6th Study Conference on BALTEX

Międzyzdroje, Island of Wolin, Poland, 14 to 18 June 2010

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Detection and attribution of an anthropogenic effect on temperature and precipitation changes in the Baltic Sea catchment

Jonas Bhend[1] and Hans von Storch[2,3]

[1] Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland (jonas.bhend@gmx.ch)
[2] Institute for Coastal Research, GKSS Research Centre, Geesthacht, Germany
[3] Meteorological Institute, University of Hamburg, Germany

1. Introduction

Extensive evidence of a large-scale anthropogenic climate change has been collected during the last decades. In contrast, regional-scale climate change is less well understood. Therefore, this study aims at contributing to the discussion of an observable human influence on changes in near-surface temperature and precipitation in the Baltic Sea catchment using a formal detection and attribution analysis.

Climate change detection and attribution is a signal in noise problem. We try to decompose the observed change into the responses to external forcing mechanisms, the signals, and internal variability, the noise. Detection of an external influence is reached, if we can falsify the null-hypothesis that the observed change is due to internal variability alone with a given probability of error. Attribution of the observed change to a single forcing mechanism or a combination of forcing mechanisms is less straightforward. First, we have to show that the response to the proposed forcing mechanism is consistent with the observed change. Second, we have to be able to rule out all other (physically plausible) forcing mechanisms as causes of the observed change.

2. Observed change and simulated signals

We use gridded land station data to describe the observed change in the Baltic Sea catchment. The observed temperature change is expressed in anomalies of 5-yearly averages of seasonal, area-average temperature from 1953 to 2007 according to the CRUTEM3v dataset (Jones and Moberg, 2003) as shown in the left column of Figure 1. The observed change in precipitation is derived from the GPCC v4 reanalysis product (Schneider *et al.*, 2008, right column of Figure 1). The precipitation change is expressed in relative anomalies, thereby correcting – to first order – for observation errors such as wind-induced undercatch and evaporation losses. We use all four seasons combined in the analysis.

The climate change signals are derived from model simulations with global atmosphere-ocean general circulation models (AOGCMs) from the WCRP CMIP3 database (Meehl et al., 2007). We use the simulations with observed or reconstructed temporally varying forcings for the 20th century and extend these into the 21st century with simulations driven by emissions according to the SRES A1B emission scenario. The simulations are split in two subsets: 34 (29 for precipitation) simulations of 11 (10) models are driven with varying anthropogenic (at least greenhouse gases and sulfate aerosols) and natural (solar and volcanic) forcings in the 20th century. The multi-model ensemble mean of these simulations is used to estimate the ALL signal (thin solid lines in Figure 1). 20 simulations from 12 models are driven with anthropogenic forcings only in the 20th century. These are used to derive the ANT signal (crosses in Figure 1). Furthermore we use the pooled control runs from the 23 (22) models to estimate internal variability (not shown).

Additional analyses reveal that dynamical downscaling has only a minor effect on the representation of the response to anthropogenic forcing in area-average quantities in the Baltic Sea catchment (not shown). We note, however, that there are significant systematic model biases in the representation of the mean climate in this region likely due to misrepresented small-scale processes such as snow cover/snow melt and convective precipitation. Furthermore, we stress that the variability in area-average precipitation is underestimated in all the models analyzed. As a first-order correction, we inflate the variability in the models to better match the observations. Nonetheless, we recommend interpreting detection and attribution results for precipitation with caution.

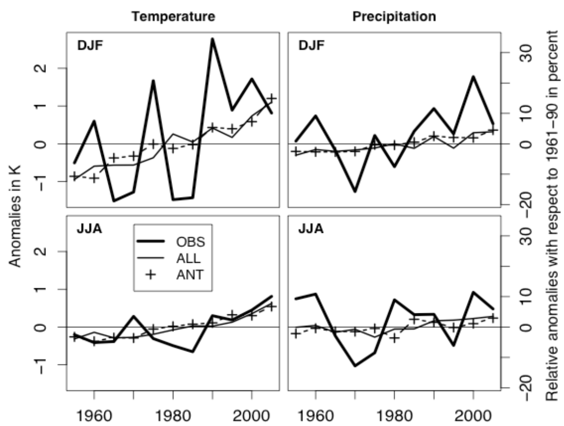

Figure 1. Time series of observed area-average temperature anomalies according to CRUTEM3v (left column, solid thick lines) and relative precipitation anomalies according to GPCC v4 (right column, solid thick lines) along with the climate change signals as derived from the simulations in the CMIP3 multi-model ensemble with anthropogenic forcing only (crosses) and anthropogenic and natural forcing (thin black lines)

3. Total least squares regression

We compare the observed and simulated temperature and precipitation changes using total least squares regression, a variant of optimal fingerprinting, as introduced by Allen and Stott (2003). We assume that the temporal evolution of the signal is known, but the scaling is uncertain. The regression model (equation 1) accounts for contamination of the observed change (y) and of the estimated signal (x) with noise from internal variability (ν_x and ν respectively).

$$y = a(x + \nu_x) - \nu \qquad (1)$$

We assume that the internal variability in the observations and the models have both the same covariance structure, the magnitude of the noise contamination in the signal (ν_x)

compared to the noise in the observations (ν), however, is reduced by the square root of the number of ensemble members used to estimate the signal.

In the linear regression framework, the detection and attribution problem can be expressed as follows: Detection of an external influence is achieved if the null-hypothesis $a = 0$ (i.e. the observed change is due to internal variability ν alone) can be falsified. The proposed signal x is consistent with the observed change y if the best-fit scaling a is not significantly different from 1 (see Figure 2).

4. Results and Discussion

We find a detectable external signal in seasonal temperature anomalies from 1953 to 2007 (Figure 2). Both the anthropogenic and the all-forcings signals are detected with 10% risk of error (i.e. zero scaling on these signals is inconsistent with the data). The best-fit scalings for the anthropogenic and all-forcings signals are very similar and close to unit scaling, indicating that either of the proposed responses is a plausible explanation for the observed change. From the small difference in scaling on the anthropogenic and all-forcings response follows, that the response to natural forcings is rather weak and unimportant in explaining the observed change or not well-known. This is further confirmed by using an estimate of the natural signal in the single-signal detection analysis. Unit scaling on the natural signal is inconsistent with the observations.

The natural signal, however, is computed as the difference between the all-forcings and anthropogenic signals. Therefore, the natural signal reflects not only differences in forcing mechanisms between the all-forcings and anthropogenic signals, but also the different set of models used to derive the former two signals. Additional analyses with model simulations driven by natural forcings only confirm that natural forcing alone is no plausible explanation for the observed temperature change in the Baltic Sea catchment (not shown).

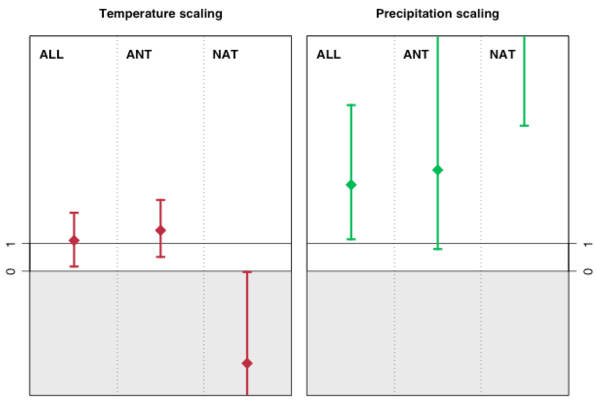

Figure 2. Scaling factors and corresponding confidence intervals of a single-signal detection analysis with time series of 5-yearly averages of seasonal area-average temperature and precipitation anomalies from 1953 to 2007. The signals are derived from simulations of the CMIP3 ensemble with all forcings (left), anthropogenic forcings (middle), and the difference between all and anthropogenic forcing signals (NAT, rightmost column). The diamonds indicate the best-fit scaling on the signals, vertical lines denote the 90% confidence interval about the best-fit scaling.

In contrast to temperature, detection results for seasonal precipitation in the Baltic Sea catchment are less consistent. Even though we detect external influences in the observed changes from 1953 to 2007 for all three different signals, we have to amplify the signals considerably to best fit the observations (Figure 2). As for temperature, the best-fit scalings on the anthropogenic and all-forcings signals are similar, thus indicating that the natural response as derived from the CMIP3 ensemble is unimportant in explaining the observed change in precipitation.

In contrast to temperature, the observed change in area-average precipitation is considerably stronger than simulated in AOGCMs. If we use signals from individual models, we have to amplify the anthropogenic and all-forcings signals by factors of three to ten to best fit the observations (not shown), the natural signals have to be amplified even more. This misrepresentation of observed precipitation changes in present-day climate models is a well-known fact (Zhang et al., 2007, Bhend and von Storch, 2008) and the limited skill in simulating changes in sea-level pressure and sea-surface temperature over Europe and the North Atlantic have been identified as possible causes (G. J. van Oldenborgh, pers. comm.).

5. Conclusions

We are able to detect an external influence on the observed temperature changes in the Baltic Sea catchment. Furthermore, the simulated response to anthropogenic forcing is consistent with the observed warming, the response to natural forcing is inconsistent. Attribution of the observed change to anthropogenic forcing requires the exclusion of all other plausible causes. Potentially important forcing mechanisms at the regional scale such as land-use changes and the indirect effects of aerosols, however, are not yet included in the models. Therefore, we are not able to formally attribute the observed change to anthropogenic forcing. Instead, we conclude that anthropogenic forcing is the dominant influence on the observed warming in the Baltic Sea catchment.

We are also able to detect an external influence on the observed precipitation changes. The simulated response to anthropogenic and natural forcings, however, is considerably (and in most cases also significantly) weaker than the observed change. We conclude that according to changes in area-average precipitation, neither the simulated response to combined anthropogenic and natural forcing, nor to anthropogenic or natural forcing alone provide plausible explanations for the observed change.

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