Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

Corresponding author's e-mail address: schaer@env.ethz.ch

Session: Global aspects

Climate models project pronounced large-scale changes of the water cycle in response to anthropogenic greenhouse gas emissions. Here we present and discuss related results from the most recent CMIP5 generation of climate model simulations, which were undertaken in the framework of the Fifth IPCC Assessment Report. Overall the spatial patterns and amplitudes of projected precipitation changes are remarkably similar as in the previous (CMIP3) simulations, despite substantial refinements in model physics and computational resolution.

The most pronounced large-scale signal in projected precipitation changes is the drying in much of the subtropics, and the moistening in much of the tropics and higher latitudes. This pattern – sometimes referred to as "the wet get wetter and the dry get dryer" – strengthens the existing precipitation contrast between climate zones, and is hence considered to be potentially of great societal importance. This pattern is also supported by theoretical considerations and observational evidence. According to CMIP5 models, the associated precipitation changes are statistically significant between about 30% and 60% of the Earth's surface, for global mean warming of 1 and 4° global mean warming. This supports the conclusion that precipitation changes will increasingly emerge during the 21st century and affect a growing fraction of the Earth's population. The aforementioned pattern is particularly pronounced in the Mediterranean region.

The presentation will also highlight some of the key limitations in the aforementioned reasoning, among these the sensitivity of large-scale precipitation to aerosol emissions, as well as process-related uncertainties that may be particularly relevant over land.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Physical Constraints on the Water Cycle and Precipitation

Tapio Schneider (1)

(1) Department of Earth Sciences, ETH Zurich, Switzerland

Corresponding author's e-mail address: tapio@ethz.ch

Session: Global aspects

This talk surveys physical constraints that place limits on how the water cycle and global as well as local extreme precipitation can change with climate. It discusses how the surface energy balance constrains global rates of evaporation and precipitation, and why energetic constraints imply that global precipitation reaches an asymptotic limit in very warm climates, beyond which precipitation essentially cannot increase. Local and especially extreme precipitation is not similarly constrained but can increase rapidly as the climate warms. But it is constrained by the way in which condensation occurs in updrafts in the atmosphere, which implies separate limits on how extreme precipitation increases with surface temperature.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

The Earth radiation balance as driver of the global hydrological cycle

Martin Wild

Institute for Atmospheric and Climate Science, ETH Zurich, CH-8092 Zurich, Switzerland

Corresponding author's e-mail address: martin.wild@env.ethz.ch

Session: Global aspects

The global energy and water cycles are closely interlinked. The radiative energy available at the surface (surface radiation balance) provides the energy for surface evaporation, which globally equals precipitation. Estimates of the global mean surface radiation balance can thus be used to constrain the magnitude of global mean precipitation. Vice versa, estimates of global mean precipitation may be used to constrain the surface radiation balance. There are now multiple lines of evidence that the global mean downward longwave radiation at the surface is considerably higher than suggested in may previous estimates, including the ones presented in previous IPCC reports. The estimate for the downward longwave radiation in IPCC-AR4 is, at 324 Wm^{-2}, about 20 Wm^{-2} lower than current best estimates based on both surface and satelite observations. Such a higher downward longwave radiation, everything else unchanged, would imply more evaporation, precipitation, and thus a more intense water cycle. This has led to recent controversial debates, as it has been argued that such high values of downward longwave radiation are impossible, as they would lead to excessive evaporation/precipitationcompared to available observational references. Here I argue that this apparent discrepancy between the global water cycle estimates and the energy cycle estimates including the higher downward longwave radiation can be resolved, 1) by an increase of the best estimate of global mean precipitation within its uncertaninty range, and 2) by reducing the best erstimate for the downward solar radiation at the surface. Such a lower downward solar flux would not violate observational evidence, as comparisons with surface observations suggest that many climate models and other estimates overestimate the absorbed solar radiation at the surface.

Due to the close interlink between the energy and water cycle, any change in surface radiative energy may lead to a change in the intensity of the global hydrological cycle. Over the past decades, increasing greenhouse gases lead to an increase in downward longwave radiation, thus favouring an overall intensification of the hydrological cycle. However, also the surface solar radiation underwent strong decadal variations ("dimming/brightening") which modulated the available radiative energy at the Earth surface on multidecadal timescales. The combined shortwave and longwave effect caused an overall decrease in the surface radiative energy available at the surface from the 1950s to the 1980s, and a subsequent increase. These variations are reflected in the observed decadal variations of global land precipitation. Current GCMs realistically reproduce the greenhouse-induced increase in downward longwave radiation, but fail to adequately capture the decadal variations in surface solar radiation. This is reflected in an unrealistic simulation of the decadal variation in global mean land precipitation.

Related recent references:

Wild, M., Folini, D., Schär, C., Loeb, N., Dutton, E.G., and König-Langlo, G., 2013: The global energy balance from a surface perspective, Clim. Dyn., in press. Doi:10.1007/s00382-012-1569-8.

Wild, M., 2012: New Directions: A facelift for the picture of the global energy balance. Atmospheric Environment, 55, 366-367.

Stephens, G.L., Li, J.-L., Wild, M., Clayson, C.A., Loeb, N., Kato, S., L'Ecuyer, T., Stackhouse, P.W., and Andrews, T., 2012: An update on Earth's energy balance in light of the latest global observations, Nature Geoscience, 5, 691-696, doi:10.1038/ngeo1580.

Wild, M. 2012: Enlightening Global Dimming and Brightening. Bull. Amer. Meteor. Soc., 93, 27–37, doi:10.1175/BAMS-D-11-00074.1

Wild, M., and Liepert, B., 2010: The Earth radiation balance as driver of the global hydrological cycle, Environm. Res. Lett., 5, 025203,doi: 10.1088/1748-9326/5/2/025203.

Wild, M., Grieser, J. and Schär, C., 2008: Combined surface solar brightening and greenhouse effect support recent intensification of the global land-based hydrological cycle. Geophys. Res. Lett., 35, L17706, doi:10.1029/2008GL034842.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Robustness and uncertainties in future hydrological regimes of Swiss catchments

Nans Addor (1), Ole Rössler (2,3), Nina Köplin (2,3,*), Luzi Bernhard (4), Thomas Bosshard (5,*), Rolf Weingartner (2,3), and Jan Seibert (1)

(1) Department of Geography, University of Zurich, Zurich, Switzerland
(2) Oeschger Centre for Climate Change Research, University of Bern, Switzerland
(3) Institute of Geography, University of Bern, Switzerland
(4) WSL Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland
(5) Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland
(*) now at: Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

Corresponding author's e-mail address: nans.addor@geo.uzh.ch

Session: Impacts

Projections of discharge under future climate are impaired by uncertainties arising from different sources: the emission scenarios, the climate models, the post-processing and sampling of the climate projections, and the hydrological models structure and parameterisation. In this study, carried out in the framework of the CH2014-Impacts Initiative, we investigated the contribution of each of these sources to the final simulation uncertainty for discharge. We therefore performed analyses of variance (ANOVA) in six catchments representative of the typical Swiss discharge regimes. The catchments are distributed among the Jura, the Swiss Plateau and the Alps, and are expected to react differently to climate change. We used climate projections of the CH2011 dataset obtained from the Center for Climate Systems Modeling (C2SM). This dataset consists of two types of projections, both relying on the delta change technique. The delta coefficients are determined either in a deterministic way by spectral smoothing of 10 GCM-RCM chains or in a probabilistic way by a Bayesian multi-model approach combining 20 runs until 2050, and then 14 runs until 2099. In addition to the climate projections for emission scenario A1B chosen for the ENSEMBLES project, the CH2011 team generated simulations for the scenarios A2 and RCP3PD using pattern scaling. This enabled us to address the influence of the uncertainty in greenhouse gases emissions on discharge projections. We ran hydrological simulations using

three conceptual models: HBV, PREVAH and WaSiM. HBV and PREVAH rely on a similar reservoir structure, while WaSiM uses the process-oriented Richards-equation approach. PREVAH and WaSiM rely on a higher level of spatial discretization than the lumped HBV model. The use of the three different models allowed evaluation of the sensitivity of discharge projections to the hydrological model complexity and structure. Simulations were run for the periods 2020-2049, 2045-2074 and 2070-2099 to assess the variation of the different sources of uncertainty over time.

Robust changes in discharge regimes emerge from our ensemble of simulations: (i) drier summers projected by all the model runs, irrespectively of the emission scenario, climate model, post-processing or the hydrological model, for all but one catchment (ii) earlier snow-ice melt in both alpine catchments and (iii) larger winter flows in most catchments. The contribution of the emission scenarios to the final uncertainty captured by our ensemble appears to be significant by the end of the century, especially in alpine catchments. Overall, the uncertainties stemming from the climate models dominate. Preliminary results suggest that, even if greenhouse gas concentration is constrained to the lowest level (RCP3PD), climate change signal is expected to emerge from natural discharge variability for all catchments by the end of the century. However, limiting emissions to RCP3PD levels could reduce the impacts on runoff by approximately a factor two in comparison to the impacts projected for scenario A2 for 2070-2099.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Glacier Evolution and Runoff in a Changing Climate

Andreas Bauder and Martin Funk

Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW), ETH Zürich, Zürich, Switzerland

Corresponding author's e-mail address: bauder@vaw.baug.ethz.ch

Session: Impacts

Glaciers are important components of the water cycle and regulate runoff. Storage of snow and release of melt water moderates runoff variability over seasons and from year to year. In warm and dry years, enhanced ice melt provides additional water when direct runoff from precipitation is short, whereas in cool and wet years reduced runoff results from storage of precipitation. Glaciers are intimately related to climate as they respond sensitively to variations in mass and energy fluxes at the surface. Changes of mountain glaciers affect sea level, the management of water resources, and natural hazards.

A rapid mass loss of mountain glaciers has been observed over the last decades in response to ongoing climate change. Due to the projected future global warming a significant glacier loss is expected. Results of a newly compiled dataset of glacier evolution in Switzerland since the beginning of the twentieth century and projections until the end of the 21st century based on regional climate scenarios of C2SM are presented. Implications of the glacier evolution on the water resources will be discussed.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Impact of the CH2011 climate scenarios on water resources - an estimate for Switzerland

Luzi Bernhard (1), Sven Kotlarski (2), Massimiliano Zappa (1)

(1) Swiss Federal Research Institute WSL, Hydrological Forecasts, Birmensdorf, Switzerland
(2) Institute for Atmospheric and Climate Science IAC, ETH Zürich, Zürich, Switzerland

Corresponding author's e-mail address: bernhard@wsl.ch

Session: Impacts

The projected climate change might have significant impacts on snow cover and glaciers, and thus on Alpine water resources. Within the study CCHydro (BAFU) we realized high temporal and spatial resolution scenarios of the water cycle and the discharges for the different climates and elevations of Switzerland. To reflect the estimated local climate change in a large basin, the climate scenarios of the ENSEMBLES project were calculated, using the delta change method on a daily basis, based on the A1B emission scenario for temperature and precipitation.

For the periods 2021-2050 and 2070-2099 were simulated the local meteorological changes and the resulting changes in the glaciation, the snowpack and runoff in comparison with the control period 1980-2009. These studies have been extended by the use of the CH2011 scenarios by MeteoSwiss. These are based on a probabilistic method, representing the model uncertainty and the decadal variability. In contrast to the daily based approach, the projected climate data are available for five regions of Switzerland only. In addition to the A1B scenario two further emission scenarios are provided: RCP3PD (moderate) and A2 ("worst case").

Looking at the expected changes, primarily the ice melt part of the total runoff will decline (- 22%) in the first half of this century, which is expected to level off by the end of this century. However, the snow melt fraction of the total runoff is expected in the near future by about 15% and decrease in the second period by up to 40%. If we compare the A1B-based CCHydro results with the optimistic scenario RCP3PD, we can clearly demonstrate that a reduction of greenhouse gases will have a positive effect by the end of the century. In contrast, the A2 results are comparable with the A1B values, with stronger anomalies by the end of the century.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

To what extent can we reduce climate change impacts on freshwater resources by climate mitigation?

Petra Döll

Institute of Physical Geography, Goethe University, Frankfurt, Germany

Corresponding author's e-mail address: p.doell@em.uni-frankfurt.de

Climate mitigation aims at limiting the magnitude and rate of greenhouse gas emissions and thus climate change such that negative impacts of climate change, e.g. on freshwater resources, are reduced as compared to futures without effective climate mitigation. To support the implementation of climate mitigation policies, it is helpful to assess the effect of emissions reductions on the impact of climate change on future freshwater resources and on freshwater-related vulnerability of humans. Unfortunately, such assessments are subject to large uncertainties due to the translation of emissions pathways to climatic changes, the translation of climatic changes to changes in freshwater systems, and the translation of changes in the physical freshwater system to vulnerability of humans. In my presentation, I will show the results of selected global-scale studies on the impacts of reduced emissions on freshwater resources and availability, taking into account as far as possible the related uncertainties.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Water Governance and Management under increasing uncertainty: A case study from the Upper Rhône Basin.

Margot Hill (1), Simone Fatichi (2), Andrew Allan (3) Jürg Fuhrer (4), Markus Stoffel (1, 5), Franco Romerio (1), Ludovic Gaudard (1), Paolo Burlando (2), Martin Beniston (1), Elena Xoplaki (6), Andrea Toreti (6).

(1) Research Group on Climate Change and Climate Impacts, Institute for Environmental Sciences, University of Geneva, Carouge, Switzerland
(2) Institute of Environmental Engineering, ETH-Zürich, Zürich, Switzerland
(3) UNESCO Centre for Water Law, Policy and Science, University of Dundee, Dundee, Scotland
(4) Agroscope Reckenholz-Tänikon ART, ETH-Zürich, Reckenholz, Switzerland
(5) Laboratory for Dendrogeomorphology, Institut of Geological Sciences, University of Bern, Bern, Switzerland
(6) Climate Dynamics and Climate Change, Department of Geography, Justus-Liebig-University Giessen, Giessen, Germany

Corresponding author's e-mail address: margot.hill@unige.ch

Session: Impacts

Climate change represents a major increase in uncertainty that water managers and policy makers will need to integrate into plans and decision making. A certain level of uncertainty has always existed in water resources planning, but the speed and intensity of changes in baseline conditions that climate change embodies might require a shift in perspective. This article draws on both the social and physical science results of the EU-FP7 ACQWA project to better understand the challenges and opportunities for adaptation to climate change impacts on the hydrology of the Upper Rhône Basin in the Canton Valais, Switzerland. It first presents the results of hydro-climatic change projections downscaled to more temporally and spatially-relevant frames of reference for decision makers. Then, it analyses the current policy and legislative framework within which these changes will take place, according to the policy coherence across different water-relevant frameworks as well as the integration and mainstreaming of climate change. It compares the current policy and legislative frameworks for different aspects of water resources management to the projected impacts of climate change on the hydrology of the Upper Rhône Basin, in order to examine the appropriateness of the current approach for responding to a changing climatic context. Significant uncertainties pose numerous challenges in the governance

context. The study draws on adaptive governance principles, to propose policy actions across different scales of governance to better manage baseline variability as well as more 'unpredictable' uncertainty from climate change impacts.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Impacts of climate change on ecological and economical functions of rivers in Central Europe - Experiences from the KLIWAS research programme

Enno Nilson, Maria Carambia, Bastian Klein, Peter Krahe

Federal Institute of Hydrology/Department Water Balance, Forecasting an Predictions, Koblenz, Germany

Corresponding author's e-mail address: nilson@bafg.de

Session: Impacts

Large rivers have a wide range of ecological and economical functions. Climate change has the potential to change the streamflow dynamics. This may lead to undesired pressures and affect the functions of rivers. Consequently, a discussion has been started on adaptation needs and feasible measures to overcome possible negative effects. Especially for transboundary river basins it is a challenge to find a common perspective on the future development as a basis for coordinated adaptation planning. Based on regional climate projections provided by the ENSEMBLES project and enhanced by national projects an integrated framework has been developed for the generation of streamflow projections as well as for the delineation of discharge scenarios. These scenarios takes into account the uncertainty associated with the climate change information in a very pragmatic but transparent way.

To address the interfaces to various impact assessment tools, discharge as well as hydro-meteorological time series are offered which represent a range of possible changes. Among others, impacts on water temperature and ecology, floodplain vegetation, inland navigation, and mass-cargo industries are assessed. This presentation explains the research framework using discharge changes of the Rhine River and potential impacts on the inland navigation sector as a case study. The results show that i) until the mid of the 21st century (2021-2050) the impact of climate change on inland navigation and the shipping industry along the Rhine River remains in the range observed during the last decades. ii) In the second half of the 21st century (2071-2100) impacts increase and lead to significant additional costs of transport as compared to the present. In a pessimistic discharge scenario costs may rise in the range of 20% to 35% for vessel types that are currently underway on the Rhine River. An optimistic scenario shows increases of 15% to 25%. (iii) Several adaptation options exist to reduce the vulnerability of inland navigation significantly.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

The impact of climate change on Swiss water resources and consequences for the production of hydro-electricity in the future

Bruno Schädler (1, 2)

(1) Institute of Geography/Group for Hydrology, University of Bern, Bern, Switzerland
(2) Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland

Corresponding author's e-mail address: bruno.schaedler@giub.unibe.ch

Two recently completed research projects, carried out jointly by several Swiss research institutes, focused on the impact of climate change on water resources and the production of hydro-electricity during the 21st century. All the research was based on the CH2011 regional climate scenarios drawn up for Switzerland. The A1B emissions scenario was taken as a starting point. The projected development of glacier surface area and volume for all Swiss glaciers was calculated until the end of the 21st century. With the help of various types of approaches with a time resolution of up to one hour, models were drawn up for detailed water resources and runoff time series for 180 average-sized catchments as well as all large catchments in Switzerland.
In the future, there will be little change in the overall amount of water available in Switzerland. Owing to the rise in the snow-line that will accompany a rise in temperature, the volume of snow and ice stored in the Alps will be drastically reduced: the glaciers will disappear almost totally and in the distant future (2085) spring snow reserves will be 40 to 70 % smaller than at present. Together with a seasonal shift in precipitation from summer to winter, runoff regimes will change throughout Switzerland.
With the exception of high-altitude catchments in late summer, the variability of runoff regimes will be outside the natural norm in the near future. Significant hydrological projections for the near future, however, predict only minor runoff changes.
The simulated change in flood seasonality is a function of the change in flow regime type. Decreasing summer precipitation in the scenarios also affects the flood seasonality and leads to a decrease in seasonality, i.e. a higher temporal variability in most cases. The magnitude of mean annual floods and more clearly of maximum floods (over a 22 year period) is expected to increase in the future, owing to changes in flood generating processes and extreme precipitation. Simulations for catchments in the southern Alps show a different pattern, however: mean annual floods will decrease in the distant future, i.e. in the latter part of the 21st century.

Lower rates of runoff will become more frequent and at times more marked, in particular in sensitive areas such as the Central Lowlands, the Valais and the Tessin.
Today, around 55% of the electricity used in Switzerland is produced by hydro-electric power stations. In the near future (until around 2035) there will be only a slight change in the rate of production of hydro-electricity; it will actually increase somewhat in the Alps owing to more glacier melt, and in the central and eastern Alpine foothills as well as in the Central Lowlands because of changes in runoff patterns. In the more distant future (until around 2085), however, the rate of production of hydro-electricity will drop by some 10% in the higher regions that are today covered by glaciers in the southern and eastern Valais and in the Tessin.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Snow variability in Switzerland

Simon Scherrer (1), Elias Zubler (1), Mischa Croci-Maspoli (1), Christian Wüthrich (2), Rolf Weingartner (3) and Christof Appenzeller (1)

(1) Climate Division, Federal Office of Meteorology and Climatology MeteoSwiss, Zürich, Switzerland
(2) Amt für Umweltschutz Kanton Uri, Altdorf, Switzerland
(3) Group for Hydrology, Institute of Geography University of Berne, Bern, Switzerland

Corresponding author's e-mail address: simon.scherrer@meteoswiss.ch

Session: Impacts

Snow is an important socio-economic factor in Switzerland (tourism, hydro-electricity, drinking water, road maintenance) and responsible for considerable natural hazards. Snow is also a key climate variable and a high-quality long-term snow series can be used as an excellent indicator of climate change.

In the first part we present a climate analysis of snow variability using the observed Swiss snow series from MeteoSwiss. Some new unique snow series date back almost 150 years. For the last 50–80 years data from 71 stations is available to get a more complete picture of the Swiss snow variability. Important snow climate indicators such as new snow sums (NSS), maximum new snow (MAXNS) and days with snowfall (DWSF) are presented. The results reveal large decadal variability with phases of low and high values for NSS, DWSF and DWSP. For most stations NSS, DWSF and DWSP show the lowest values recorded and unprecedented negative trends in the late 1980s and 1990s. For MAXNS, however, no clear trends and smaller decadal variability are found. Both the NSS and DWSP snow indicators show a trend since the year 2000, especially at low and medium altitudes. This is consistent with the recent 'plateauing' (i.e. slight relative decrease) of mean winter temperature in Switzerland and illustrates the importance of decadal variability in understanding the short-term trends in key snow indicators.

In the second part we present estimates of present and future DWSF using temperature change data from the CH2011 initiative and a simple delta-change approach for temperature. For simplicity we assume no changes in the wet days frequency. Results show that for the median change of the A1B scenario by 2060 the DWSF might decline by 50-75% in the Swiss lowlands and by roughly 20 days in the Alpine summit regions. At the end of the 21st century an almost complete absence of DWSF can be expected in the lowlands of the Ticino and around the Lake Geneva.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Boundary layer water vapour deuterium excess as a proxy for surface evaporation characteristics

Franziska Aemisegger, Stephan Pfahl, Harald Sodemann, Heini Wernli

Institute for Atmospheric and Climate Science, ETH, Zuerich, Switzerland

Corresponding author's e-mail address: stephan.pfahl@usys.ethz.ch

Session: Regional to local aspects

Evaporation from the ocean and land surface is a key coupling process in the hydrological cycle. Changes in surface evaporation driven by changes in atmospheric conditions and water availability have a strong impact on the regional water cycle. Studying the evaporation process and its link to the atmospheric circulation is thus central for a better understanding of the feedbacks between the surface water components and the atmosphere. Stable water isotopes are naturally available tracers of water phase changes in the atmosphere. The difference in volatility and diffusivity of the isotopologues lead to isotopic fractionation during phase transitions. The strength of this fractionation process depends on environmental conditions like relative humidity and temperature. To characterise the evaporation source of low-level oceanic and continental water vapour we use deuterium excess measurements from a Picarro cavity ring-down laser spectrometer. We performed two measurement campaigns: (1) in the Mediterranean during the first special observation period of the international programme HyMeX onboard the research aircraft D-IBUF (TU Braunschweig) and (2) at a field site in the Swiss prealps (Rietholzbach). To reconstruct the previous history of the air parcel in which we measure the deuterium excess signature and particularly its associated catchment area of surface evaporation we used an established Lagrangian moisture source identification scheme. We show that the relation between deuterium excess in atmospheric water vapour at the measurement point and the relative humidity conditions at the geographical location of evaporation exhibits different characteristics for ocean evaporation compared to land surface evaporation. The intensity of continental moisture recycling and the transpiration part of the continental evaporation flux can be deduced from this relation at the seasonal timescale as well as for individual weather systems.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Evaluation of the cloud-resolving climate model approach

Nikolina Ban (1), Jürg Schmidli (1) and Christoph Schär (1)

(1) Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

Corresponding author's e-mail address: ban.nikolina@env.ethz.ch

Session: Regional to local aspects

The uncertainties in current global and regional climate model integrations are partly related to the representation of clouds, moist convection, and complex topography. Reducing the grid spacing down to some few kilometers and switching off the convection parametrization (cloud-resolving models) is thus an attractive approach. On climate time scales, cloud-resolving methods have been used for process studies, but application to long-term scenario simulations has been very limited. Here we present a cloud-resolving simulation for a 10-year long period (1998-2007) integrated with the COSMO-CLM model and forced by reanalysis data. Two one-way nested grids are used with horizontal resolutions of 2.2 km for a cloud-resolving model (CRM) simulation on an extended Alpine domain (1100km x 1100km), and of 12 km for a cloud-parameterizing simulation (CPM) covering Europe. The CRM is driven by lateral boundary conditions from the CPM run, while the CPM run is driven by lateral boundary conditions from ERA-Interim reanalysis. Validation is conducted against high-resolution surface data. The CRM model improves the simulation of the diurnal cycles of precipitation and temperature, while CPM has a poor diurnal cycle associated with the use of parametrized convection. The assessment of extreme precipitation events reveals the underestimation of the frequency and intensity for CPM, while CRM captures extreme precipitation on sub-daily time scales quite well. We also present results on the scaling of precipitation extremes with temperature. The CRM exhibits Clausius-Clapeyron scaling for daily precipitation, and a superadiabatic scaling for hourly precipitation in the warm season.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Spatiotemporal downscaling of precipitation in regions of complex orography

R. Bordoy (1), P. Burlando (1)

(1) Institute of Environmental Engineering, ETH Zürich, Switzerland

Corresponding author's e-mail address: roger.bordoy@ifu.baug.ethz.ch

Session: Regional to local aspects

The coarse spatial and temporal resolution of current climate model outputs, even in case of the dynamically downscaled Regional Climate Models (RCMs), prevent them from resolving regional scale processes relevant for understanding the hydro-climatic response at the basin scale. Therefore, error corrections and further downscaling are necessary to make climate projections suitable for hydrologic applications and impact studies.

A new methodology of stochastic downscaling of climate model precipitation outputs to sub-daily temporal resolution and in a multisite and gridded frameworks is presented. The methodology is based on the reparametrisation for future climate of the Spatiotemporal Neyman-Scott Rectangular Pulses model. In order to generate future precipitation series accurately across a range of temporal scales, the reparameterisation procedure is carried out by estimating the model parameters using daily and hourly statistics, which are obtained by: i) applying to the daily historical statistics a factor of change computed from the control and future climate model outputs, and ii) rescaling the altered daily statistics according to the scaling properties exhibited by the historical raw moments. The methodology represents a robust, efficient and unique approach to generate multiple series of spatially distributed sub-daily precipitation scenarios by Monte Carlo simulation. It presents thus a unique alternative for addressing the internal variability of the precipitation process at high temporal and spatial resolution, as compared to other downscaling techniques, which are affected by both computational and resolution problems. The application of the presented approach is demonstrated for the Rhone catchment, a region of complex orography.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Understanding and modeling heat waves and droughts in the Euro-Mediterranean region

P. Drobinski[(1)]

(1) Institut Pierre Simon Laplace/Laboratoire de Météorologie Dynamique, CNRS & Ecole Polytechnique, Palaiseau, France

Corresponding author's e-mail address:
philippe.drobinski@lmd.polytechnique.fr

Session: Regional to local aspects

The Mediterranean basin has quite a unique character that results both from physiographic and climatic conditions and historical and societal developments. Because of the latitudes it covers, the Mediterranean basin is a transition area under the influence of both mid-latitudes and tropical variability. Because in such transition area, the Mediterranean basin is very sensitive to global climate change. Regarding on-going climate change, the Mediterranean area is considered as one major "hotspots" with strong warming and drying. The vulnerability of the Mediterranean population may thus increase with higher probability of occurrence of events conducive to heat waves and droughts which are among the most devastating natural hazards.

There is thus strong motivation to understand and model the Mediterranean climate system and specifically the processes at various time and spatial scales leading to heat waves and droughts, not only as separate processes within each Earth compartment, but as coupled mechanisms with feedback loops. Such issues are central to the HyMeX program (Hydrological cycle in the Mediterranean Experiment). This is indeed crucial to characterize how these processes will respond to climate change, in order to make decision on development of adaptation strategies to face risks related to changing climate.

The presentation will show results on the role of soil-moisture and vegetation feedbacks as well as of anthropogenic land cover change on heat waves and droughts as a prerequisite for mitigation strategy elaboration.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

A closer look on the Precipitation Change Signal over Switzerland

Andreas Fischer (1), Denise Keller (1,2), Jan Rajczak (3), Mark Liniger (1), Christof Appenzeller (1)

(1) Federal Office of Meteorology and Climatology MeteoSwiss, Zurich, Switzerland
(2) Center for Climate Systems Modeling, ETH Zurich, Switzerland
(3) Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

Corresponding author's e-mail address: andreas.fischer@meteoswiss.ch

Session: Regional aspects

Fundamental changes in the hydrological cycle are expected in a future warmer climate. This is of particular relevance for the Alpine region, as a source and reservoir of several major rivers in Europe and being prone to extreme events such as floodings. For Switzerland, the recent CH2011 probabilistic multi-model assessment based on the ENSEMBLES climate model matrix projects summer mean precipitation to significantly decrease by the end of this century. In winter and in the transition seasons, the models simulate both increases and/or decreases in mean precipitation. While in this recent scenario assessment seasonal mean changes were considered solely, some of the multifaceted characteristics of precipitation (changes) remained unanswered, such as changes in the temporal structure, precipitation type and rain intensity.

Here, we focus on these aspects of change using the ENSEMBLES models aiming at decomposing the seasonal mean change signals over Switzerland at the end of the century. We investigate multi-model changes of several precipitation parameters. In particular, total and convective precipitation data are analysed on daily resolution to infer intensity-frequency changes conditioned on the convective fraction. To study higher-intensity rainfall changes, hourly maximum precipitation data are used.

While mean intensity significantly increases in spring and fall north of the Alps, the mean summer drying is mainly an effect of a change in wet day frequency. In parallel, modeled hourly maximum precipitation is projected to significantly increase in all seasons with median changes of more than 10%, thereby also exceeding the change in mean wet day intensity. In the presentation we will further show that the drying signal in summer is pre-dominantly determined by changes in large-scale precipitation, while its convective counterpart remains relatively unaffected in the ENSEMBLES

models. This modeled rain type change goes in line with a change in the temporal wet-dry-sequence favouring the occurrence of long dry spells at the expense of short dry spells.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Forcing and evaluation of water-cycle models with observations: A new suite of spatial climate analyses for Switzerland

Christoph Frei

(1) Federal Office of Meteorology and Climatology MeteoSwiss, Zürich, Switzerland

Corresponding author's e-mail address: christoph.frei@meteoswiss.ch

Session: Regional to local aspects

Much of our inference on processes and sensitivities of the regional water cycle is indirect, because only few of the involved fluxes are observed. Regional climate models and soil water/runoff models are key instruments for the analysis, prediction and study of impacts, whereas observations of surface climate variables are needed for conditioning (e.g. forcing of hydrological models) or as a reference for model evaluation. An interesting data source for these purposes are spatio-statistical analyses of in-situ observations, framed into spatially comprehensive regular grids. This contribution gives an overview of a new suite of such grid datasets for the territory of Switzerland.

The suite encompasses datasets for three parameters (temperature, precipitation and sunshine duration), they exhibit a grid-spacing of 2 kilometers and expand over a 50-year period (1961-2010) at daily time resolution. The methods used for the construction of these datasets were designed separately for each parameter and, where possible and meaningful, they also integrate information from satellites and radar as a complement to station data. The presentation introduces the developments made to address effects of complex topography and it will depict results for challenging weather situations to illustrate advancements over existing datasets and methods. Particular attention will be given to uncertainties in the grid datasets and their role for applications. Along these lines, the contribution also presents results from stochastic simulations that frame uncertainties in an "observation ensemble", a promising alternative to classical "best estimates". The gridded datasets for Switzerland are regularly updated and are available from MeteoSwiss, free of charge for research.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Impact of Ocean Mesoscale Eddies on Local Rain

Ivy Frenger (1,2), David Byrne (1,2), Nicolas Gruber (2), Reto Knutti (3), Matthias Münnich (2), Lukas Papritz (1,4)

(1) Center for Climate Systems Modeling, ETH Zurich, Switzerland
(2) Environmental Physics, Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich, Switzerland
(3) Climate Physics, Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland
(4) Atmospheric Dynamics, Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

Corresponding author's e-mail address: ivy.frenger@env.ethz.ch

Session: Regional to local aspects

While sea surface temperature (SST) anomalies associated with ocean mesoscale eddies affect evaporation in a very direct manner, little is known about how these SST anomalies may influence rainfall and hence the net freshwater balance of the surface ocean. Ocean mesoscale eddies dominate ocean kinetic energy, several hundred to thousand mesoscale eddies populate the Southern Ocean at any time. They typically feature SST anomalies and the ocean is thought to force the atmosphere at the mesoscale in contrast to larger scales. Hence, one may expect ocean eddies to have a local impact on the atmosphere and to play a role in the overall coupling of the atmosphere and the ocean.
Here we show based on satellite observations of about 600,000 eddies occurring between 1997 and 2010, that ocean eddies significantly alter local atmospheric conditions: an SST anomaly of 1°C causes a mean change of wind of 5%, of cloud fraction of 3%, of liquid cloud water of 6% and finally of rain rate and probability of 8%. This impact on the atmosphere is striking given the fact that oceanic eddies constitute non-stationary SST fronts of moderate size relative to the much larger atmospheric low pressure systems which are constantly passing by at these latitudes. The spatial pattern of these changes is consistent with a mechanism labeled downward momentum mechanism in which the SST anomalies related to eddies modify the stability and thus turbulence of the atmospheric boundary layer. We will investigate the mechanisms and potential feedbacks of the atmospheric modifications on the ocean in a regional high-resolution coupled atmosphere-ocean model (COSMO-ROMS) over the South Atlantic.

Symposium The Water Cycle in a Changing Climate
ETH Zürich - July 1-2, 2013

Downscaling from global scales – how far down the regional to local scale can we go?

Clare Goodess

Climatic Research Unit, University of East Anglia, Norwich, UK

Corresponding author's e-mail address: c.goodess@uea.ac.uk

The growing demand for climate information to support climate change risk assessments and adaptation decision making is reflected in the current move towards formalization through initiatives such as the Global Framework for Climate Services and by projects such as CLIM-RUN. The emphasis on adaptation brings a particular need for information at regional to local scales. This poses both scientific and communication challenges in providing downscaled climate projections and accompanying guidance. Over the last decade considerable progress has been made in the development, evaluation and application of downscaling approaches – with European projects such as STARDEX (focused on statistical downscaling), PRUDENCE (focused on dynamical downscaling) and ENSEMBLES (using both statistical and dynamical downscaling) playing a leading role. These projects have demonstrated the value of multi-model ensembles at the regional scale and provided an opportunity to inter-compare different downscaling approaches. Thus they have helped to set the stage for the current CORDEX international initiative.

A number of European countries have drawn on these developments in order to produce national climate change projections of varying complexity. The UKCP09 probabilistic projections encompass both dynamical and statistical downscaling approaches but their methodological complexity raises a number of practical and communication issues for user communities. At the same time, they do not meet all user needs. Thus further work has been and is being undertaken – for example, using a combination of dynamical and statistical downscaling approaches to explore urban heat island effects.

User requirements for information about extreme events provide an illustration of the gaps and uncertainties that remain particularly with respect to extremes associated with the water cycle. This is reflected in the recent IPCC Special Report on Extremes.

All downscaling methods, including bias correction techniques, are inevitably based on assumptions about the stationarity of statistical relationships or parameterisations and also of model errors. The ability to reproduce present-day conditions can only be considered as a 'necessary but not sufficient' guide as to the robustness or reliability of future projections. Downscaling is also constrained by the skill of the larger-scale projections, i.e., of global climate models. Thus while it is always important to assess the added value of downscaling, it should be recognized that there are limitations to both the temporal and spatial scales at which information can be considered reliable and appropriate to provide to users.