# Systematic Errors in the IPCC AR4 Model Simulations of Atmospheric and Terrestrial Components of the Arctic Ocean Freshwater Budget

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VOEIKOV MAIN GEOPHYSICAL OBSERVATORY

## 1. OBJECTIVES

(1) a synthesis of the most recent simulations of the arctic freshwater budget components for use in the IPCC AR4

(2) a determination of whether demonstrable progress has been achieved since the late 1990s in the simulation of the arctic freshwater budget.

## 2. MODELS AND OBSERVATIONAL DATA

- 21 models of the IPCC AR4 (20C3M)
- Arctic precipitation climatology: Bryazgin, 1976; Khrol, 1996
- Precipitation and evapotranspiration for the terrestrial watersheds of the Arctic: Serreze et al, 2003; Korzun, 1978
- ECMWF 40-year reanalysis (ERA-40)

## 3. SIMULATION OF THE RECENT CLIMATOLOGY

Two time periods were selected for the analysis: 1980-1999 and 1960-1989

Figure 1 compares the simulated annual mean precipitation for the period 1960-1989 against the corresponding climatologies of (a) ERA-40 and (b) Bryazgin. Among likely causes of the precipitation biases (and possibly of some differences between ERA-40 and Bryazgin shown at Figure 1c) are unresolved orographic effects due to insufficient spatial resolution of most models (too small an orographic enhancement of precipitation by the models' smoothed topography, e.g. on the western Scandinavia slope).

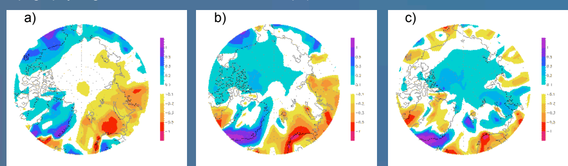
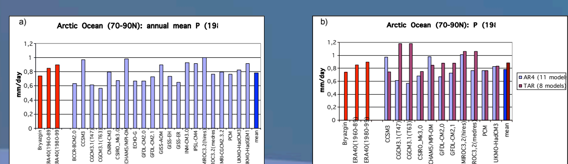



*Figure 1. Geographical distribution of the annual mean precipitation biases (mm/day): (a) 19-model-mean (1st ensemble member from each model) minus ERA40 (1960-1989); (b) 19-model mean minus Bryazgin ; (c) ERA40 minus Bryazgin.*

The across-model scatter is illustrated by Figure 2a, which shows annual mean precipitation averaged over the Arctic Ocean (70-90°N) from each IPCC AR4 model simulation and from the ERA-40 for the period of 1980-1999. The Bryazgin climatology is also shown in the figure. The model-derived estimates are generally within about 10% of the observational estimates.



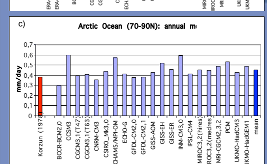




*Figure 2. Annual mean P and P-E over the Arctic Ocean (70-90N) (1980-99): (a) P in IPCC AR4 model simulations vs. an estimate based on observations by Bryazgin and ERA-40; (b) P in the subset of models allowing for a comparison between their IPCC AR4 and earlier TAR versions (the model means were calculated for the 8 TAR models and the 11 AR4 models); (c) P-E in IPCC AR4 model simulations vs. an observationally based estimate*

Compared to the previous (IPCC Third Assessment Report, TAR) generation of AOGCMs (Figure 2b), nine of the eleven AR4 models show more or less pronounced decrease of the annual mean arctic precipitation. Altogether, the multi-model ensemble mean of this subset shows a decrease of precipitation compared to the TAR simulation. The annual mean P-E over the Arctic Ocean simulated by the 21-models for the period 1980-1999 is generally higher than the existing observationally-based climatological estimate of Korzun (Figure 2c).

The 21-model mean seasonal cycle of P in the area 70-90°N is in qualitative agreement both with the ERA-40 for the time period of 1980-99, and with Bryazgin's climatology. While there are substantial differences among the individual simulations throughout the year (Figure 3a), the model mean varies seasonally almost entirely within the range between the observational data and the reanalysis. The amplitude of the model-mean seasonal cycle is smaller than that in the ERA-40 and Bryazgin. Compared to the IPCC TAR, the new models used for the IPCC AR4 appear to show an improvement, with a decrease of precipitation from fall to spring (Figure 3b).

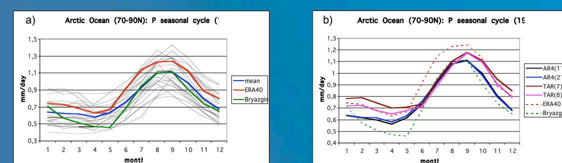



*Figure 3. P seasonal cycle over the Arctic Ocean (1980-1999): (a) 21 models (1st ensemble members compared against Bryazgin and ERA-40 (1980-1999); (b) model means for four subsets of models: 21 AR4 models, 11 AR4 models whose earlier versions were available from TAR, and the corresponding 8 TAR versions*

For the evaluation of model performance in simulating precipitation and evapotranspiration over the Arctic Ocean terrestrial watersheds, four major river basins were chosen: the Ob, the Yenisey, the Lena, and the MacKenzie. Figure 4 compares the seasonality of precipitation in the IPCC AR4 simulations with the observationally-based estimates and ERA-40 for the time period of 1960-1989. Although the simulated precipitation amounts clearly vary among the models, particularly in summer, most models qualitatively capture a realistic seasonal course of the precipitations in all four basins, which are characterized by summer maxima and winter minima.

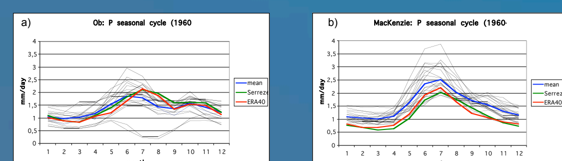



*Figure 4. P over Arctic Ocean terrestrial watersheds (1960-89): a) the Ob; b) the MacKenzie*

Quantitatively, compared with the estimates by ERA-40 and by Serreze et al., the 21-model mean (as well as the 19-model mean with the two GISS models excluded) shows an underestimate in summer in the Ob basin and an overestimate either in some seasons or throughout the year in the other three river basins. Among the problems responsible for the simulated precipitation biases and the inter-model scatters, the most suspicious are atmospheric large-scale circulation biases in winter and the variety of both atmospheric convection and land hydrology schemes employed by the AR4 AOGCMs. In the annual mean, the models show outstanding skill in producing precipitation in these river basins (Figure 5).

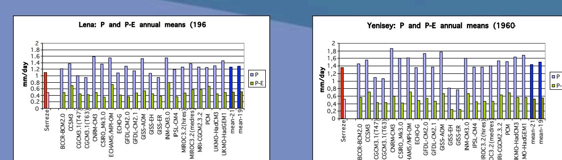
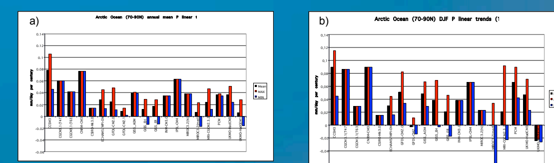



*Figure 5. Annual mean P and P-E over the Lena and the Yenisey watersheds compared to observational estimates by Serreze et al. for the period 1960-1989*

## 4. SIMULATION OF THE 20TH CENTURY VARIABILITY AND TRENDS

Figure 6a shows the 20th century precipitation linear trends over the Arctic Ocean (70-90°N) in ensemble simulations with each of 21 models. With the exception of 3 models, all individual model ensemble members have positive 20th century trends in the arctic annual mean precipitation. All model ensemble means without exceptions are positive. However, the 20th century trend of arctic precipitation is characterized by a pronounced seasonality: while the winter arctic precipitation shows tendencies similar to the annual means (Figure 6b), the summer precipitation does not demonstrate any systematic change through the 20th century). Unfortunately, the successful simulation of the area-averaged annual mean P-E evolution is not a robust feature of any model or any basin. A more robust feature of the temporal variability of P-E over the Arctic Ocean terrestrial watersheds appears to be the generally positive trends of this variable over the last third of the 20th century. Figure 6c shows the linear trends simulated in all ensemble members from each model for the period 1965-1999 over the entire terrestrial watershed draining into the Arctic Ocean.



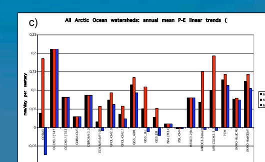




*Figure 6. Precipitation linear trends (mm/day per century) in all model ensemble members: maximum (MAX) and minimum (MIN) values for each model ensemble, and values for the ensemble means (Mean) over the Arctic Ocean (70-90°N) for 1900-1999: (a) annual mean; (b) DJF; (c) P-E linear trends (mm/day per century) in all model ensemble members: maximum (MAX) and minimum (MIN) values for each model ensemble, and values for the ensemble means (Mean) over the entire Arctic Ocean terrestrial watershed for 1965-1995.*

## 5. CONCLUSIONS

- Compared to the individual simulations, the multi-model ensemble means of precipitation showed reasonable agreement with available observations
- In spite of the observational uncertainties, it appears that the models still tend to oversimulate area averaged precipitation over major river basins draining into the Arctic Ocean. Geographically, the AR4 model-mean precipitation biases in the Arctic and sub-Arctic have retained their major patterns, which are, at least partly attributable to the insufficiently resolved local orography, as well as to biases in large scale atmospheric circulation and sea-ice distribution.
- The P-E over major terrestrial watersheds, which provides a measure of the river discharge into the Arctic Ocean, generally is also slightly oversimulated.
- Compared to the previous (TAR) generation of AOGCMs, there are some indications that models as a class have improved in simulations of the arctic precipitation; in particular, the model-mean bias is well within the range of uncertainty of the observational estimates, and the number of models reproducing the key characteristics (mean, seasonality, trends) of arctic precipitation has increased since TAR. At the present time, it is too soon to specify what particular improvements in model physics or/and numerics and resolution are responsible for this progress. Hopefully, ongoing analysis – and, more importantly, controlled experiments with model resolution, cloud parameterizations, treatment of land-surface processes, sea-ice parameterizations, and other process formulations –will help to sort out the possible causes in the coming years.

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