1.7 EVALUATION OF TERRESTRIAL WATER STORAGE VARIATIONS IN REGIONAL CLIMATE SIMULATIONS OVER EUROPE USING BASIN-SCALE COMBINED WATER-BALANCE DATA

Martin Hirschi*, Sonia I. Seneviratne and Christoph Schär
Institute for Atmospheric and Climate Science,
Swiss Federal Institute of Technology (ETH), Zürich, Switzerland

1. MOTIVATION

Terrestrial water storage with its main components soil moisture, groundwater, snow and surface water plays an important role in the hydrological cycle. In particular, soil moisture is an essential element contributing to land-atmosphere coupling (e.g. Koster et al. 2004) and is known to be important for numerical weather prediction (e.g. Beljaars et al. 1996), seasonal forecasting (e.g. Koster et al. 2000), as well as climate modeling in general (e.g. Shukla and Mintz 1982; Milly and Dunne 1994). The soil moisture - precipitation feedback (e.g. Betts et al. 1996; Eltahir 1998; Schär et al. 1999) also demonstrates its relevance for local and regional climate. However, there are very few large-scale measurements of terrestrial water storage available, and therefore model results cannot be validated in most regions. In this study, we analyze an ensemble of regional climate models over Europe using a derived data set of monthly variations in terrestrial water storage.

2. METHOD

By combining the terrestrial and atmospheric water balances, the monthly changes in terrestrial water storage can be expressed as the sum of three terms (1):

$$\left\{\frac{\overline{\partial S}}{\partial t}\right\} = -\left\{\frac{\overline{\partial W}}{\partial t}\right\} - \left\{\overline{\nabla_H \cdot \vec{Q}}\right\} - \left\{\overline{R}\right\} \quad , \quad (1)$$

where S represents the terrestrial water storage of the area, W the column storage of atmospheric water vapor, $\vec{Q}$ the vertically integrated two-dimensional atmospheric water vapor flux and R the measured streamflow (assumed to include both the surface and the groundwater runoff of the area). The operator $(\nabla_H \cdot)$ represents the horizontal divergence, the overbar a temporal average (i.e. monthly means) and $\{\}$ a space average over the region.

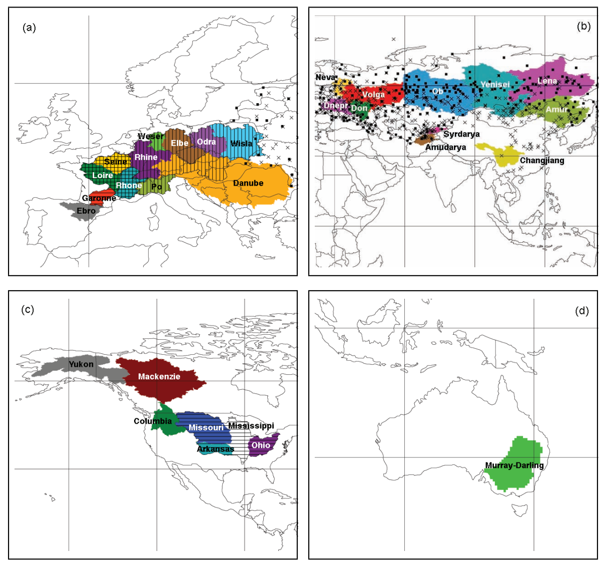

Figure 1: Available river basins in (a) Europe (vertically hatched: Central European basins; horizontally hatched: French basins), (b) Asia, (c) North America (horizontally hatched: whole Mississippi basin) and (d) Australia, as well as soil moisture measurement stations (×) and snow observations (■) used for validation of the water-balance data set (from Hirschi et al. 2005).

ERA-40 atmospheric reanalysis data was used for the terms $\left\{\overline{\partial W/\partial t}\right\}$ and $\left\{\overline{\nabla_H \cdot \vec{Q}}\right\}$, and conventional runoff data from the Global Runoff Data Centre (GRDC), the U.S. Geological Survey or from local sources for the term $\{\overline{R}\}$.

This approach has been developed over the Mississippi region (Seneviratne et al. 2004) and then applied to other major mid-latitude river basins in Europe, Asia, North America and Australia (see Figure 1) to form a diagnostic basin-scale water-balance data set of monthly terrestrial water storage variations (BSWB, Hirschi et al. 2005, data download: http://www.iac.ethz.ch/data/water_balance/).

The analysis covers the full 44-year time period (1958-

*Corresponding author address: Martin Hirschi, Institute for Atmospheric and Climate Science, ETH Zürich, Universitätsstrasse 16, 8092 Zürich, Switzerland, E-mail: martin.hirschi@env.ethz.ch

2001) of the ERA-40 reanalysis from ECMWF (European Centre for Medium-Range Weather Forecasts) but is temporally limited in some river basins depending on the availability of runoff data. Validation has shown good agreement between diagnosed estimates and observations of terrestrial water storage in Illinois (soil moisture, groundwater and snow observations) and Asia (soil moisture and snow observations, see Figure 1), both in terms of the mean seasonal cycle and its inter-annual variations.

The derived data set has illustrated its potential for the analysis and validation of regional climate models in the Rhine basin (van den Hurk et al. 2005). Here, this work is extended to other sub-continental scale domains in Europe (i.e. Danube, as well as compounds of French, Central and NE-European and Baltic Sea river basins, see Figure 2), where the terrestrial water storage variations of various regional climate models involved in the EU-project PRUDENCE (Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects, see http://prudence.dmi.dk/) is evaluated with the derived data set and direct observations of precipitation and runoff.

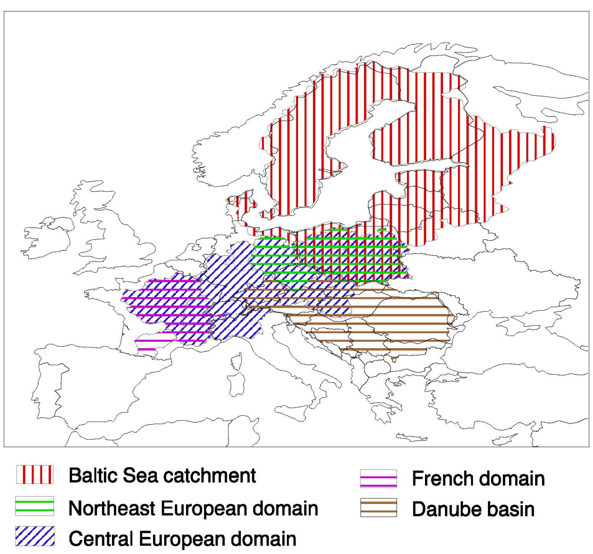

Figure 2: Analyzed European domains: Baltic Sea catchment, Northeast European domain (including the Wisla, Odra and Elbe river basins), Central European domain (Wisla, Odra, Elbe, Weser, Rhine, Seine, Loire, Rhone and Po river basins, as well as northern parts of the Danube basin), French domain (Seine, Loire, Garonne and Rhone river basins), and Danube river basin.

The analyzed models differ with respect to their physical and dynamical formulations, land use characteristics and computational domains. All models cover the major part of Europe at a resolution of approximately 50 km. They simulate a control climate (1961-1990), as well as an A2-scenario time slice (2071-2100) and are driven by the global model HadAM3H from the Hadley Centre (except ARPEGE: control run driven by observed sea-surface temperatures).

3. RESULTS

Results demonstrate that there are substantial differences between the models regarding the different components of the hydrological cycle.

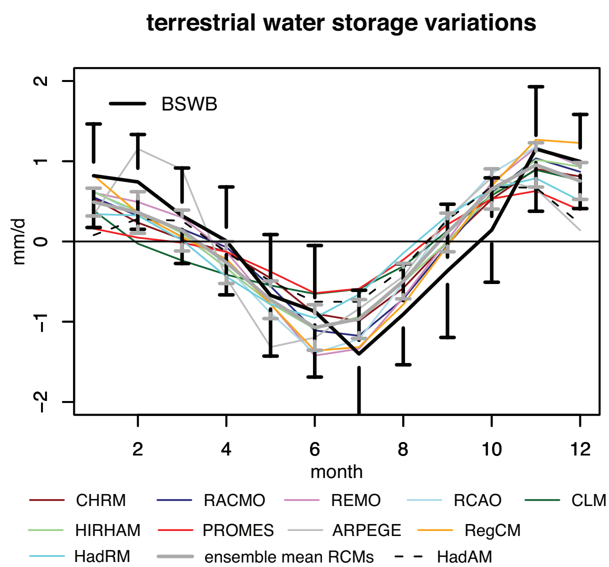

Figure 3: Modeled monthly terrestrial water storage variations compared against derived basin-scale water-balance data (BSWB) for the Danube basin and the period 1961-1990. The error bars represent the monthly standard deviations of the derived observations and of the ensemble mean of the regional models. The labels refer to the model names.

Figure 3 shows the comparison of PRUDENCE climate model runs against the derived water-balance data of terrestrial water storage variations and Figure 4 against observed precipitation from CRU in the Danube region. Several models underestimate the summer drying in terrestrial water storage, connected with an underestimation in precipitation and runoff (not shown). There are also considerable differences in winter (likely relating to the representation of snow in the models).

The inter-annual variations (i.e. the monthly standard deviations represented by the error bars) of the model ensemble mean are smaller than observed in both cases.

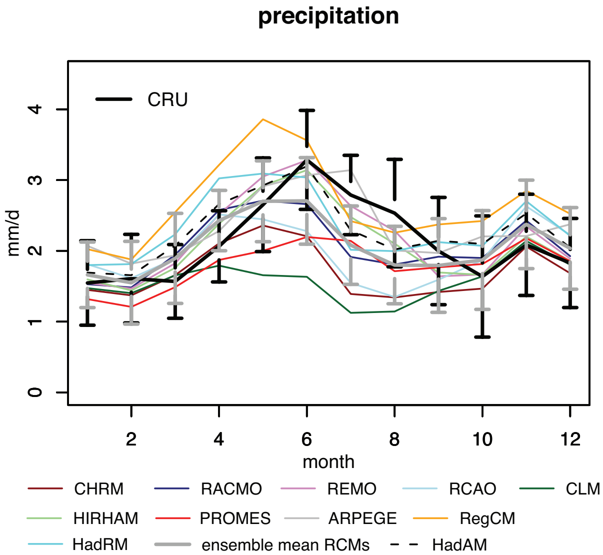

Figure 4: As Figure 3, but for modeled precipitation compared against observed CRU precipitation.

4. REFERENCES

Beljaars, A. C. M., P. Viterbo, M. J. Miller, and A. K. Betts, 1996: The anomalous rainfall over the United States during July 1993: Sensitivity to land surface parameterization and soil moisture anomalies. *Mon. Wea. Rev.*, **124**, 362–383.

Betts, A. K., J. H. Ball, A. C. M. Beljaars, M. J. Miller, and P. A. Viterbo, 1996: The land–surface atmosphere interaction: A review based on observational and global modeling perspectives. *J. Geophys. Res.*, **101**, 7209–7225.

Eltahir, E. A. B., 1998: A soil moisture-rainfall feedback mechanism. 1. Theory and observations. *Water Resour. Res.*, **34**, 765–776.

Hirschi, M., S. I. Seneviratne, and C. Schär, 2005: Seasonal variations in terrestrial water storage for major mid-latitude river basins. *J. Hydrometeor.*, in press.

Koster, R. D., P. A. Dirmeyer, Z. Guo, G. Bonan, E. Chan, P. Cox, C. T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, C. H. Lu, S. Malyshev, B. McAvaney, K. Mitchell, D. Mocko, T. Oki, K. Oleson, A. Pitman, Y. C. Sud, C. M. Taylor, D. Verseghy, R. Vasic, Y. Xue, and T. Yamada, 2004: Regions of strong coupling between soil moisture and precipitation. *Science*, **305**, 1138–1140.

Koster, R. D., M. J. Suarez, and M. Heiser, 2000: Variance and predictability of precipitation at seasonal-to-interannual timescales. *J. Hydrometeor.*, **1**, 26–46.

Milly, P. C. D. and K. A. Dunne, 1994: Sensitivity of the global water cycle to the water-holding capacity of the land. *J. Climate*, **7**, 506–526.

Schär, C., D. Lüthi, U. Beyerle, and E. Heise, 1999: The soil-precipitation feedback: A process study with a regional climate model. *J. Climate*, **12**, 722–741.

Seneviratne, S. I., P. Viterbo, D. Lüthi, and C. Schär, 2004: Inferring changes in terrestrial water storage using ERA-40 reanalysis data: The Mississippi river basin. *J. Climate*, **17**, 2039–2057.

Shukla, J. and Y. Mintz, 1982: Influence of land-surface evaporation on the earth's climate. *Science*, **215**, 1498–1501.

van den Hurk, B., M. Hirschi, C. Schär, G. Lenderink, E. van Meijgaard, A. van Ulden, B. Rockel, S. Hagemann, P. Graham, E. Kjellström, and R. Jones, 2005: Soil control on runoff response to climate change in regional climate model simulations. *J. Climate*, **18**, 3536–3551.