Prediction of Spring Elbe Discharge Based on Stable Teleconnections with Winter Global Temperature and Precipitation

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ABSTRACT

The predictability of Elbe streamflow anomalies during spring is examined using previous winter sea surface temperature (SST), temperature over land (TT), and precipitation (PP) anomalies. Based on running correlation analysis, the authors identify several regions where the spring streamflow anomalies are stable correlated with SST, TT, and PP anomalies from the previous winter. During the period 1902–71 the Elbe spring streamflow is stable correlated with previous winter PP anomalies from its catchment area, with TT anomalies from the Black Sea–Caspian Sea region, northwestern Europe, and northern Canada as well as with SST anomalies from the tropical Pacific, the Indian Ocean, and several regions of the North Pacific and the North Atlantic. An index based on winter SST, TT, and PP anomalies from these regions is highly significantly correlated with spring streamflow anomalies during this period. Based on SST, TT, and PP anomalies from stable correlated regions, a forecast scheme is developed and applied to predict spring streamflow anomalies during the last decades. The prediction based on this statistical scheme represents a marked improvement relative to the forecast based on teleconnection indices that are traditionally used for streamflow prediction.

1. Introduction

One of the most difficult issues of hydrology is how to appreciate the seasonal variability of rivers discharge. Water is a vital resource for humans as well as natural ecosystems. It has been established that changes in the cycling of water between land, sea, and air can have significant impacts on the environment, economy, and society through their effects on the water resources and their management (Arnell 1995, 1999; Arnell and Reynard 1996). The availability of water is greatly influenced by climate conditions that vary on seasonal, interannual, and decadal time scales. Characterization of hydrological variability on climatic time scales and identification of connections to climate forcings provide potential improvement for hydrological forecasts when these forcings are predictable or slowly evolving (Souza and Lall 2003; Croley 2003).

In recent years, interest in seasonal predictability of river discharge variability over Europe has increased markedly (Trigo et al. 2004; Rimbu et al. 2004, 2005). On seasonal time scales, anomalous atmospheric conditions are often linked with seasonal variations in river streamflow via variations in precipitation and temperature (Dettinger and Diaz 2000; Cullen et al. 2002). For example, spring and summer rainfall and temperature anomalies across Europe may be forecast from prior knowledge of varying boundary conditions such as anomalous sea surface temperature in the North Atlantic (Colman 1997; Colman and Davey 1999; Wilby 2001) and/or the tropical Pacific (Kiladis and Diaz 1989; Lloyd-Hughes and Saunders 2002; van Oldenborgh et al. 2000). Spring precipitation over central Europe is higher than normal following warm El Niño events.

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combined with lower SSTs west of Ireland (Lloyd-Hughes and Saunders 2002). Predictability is found to be higher in El Niño–Southern Oscillation (ENSO) extreme years (Brankovic et al. 1994), implying that at least part of the available skill can be attributed to the forcing from the tropical Pacific Ocean.

Two of the most important phenomena that influence streamflow variability are the North Atlantic Oscillation (NAO) and ENSO (Detttinger and Diaz 2000; Cullen et al. 2002). The indices of these large-scale climatic patterns are used as predictors for seasonal streamflow anomalies over Europe (Rimbu et al. 2005; Cullen et al. 2002; Trigo et al. 2004). Significant lag-correlations were identified between the NAO index and several river streamflow anomalies from the Iberian Peninsula (Trigo et al. 2004) and Tigris–Euphrates streamflow anomalies (Cullen et al. 2002). Rimbu et al. (2004) found significant lag-correlation between NAO and ENSO indices and the Danube streamflow. However, the association between NAO and ENSO and streamflow from the Iberian Peninsula (Trigo et al. 2004) and from southeast Europe (Rimbu et al. 2004; Cullen et al. 2002) is nonstationary; that is, the strength of the correlation between these two phenomena and streamflow anomalies has changed over time. These teleconnection patterns, though dominant on a large scale, often fail to provide forecast skill in individual basins (McCabe and Dettinger 2002; Grantz et al. 2005). The predictability of precipitation and streamflow from Europe using NAO and ENSO as predictors is limited due to nonstationarity. One way to improve the seasonal forecast for streamflow would be to identify stable predictors.

This paper describes a forecasting scheme for spring Elbe streamflow based on stable lag-correlation with temperature and precipitation indices. It is shown that, when climate indices from key regions are used together as predictors, the forecast improves compared to the case when they are used separately.

The present study is structured as follows. In section 2 we describe the datasets and methods used in this paper. In section 3 the main results are presented. The main conclusions and a discussion follow in section 4.

2. Data and methodology

a. Datasets description

The Elbe rises at an elevation of about 1400 m in the Giant Mountains on the northwest border of the Czech Republic. It is approximately 1100 km long and covers a catchment area of about 150,000 km² that is inhabited by 25 million people. It passes through the Czech Republic and Germany and discharges into the German Bight, North Sea (Fig. 1; this picture is placed at the disposal of the Potsdam Institute for Climate Impact Research and River Basin Community Elbe). The monthly time series of Elbe discharge, used in this paper, were recorded at Neu Darchau (53°14′N, 10°53′E), which is situated in the lower part of the Elbe catchment area (last gauging station), and were provided by the German Federal Institute of Hydrology (BfG) in Koblenz, Germany. The hydrological discharge regime is characterized by a pronounced seasonal cycle, the rising limb of which is situated between January and April and the falling one between June and September, the highest values being recorded in April. These high discharge values recorded in the spring months may be related to the melting of snow in the catchment area and the soil humidity.

Taking into account that the highest discharge values are recorded in the spring season (Fig. 2, upper right), we focused our analysis on this specific season, March–May (MAM). The spring Elbe streamflow for the period 1902–2001 is presented in Fig. 2. It shows strong interannual and decadal variations. The strongest positive discharge anomaly during the analyzed period occurred in 1940–42, a period dominated by strong climate anomalies (Brönnimann et al. 2004; Brönnimann 2007). From the monthly time series we computed the seasonal spring mean by averaging the months MAM. From the seasonal means we calculate the seasonal anomalies against the mean over the period 1902–2001. The time series were detrended and normalized by the corresponding standard deviation to obtain normalized anomalies of Elbe streamflow for MAM.

As predictors we used the following datasets:

1) The SST was taken from the Kaplan dataset (Kaplan et al. 1998). This dataset has a resolution of 5° latitude × 5° longitude and covers the period 1901–2001. We used the winter SST field—December–February (DJF). The time series were detrended and normalized by the corresponding standard deviation to obtain normalized anomalies of SST for DJF.

2) The temperature (TT) and precipitation (PP) was taken from the Climatic Research Unit (CRU) TS2.1 dataset (Mitchell et al. 2003). The datasets have 0.5° × 0.5° horizontal resolution and cover the period 1902–2001. The same data processing was used as for SST.

3) We also used the time series of the monthly teleconnection indices described in Table 1. The seasonal values of these indices were calculated using the same methodology as for the Elbe streamflow data but for the winter season (DJF).
Large-scale sea level pressure (SLP) patterns associated with the river streamflow variability are based on the updated version of the SLP dataset constructed by Trenberth and Paolino (1980). This dataset has 5° latitude × 5° longitude resolution.

b. Methodology

For the forecast scheme all datasets were separated into two parts: 1) the calibration period (1902–71) and 2) the validation period (1972–2001).

The forecast scheme for seasonal prediction of spring Elbe streamflow anomalies using SST, TT, and PP from the previous winter is based on a methodology similar to that used for seasonal prediction of Danube streamflow (Rimbu et al. 2005). The basic idea of this scheme is to use SST, TT, and PP anomalies from regions with stable teleconnections as predictors (Lohmann et al. 2005). However, in our study we have used a different criterion to define the stability of the correlation (Lohmann et al. 2005) and added new predictors, that is, the anomalies of TT and PP over land, comparative with previous studies (Rimbu et al. 2005). We correlate the spring streamflow anomalies with global SST, TT, and PP anomalies from the previous winter in a moving window of 31 yr. The correlation is considered to be stable for those grid points where spring streamflow and winter SST, TT, or PP anomalies are significantly correlated at the 90% level \(r > 0.24\) or 80% level \(r > 0.17\) for more than 80% of the 31-yr windows covering the period 1902–2002. The regions where correlation is positive and stable at the 90% (80%) level will be represented as red (orange) on a global map. The regions where correlation is negative and stable at 90% (80%) level will be represented as blue (violet). Such maps will be referred to in our study as stability correlation maps. The stability correlation maps derived in our study remain qualitatively the same if the significance levels that define the stability of the correlation vary within reasonable limits.

To better understand how the correlation stability...
maps are constructed. We present as an example the decadal variation of the correlation between spring Elbe streamflow and SST anomalies from several grid points (Fig. 3). The spring streamflow and winter SST from the 10.5°N, 140.5°W grid point are positively correlated for all 31-yr windows covering the period 1901–2002 and above the 90% significant level for more than 80% of the windows. The streamflow and SST from the grid point 5.5°N, 70.5°E is positive and above the 80% significance level for more than 80% of the windows (Fig. 3). Therefore, these grid points are stably correlated with streamflow and are represented on the stability map of the correlation as red and orange, respectively (Fig. 4a). The spring streamflow and SST from grid points 30.5°N, 70.5°W and 40.5°N, 170.5°E are negative and above the 90% and 80% significance level, respectively, for more than 80% of the windows. Also these grid points are stably correlated with streamflow and are represented on the stability correlation map as blue and violet, respectively (Fig. 4). On the contrary, the streamflow and SST from grid point 10.5°N, 55.5°W are significantly correlated for less than 80% of the windows, and therefore the correlation is unstable according to our criteria. Such a grid point appears in white color on the stability map of correlation (Fig. 4).

c. Model evaluation

Several methods are common to assess the skill of forecast models (i.e., Wilks 1995; von Storch and Zwiers 1999). We employ the percentage improvement in the rms error over a climatological forecast (RMSE$_{cl}$) and over persistence (RMSE$_{per}$). The RMSE skill measure

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is one of the most robust. Climatology is taken as the standardized long-term average prior to each year being forecasted, while persistence is taken as winter (DJF) Elbe streamflow standardized anomalies. We computed the skill score $S$ (Wilks 1995), defined as

$$S = 1 - \frac{\text{RMSE (forecast)}}{\text{RMSE (reference forecast)}},$$

where the reference forecast is either climatology or persistence.

The skill score is one for perfect forecasts, zero for forecasts no better than the reference forecast, and is unbounded below zero for forecasts that are worse than the reference forecast.

3. Stable teleconnections of the Elbe streamflow

a. Sea surface temperature

The stability correlation map between spring streamflow and winter SST anomalies from the grid points indicated in the upper-right corner of the figure. The correlation is plotted at the beginning of each 31-yr window. The first points represent the correlation between streamflow from 1902 to 1933 and SST from 1901/02 to 1932/33.

is one of the most robust. Climatology is taken as the standardized long-term average prior to each year being forecasted, while persistence is taken as winter (DJF) Elbe streamflow standardized anomalies. We computed the skill score $S$ (Wilks 1995), defined as

$$S = 1 - \frac{\text{RMSE (forecast)}}{\text{RMSE (reference forecast)}},$$

where the reference forecast is either climatology or persistence.

The skill score is one for perfect forecasts, zero for forecasts no better than the reference forecast, and is unbounded below zero for forecasts that are worse than the reference forecast.

Fig. 4. (a) Stability map of the correlation between spring flow and winter SST anomalies. Regions where the correlation is stable, positive, and significant at the 90% (80%) level for at least 80% of the windows are shaded red (orange). The corresponding regions where the correlation is stable but negative are shaded blue (violet). (b) First EOF of the SST indices (see Table 2 for definition). (c) Running correlation (31-yr window) between spring flow and PC1 of SST indices (upper panel) and spring flow anomalies (gray line) and PC1 (dark line) of winter SST from stable regions.

precipitation over Europe (Mariotti et al. 2002) were identified.

We consider that the SST anomalies from these regions represent stable predictors for Elbe spring streamflow anomalies. Based on the stability map we defined nine SST indices by averaging the normalized SST anomalies for the regions described in Table 2 (first column).

The first EOF of these indices (Fig. 4b), which explains 33.39% of the total variance, has a spatial structure consistent with the SST pattern identified in the stability map. The correlation between the first time
Hemisphere projects well onto the corresponding pattern and a small part of Siberia. The TT correlation pattern central and northern part of Europe, the Middle East, Amazonian domain, the northern part of Canada, the strong relationship between PP anomalies and river discharge over Europe (Dettinger and Diaz 2000). However, from Fig. 6a we can see that spring Elbe streamflow is stable correlated not only with NAO-related TT anomalies but also with TT anomalies from other regions. This suggests that other winter phenomena, not necessarily related with NAO, influence the spring streamflow anomalies also. For example, the stable correlation pattern from the northeastern part of South America could be related to ENSO (Marengo 1992; Ronchail et al. 2002), while those from northern North America could be connected with winter snow cover anomalies (Sobolowski et al. 2007).

Based on the stability map, we defined six TT indices by averaging the normalized TT anomalies for the regions described in Table 2 (second column). The first EOF computed on the basis of the indices defined above (Fig. 6b), which explains 40.20% of the total variance, has a structure coherent with the stability map. The correlation between the first time coefficient (PC1) associated with EOF1 and spring streamflow anomalies for a 31-yr moving window (Fig. 6c, upper part), for the period 1902–71, is significant at the 95% level (following the t test). The time series of PC1 shows variations similar with Elbe spring streamflow for the same period (Fig. 4c, lower part). The correlation between the two time series over the entire period (1902–71) is r = +0.56 significant at the 95% level.

The highest values of spring Elbe discharge during the period 1901–2002 are recorded in 1941 (Fig. 2), which is well predicted by PC1 of winter SST indices as defined above (Fig. 4c). This strong positive discharge anomaly can be related to the very strong El Niño event developing in that period (Brönnimann et al. 2004). Indeed, the SST anomaly map for the 1940/41 winter (Fig. 5a) shows strong anomalies in the regions stably correlated with spring streamflow (Fig. 4). Besides a strong Pacific–North American pattern that accompanies this El Niño event, significant positive sea level pressure anomalies are recorded in the Iceland region as well as negative sea level pressure anomalies over central and eastern Europe including the Elbe region (Fig. 5b). Such a circulation pattern is consistent with high winter precipitation anomalies over the Elbe catchment area during winter. These winter precipitation anomalies, which partly can be snow or ice, are likely to be responsible for the positive streamflow anomalies recorded in spring 1941.

b. Surface temperature over land

The stability correlation map between spring streamflow and winter TT (Fig. 6a) shows stable regions in the Amazonian domain, the northern part of Canada, the central and northern part of Europe, the Middle East, and a small part of Siberia. The TT correlation pattern associated with spring streamflow in the Northern Hemisphere projects well onto the corresponding pattern associated with NAO, consistent with a strong influence of winter NAO on spring streamflow anomalies in the Europe (Dettinger and Diaz 2000; Trigo et al. 2004). However, from Fig. 6a we can see that spring Elbe streamflow is stable correlated not only with NAO-related TT anomalies but also with TT anomalies from other regions. This suggests that other winter phenomena, not necessarily related with NAO, influence the spring streamflow anomalies also. For example, the strong correlation pattern from the northeastern part of South America could be related to ENSO (Marengo 1992; Ronchail et al. 2002), while those from northern North America could be connected with winter snow cover anomalies (Sobolowski et al. 2007).

Based on the stability map, we defined six TT indices by averaging the normalized TT anomalies for the regions described in Table 2 (second column). The first EOF computed on the basis of the indices defined above (Fig. 6b), which explains 40.20% of the total variance, has a structure coherent with the stability map. The correlation between the first time coefficient (PC1) associated with EOF1 and spring streamflow anomalies for a 31-yr moving window (Fig. 6c, upper part), for the period 1902–71, is also significant at the 95% level. The time series of PC1 and Elbe spring streamflow is shown in Fig. 6c (lower part). The correlation between the two time series, over the entire period, is r = +0.54 (significant at the 95% level).

c. Precipitation

For precipitation we identified just one significant stable region (Fig. 7a), which covers most of central and south Europe. The stable correlation between winter PP anomalies from this region and spring streamflow anomalies of the Elbe River is consistent with the strong relationship between PP anomalies and river discharge over Europe (Dettinger and Diaz 2000). However, the region of stable correlation is extended over a broad region of central and eastern Europe (Fig. 7a). The PP anomalies outside the catchment area are not stable correlated not only with NAO-related TT anomalies but also with TT anomalies from other regions. This suggests that other winter phenomena, not necessarily related with NAO, influence the spring streamflow anomalies also. For example, the stable correlation pattern from the northeastern part of South America could be related to ENSO (Marengo 1992; Ronchail et al. 2002), while those from northern North America could be connected with winter snow cover anomalies (Sobolowski et al. 2007).

Based on the stability map, we defined six TT indices by averaging the normalized TT anomalies for the regions described in Table 2 (second column). The first EOF computed on the basis of the indices defined above (Fig. 6b), which explains 40.20% of the total variance, has a structure coherent with the stability map. The correlation between the first time coefficient (PC1) associated with EOF1 and spring streamflow anomalies for a 31-yr moving window (Fig. 6c, upper part), for the period 1902–71, is also significant at the 95% level. The time series of PC1 and Elbe spring streamflow is shown in Fig. 6c (lower part). The correlation between the two time series, over the entire period, is r = +0.54 (significant at the 95% level).
necessarily directly related to spring streamflow anomalies. They can be related to SST or TT anomalies from the regions stably related with spring streamflow anomalies (Figs. 4 and 6). There are also some stable grid points over the west coast of the United States, but we will focus just on the European region.

The correlation coefficient for a 31-yr moving window between MAM streamflow and a precipitation index, defined on the region 40.5°–50.5°N, 0.5°–45.5°E, is shown in Fig. 7b. The correlation coefficient between MAM streamflow and PP index is $r = +0.50$ during the period 1902–71.

d. Combination of indices

To identify the most skillful predictors when considering the forecast scheme, we computed the EOF taking into account all of the indices defined above (SST + TT + PP). Beside the EOF analysis we also tried to develop a forecast model based on linear regression (not shown). We used a stepwise regression model in
order to identify the optimal number of indices to be used for the flow prediction. Taking into account that the results using the EOF analysis and the ones obtained using regression were almost similar, we have decided to present just the results for the EOF analysis.

The first EOF (Fig. 8a) explains 35.05% of the total variance. The correlation coefficient for the 31-yr moving window between the first time coefficient (PC1) corresponding to EOF1 and MAM streamflow is higher than when considering each index separately (Fig. 8b). The correlation coefficient for the 31-yr running window is significant at the 95% level, in contrast with the correlation between spring streamflow and winter NAO and Niño-3 indices. The correlation coefficient between spring streamflow and winter NAO (Niño-3) index, over the same period, is \( r = -0.27 \) (0.26). Furthermore, the PC1 is also a better predictor than the previous winter Elbe discharge (Fig. 8b, upper panel). We can conclude that PC1 is a better predictor for spring streamflow than winter NAO and Niño-3 indices as well as the previous winter Elbe discharge, especially when considering SST + TT + PP indices together.

Taking into account that other teleconnection patterns have also been found to have an important impact on the precipitation variability in the European region, we computed the correlation, in a 31-yr window, between Elbe spring anomalies and other teleconnection indices from the North Atlantic region, such as east Atlantic, east Atlantic/western Russia, Scandinavian, and Polar/Eurasian patterns (Barnston and Livezey 1987). The influence of these teleconnection patterns on the variability of precipitation and temperature in different regions in Europe was emphasized in different studies (Slonosky et al. 2001; Goodess and Jones 2002; Martin et al. 2004; Rodríguez-Puebla et al. 2001; Trigo 2006).

The correlation coefficients between Elbe streamflow and the wintertime series of these teleconnection indices are shown in Fig. 9. For this analysis we used just the period 1950–2001 owing to the lack of data before 1950. As in the case of NAO and Niño-3, the correlation is much smaller when compared to PC1. One reason that could explain this is these teleconnection patterns have weak projection on the precipitation field over the Elbe catchment area.

e. Potential predictability

Rimbu et al. (2005) showed that prediction based on SST identified in stable key regions improves compared to prediction based on NAO and ENSO indices.

Assuming that the regions of stable teleconnections established for the period 1902–71 do not change significantly for the period 1972–2001, we calculate the SST, TT, and PP indices for the region defined above and the corresponding PC1 successively, using the data from 1902–72, 1902–73, . . . , to 1902–2001. The last values of PC1 based on these updated winter SST, TT, and PP indices represent the streamflow anomaly forecast for the next spring. The result of the forecast is represented in Fig. 10. The predicted and observed spring streamflow anomalies are significantly correlated (\( r = 0.63 \)). The correlation between predicted spring streamflow anomalies based on winter NAO and Niño-3 indices is \( -0.16 \) and 0.17, respectively. Therefore, the prediction based on our statistical scheme is a marked improvement compared to prediction based only on NAO and Niño-3 indices.
To better assess the skill of the forecast, we made use of the rms error and skill score (Wilks 1995). The results of this analysis are shown in Table 3. From Table 3, it can be seen that, although our forecast model is not very accurate, it does exhibit a useful skill that is approximately 20% better than both climatology and persistence. In the case of NAO and Niño-3, the skill score shows negative values, which implies that the forecast based on them has less accuracy than climatology or persistence.

4. Discussion and conclusions

We have investigated the predictability of spring Elbe streamflow anomalies, using SST, TT, and PP anomalies from previous winters as predictors. It appears that the teleconnections with SST, TT, and PP are stable over various regions of the globe. Large areas in the central Pacific and North Atlantic, extending to the Red Sea, of winter SST anomalies are stably correlated with Elbe spring streamflow, consistent with previous studies related to the impact of SST anomalies on European climate (Dettinger and Diaz 2000; Mariotti et al. 2002; Rimbu et al. 2004, 2005). Several key regions where MAM streamflow is stably correlated were also identified in the global TT field. Key regions from the northern part of Canada, the Amazonian region, Europe, the Middle East, and a small part of Siberia are stably correlated with MAM streamflow. For precipitation the most stable region is the central and northern
part of Europe. Therefore, the spring Elbe streamflow anomalies are related not only with regional winter climatic anomalies but also with climate anomalies from several key regions located far from Elbe region. We have shown that the forecast skill improves when these remote predictors are considered in the forecast scheme.

The signal-to-noise ratio was increased by deriving the first EOF of the SST, TT, and PP indices calculated over the stable regions. The corresponding time series (PC1) is then used as a predictor for the streamflow anomalies. We also found that the correlation coefficient increases when we calculate the EOF using all the indices (SST + TT + PP), comparing to the case when we make the analysis separately on each of them. It has also been found that the prediction of spring stream-
flow anomalies based on the method described above is better than the prediction based on NAO and ENSO.

Winter precipitation in central Europe is mainly influenced by cyclonic activity carried by the prevailing westerlies. During the winter season the dominant patterns of climate variability over Europe that produce significant precipitation anomalies are the NAO and ENSO (Mariotti et al. 2002; Cullen et al. 2002). However, the impact of ENSO on European climate could be dependent on the strength of ENSO anomalies (van Loon and Madden 1981) or on the phases of ENSO. Pozo-Vázquez et al. (2005) showed that the impact of La Niña events on European climate is stronger than the impact of El Niño events. Strong La Niña events during autumn give a detectable signal in winter precipitation over Europe. Such winter precipitation anomalies are likely recorded as Elbe streamflow anomalies in the next spring, consistent with the stable correlation between spring streamflow anomalies and winter precipitation.

The enhanced predictability of spring streamflow can also be related to the relatively high predictability of spring precipitation from winter SST as discussed in recent studies (van Oldenborgh et al. 2000; Knippertz et al. 2003). Predictability is found to be higher in El Niño–Southern Oscillation extreme years (Branković et al. 1994), implying that at least part of the available skill can be attributed to the forcing from the tropical Pacific Ocean. Merkel and Latif (2002) suggested that an El Niño–related weakening of the North Atlantic mean meridional pressure gradient and a southward shift of the North Atlantic storm track induce wetter conditions over central Europe and the Western Mediterranean and colder temperatures over Scandinavia.

Our analysis shows that winter SST, TT, and PP anomalies from several key regions provide a significant source of predictability for Elbe spring streamflow. Also, a small, but significant, potential predictability was detected for summer streamflow anomalies using previous spring SST, TT, and PP anomalies from several key regions.

Our forecast scheme shows an improvement of about 20% when compared with climatology and persistence and major advantages relative to the forecast based on different teleconnection patterns.

We argue that a skillful prediction based on stable teleconnections can provide guidance for water management in the Elbe River catchment area, with consequences for the economy, agriculture, and hydroelectricity.

Acknowledgments. The authors are grateful to Dr. Mihai Dima for providing thoughtful comments. Thanks are due to the German Federal Institute of Hydrology (BfG) for supplying the datasets for the Elbe River discharge.

REFERENCES


**Table 3. Seasonal forecast skill score measured against climatology (second column) and against persistence (third column).**

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<th>$S_{\text{pers}}$</th>
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<td>PC1 (SST + TT + PP)</td>
<td>0.20</td>
<td>0.21</td>
</tr>
<tr>
<td>NAO</td>
<td>$-0.51$</td>
<td>$-0.49$</td>
</tr>
<tr>
<td>Niño</td>
<td>$-0.28$</td>
<td>$-0.27$</td>
</tr>
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*FIG. 10. Observed (black line) and predicted (gray line) spring flow anomalies for the period 1972–2001 based on winter (SST + TT + PP) anomalies from the stable regions.*