Open Boundary Conditions & Runoff for the ECOSUPPORT/INFLOW numerical simulations

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Introduction

This report briefly explains how the open boundary conditions (SSH) and the river runoff were computed in order to serve as forcing for the ECOSUPPORT and INFLOW simulations. Both simulations are forced by atmospheric climate scenarios, and it is based on these scenarios that both SSH and runoff are estimated. The method used in order to compute the SSH at the Kattegat boundary condition set in the RCO domain is very close to that suggested by *Gustafsson and Andersson* (2001), except the points on which the atmospheric pressure is taken are changed to some others that provide a better fit with the SSH observed in Kattegat during the period for which measurements are available. Runoff is computed based on the fluxes of precipitation and evaporation over the drainage basins of the Baltic Sea in the climate model, and a simple statistical correlation is used.

1 Open Boundary Conditions

SSH in Kattegat is estimated based on a meridional atmospheric gradient ΔP, taken as the difference of atmospheric pressure between a point located in the Netherlands and one point located in Norway. ΔP is computed on daily average basis, which means one can define ΔP_n as the meridional pressure gradient at day n and ΔP_{n+1} as the meridional pressure gradient at day $n+1$. The SSH η at day n is defined as :

$$\eta(n) = \alpha \Delta P(n) + \beta \Delta P(n-1) \tag{1}$$

The α and β coefficients are computed thanks a simple optimisation method in order to get the best possible fit with observations, and using a re-analysis for the atmospheric forcing. Using this approach proves to work and provide a good correlation with observations, but has a standard deviation that is too low in comparison with the observations. Plotting the probability density function (Figure 1)shows that this method under-estimates the ssh for highly positive ssh values, which are essential parts of the essential inflow mechanism for the Baltic Sea. In the meantime, the method over estimates low positive sea surface heights.

If applied, this SSH if used as a forcing dataset for the numerical configuration, the overall salinity of the Baltic Sea drops to small values on a very short time scale, even if no changes in runoff occur. We suspect this shortcoming of the estimated SSH comes from the fact atmospheric depressions are under estimated in the atmospheric model used as forcing, leading to an under estimation of the meridional pressure gradient variability.

In order to overcome this problem, we proceed to an extra treatment of the SSH signal, in order to give it a better statistical agreement with the observations. In order to explain this process, we shall consider two SSH signal, $\eta_{sim}(n)$ and $\eta_{obs}(n)$ taken as the simulated and observed SSH respectively for a given discrete period of time of N time steps, meaning $1 \leq n \leq N$.

We also define as $O(\eta_{sim}(n))$ and $O(\eta_{obs}(n))$ the sorted discrete function corresponding to $\eta_{sim}(n)$ and $\eta_{obs}(n)$, and a third function F that can be defined by the relation :

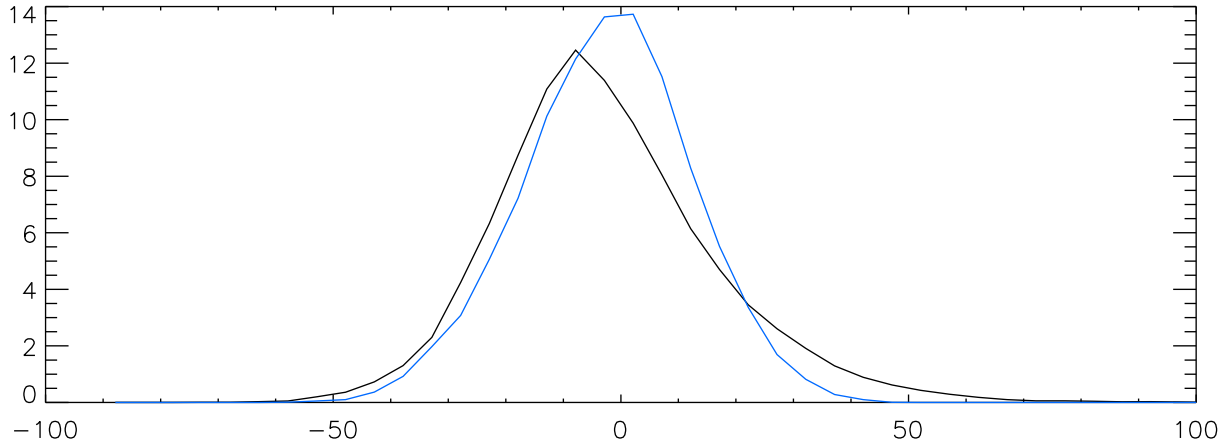

Figure 1: Probability density function of the sea surface height in Kattegat, observed ssh (black line) and re-constructed (purple line)

$$O(\eta_{obs}(n)) = F\left[O(\eta_{sim}(n))\right] \tag{2}$$

F is not known, but can be approximated with a polynomial function. In our case, we have chosen to approximate F with a 3rd degree polynomial function, which coefficients are estimated thanks to a simple optimisation method. Plotting $O(\eta_{obs}(n))$ against $O(\eta_{sim}(n))$ when F is used or not allows checking the positive effect of this simple function from a statistical perspective (Figure 2).

Once F is estimated, one defines a corrected $\eta_{sim}(n)$ as :

$$\eta_{sim-corr}(n) = F\left[\eta_{sim}(n)\right] \tag{3}$$

$\eta_{sim-corr}(n)$ has a variability that is much closer to that of $\eta_{obs}(n)$ and a slightly better fit in terms of correlation. Using it instead of $\eta_{sim}(n)$ proves to give much better results in terms of Baltic Sea salinity during present climate period. Figure 3 shows the fit is much better between the probability density function of the reconstructed and corrected ssh, than it was when using no correction.

It is for this reason that this formulation is chosen for estimating the SSH at the open boundary condition both in past, present and future climates, when SSH has to be estimated based on atmospheric numerical simulations.

2 Runoff

2.1 First Method

The estimation of runoff for the period 1960-2100 is based on a statistical method that relates the net water budget over the drainage area of the Baltic Sea. This net water budget is taken from atmospheric climate model simulations used as forcing for ECOSUPPORT & INFLOW simulations. Therefore, this method starts from a strong assumption, that is the net water budget over the Baltic Sea drainage area is realistic in these models. It must be made clear to users that the net water budget values have not been investigated, and are just used as such. However, the method will show clearly that it is mostly the annual variability of such fluxes that is used more than their values. So even if these values turned out not to be realistic from a mean point of view, the method should work as long as their variability remains realistic.

This method considers that the mean annual runoff from a given drainage area p at year n is correlated with the net water budget anomaly (in %) over this given water area for the given year and the one before:

$$R_{p,n} = b_p B_{p,n-1} + a_p B_{p,n} \tag{4}$$

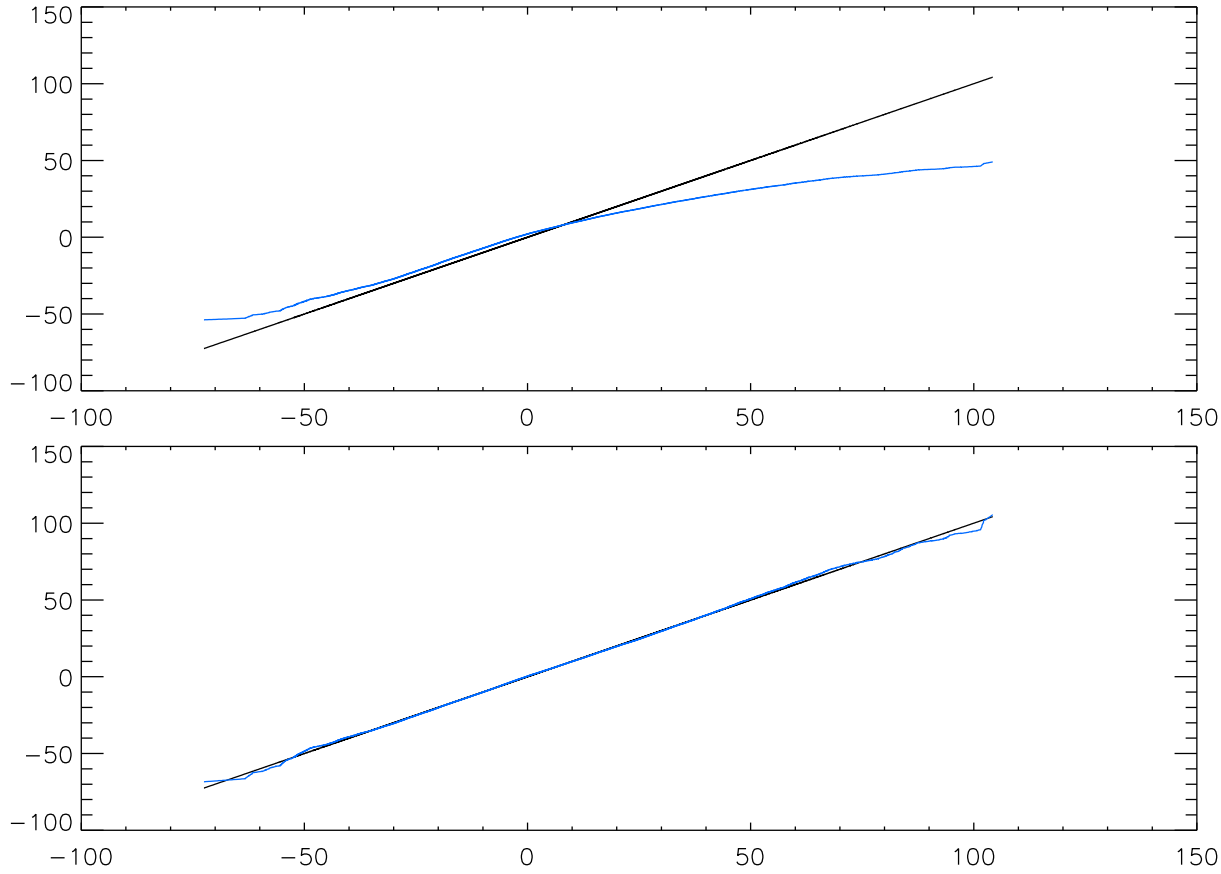

Figure 2: Reconstructed sorted Sea Surface Height against observed sorted Sea Surface Height. Upper figure shows the two sea surface heights when the F function is not used, lower figure shows the same thing but with the F function used in order to statistically correct the re-constructed Sea Surface Height

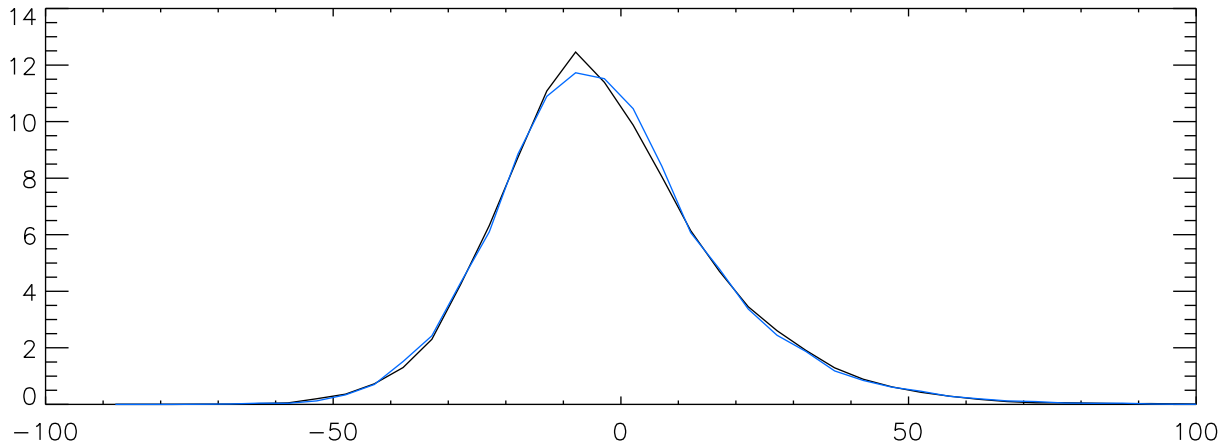

Figure 3: Probability density function of the reconstructed and statistically corrected ssh (in purple). The probability density function of the observed ssh is also shown (black line)

in which $R_{p,n}$ is the runoff for year n and for drainage area p, $B_{p,n}$ is the net water budget anomaly for year n and area p, and b_p and a_p are two coefficients. $B_{p,n}$ is computed as the anomaly (in %) of water budget for the area p and year n. In order for the anomaly to be computed one considers a mean water budget under present climate period, for which river runoff observations are available. It is based on the annual variability of $B_{p,n}$ than b_p and a_p are determined using an optimisation method, based on the annual runoff anomaly also for present climate period.
Five different basins are considered: Bothnian Bay, Bothnian Sea, Gulf of Finland, Baltic Proper and Kattegat. For each of, them the annual variability of runoff is computed based on this method. Regarding the seasonal variability, we have considered that a climatological seasonal cycle that is constant over the years for each given basin, but differs from one basin to another one in order to take into account the regional variability in terms of seasonal cycle. Of course, one could argue that the seasonal cycle in a different climate could also be different, but we believe this has little impact on the overall dynamics of the Baltic Sea which are mostly governed by inter-annual variability more than by seasonal one.

2.2 Results

We have applied this method for the period 1980-2006 in order to compute the correlation coefficients, and then used these coefficients for the period 1960-2006 which is the only period for which both runoff data and a re-analysis numerical simulation are available. Figure 4 show the results for this period. The results are consistent except for the Gulf of Finland and the Gulf of Riga. The total annual variability is fairly reproduced for the entire Baltic Sea although it is obvious the standard deviation in the re-constructed runoff is too small in comparison with the observations. Applying this method to scenario simulations gives an increase of runoff in the Baltic Sea of around 15%, not meaning that this scenario is realistic in any sense, but just that this is the consistent runoff increase that can be assumed based on the net water budget over land predicted by the climate model. The degree of uncertainty within the climate model itself is very likely to remain important.

2.3 Second Method

A second, and totally different, method was investigated by *Hansson et al.* (2010), in which some statistical predictors are used. We have applied this method to two different scenarios, and based on some basin ratios and interpolation, we have computed the monthly runoff for the basins the five basins already mentioned in the first method. We have not changed the values of the statistical predictors, therefore all the bias in terms of variability in the climate model compared with the original data of *Hansson et al.* (2010), are not taken into account. Therefore these results should be regarded as having a high degree of uncertainty.

This method shows a decrease of more than 10% when using Echam 5, and of 6% when using HadCM3, which is basically the opposite result as that obtained with the previous method. We can draw two remarks concerning this method:

- The method presented in *Hansson et al.* (2010) was based on the computation of some statistical coefficients, that are efficient into linking the inter-annual variability of temperature, zonal wind, meridional wind etc.... to that of runoff. However, the value of these statistical coefficients should depend much on that of the behaviour of the dataset that is used for their computation. The value of these coefficients is obviously closely related to the variability of the atmospheric data set that is used for their computation. The data set used by *Hansson et al.* (2010) has a certain variability that can be very different from that of the climate scenarios that we used. This method has just been tried, but in order to get something really consistent with the climate scenario that are used, we should have re-computed all the statistical coefficients, whereas we have just used those of *Hansson et al.* (2010).

- *Hansson et al.* (2010) use a method that is mostly linear, that does not take into account the non-linear interactions between statistical predictors, and that assumes that the climate system oscillates around a point of equilibrium. This assumption might not be valid if the climate system moves towards another point of equilibrium for which all the statistical coefficients should be

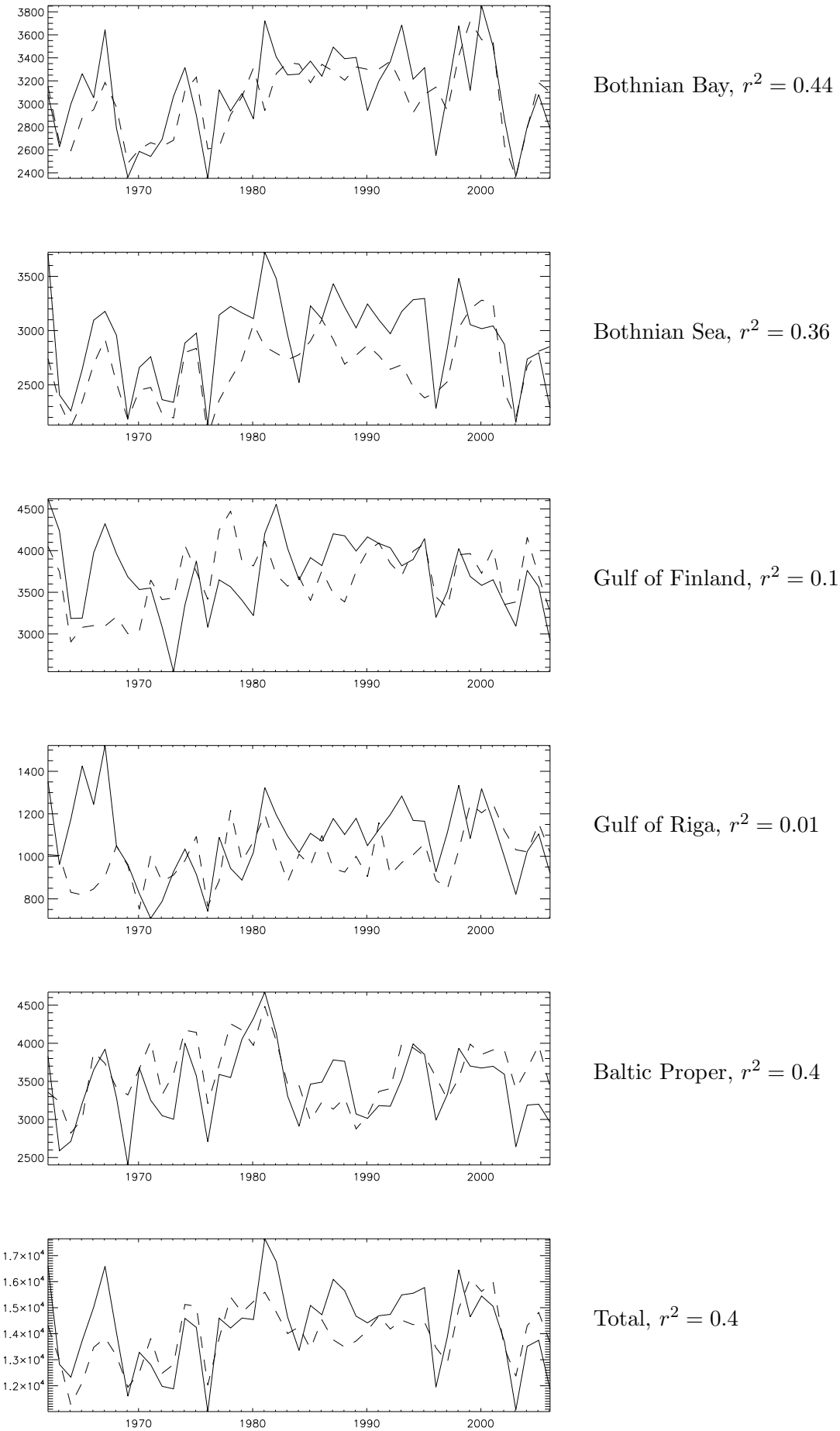

Figure 4: Inter annual variability for observed and re-constructed annual mean runoff in different basins of the Baltic Sea. Plain line shows the observed runoff, dashed line shows the re-constructed runoff

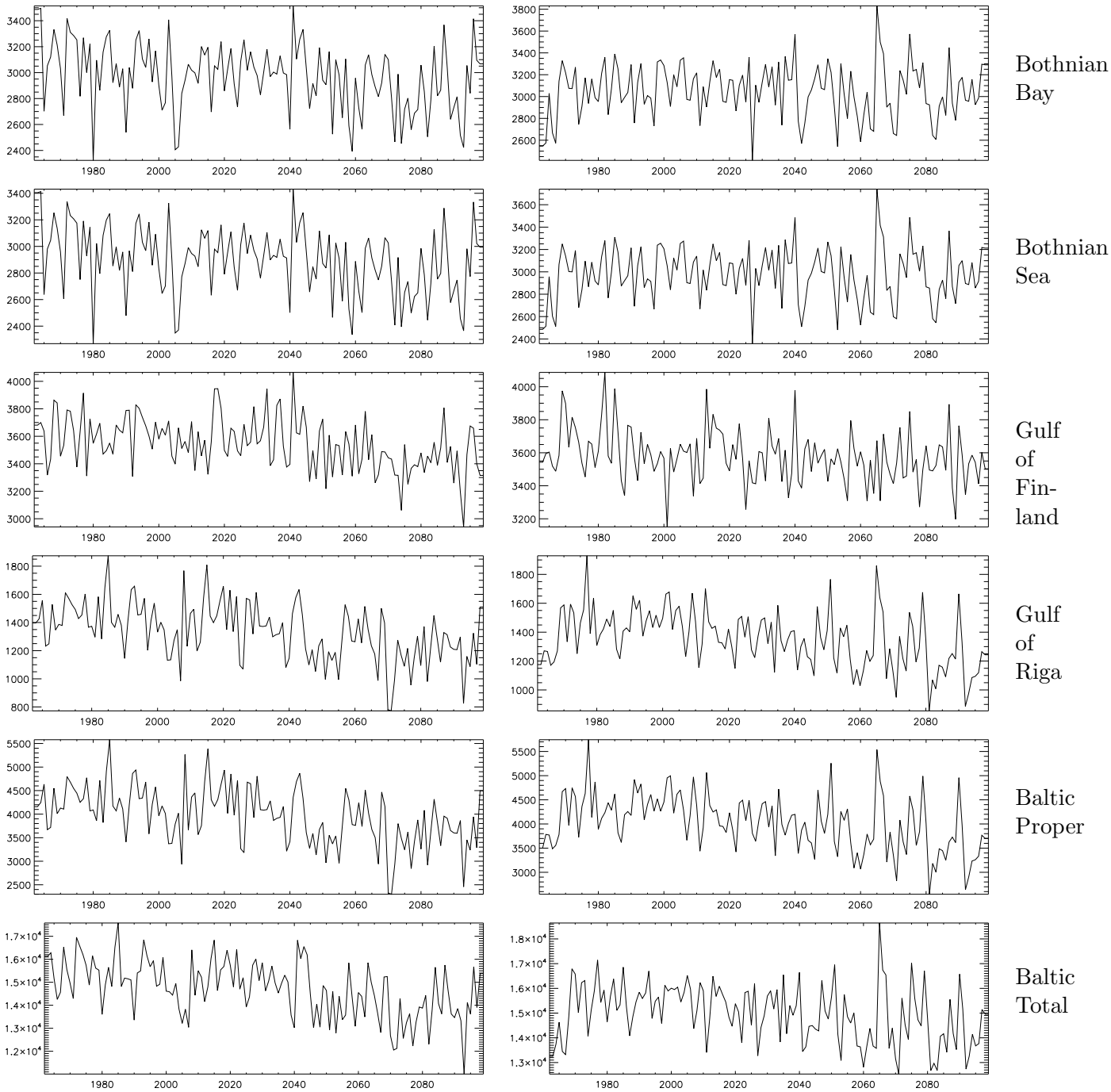

Figure 5: Inter annual variability of the constructed runoff using the method described in *Hansson et al.* (2010), and for two climate scenarios (Echam 5 & HadCM3). Based on a 30 years mean value, we have computed a decrease of 1775 $m^3.s^{-1}$ in Echam 5 simulations, and of 838 $m^3.s^{-1}$ in HadCM3 simulations.

re-computed. The same critics could be addressed to the first method that we have used, which was basically calibrated using a re-analysis. However, all the data that we used for the first method came from the same sub-model. That is only at the open boundary conditions of a zoom over the Baltic/North Sea area that a different forcing set was used, which means that over the Baltic Sea drainage basin, the atmospheric model grid size was always the same.

References

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Hansson, D., C. Eriksson, A. Omstedt, and D. Chen (2010), Reconstruction of river runoff to the baltic sea, ad 1500-1995, *Int. Jour. of Climatology*, *DOI: 10.1002/joc.2097*.