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Modelling global fresh surface water temperature

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Temperature directly determines a range of water physical properties including vapour pressure, surface tension, density and viscosity, and the solubility of oxygen and other gases. Indirectly water temperature acts as a strong control on fresh water biogeochemistry, influencing sediment concentration and transport, water quality parameters (e.g. pH, nitrogen, phosphor, dissolved oxygen), chemical reaction rates, phytoplankton and zooplankton composition and the presence or absence of pathogens. Thus, in freshwater ecosystems the thermal regime affects the geographical distribution of aquatic species through their growth and metabolism, tolerance to parasites, diseases and pollution and life history in general.

Previous attempts to model water temperature can be divided into statistical methods establishing regression-type relationships between water and air temperature and physically-based deterministic modelling of water flow and the energy balance. Physically-based models have the advantage that they are robust in light of changes in flow regime, river morphology, radiation balance and upstream hydrology. Such models are therefore better suited for projecting the effects of global change on water temperature. Till now, physically-based models have only been applied to well-defined fresh water bodies of limited size (e.g., lakes or stream segments), where the numerous parameters can be measured or otherwise established, whereas attempts to model water temperature over larger scales has thus far been limited to regression type of models.

Here, we present a first attempt to apply a physically-based model of global fresh surface water temperature. The model adds a surface water energy balance to river discharge modelled by the global hydrological model PCR-GLOBWB. In addition to advection of energy from direct precipitation, runoff and lateral exchange along the drainage network, energy is exchanged between the water body and the atmosphere by short and long-wave radiation and sensible and latent heat fluxes. Also included are ice-formation and its effect on heat storage and river hydraulics

We used the coupled surface water and energy balance model to simulate global fresh surface water temperature at daily time steps on a 0.5x0.5 degree grid for the period 1970-2000. Meteorological forcing was obtained from the CRU data set, downscaled to daily values with ECMWF ERA40 re-analysis data. We compared our simulation results with daily temperature data from rivers and lakes (USGS, limited to the USA) and compared mean monthly temperatures with those recorded in the GEMS data set. Results show that the model is able to capture well the mean monthly surface temperature for the majority of the GEMS stations both in time as well as in space, while the inter-annual variability as derived from the USGS data was captured reasonably well. Results are poorest for the arctic rivers, possibly because the timing of ice-breakup is predicted too late in the year due to the lack of including a mechanical break-up mechanism. The spatio-temporal variation of water temperature reveals large temperature differences between water and atmosphere for the higher latitudes, while considerable lateral transport of heat can be observed for rivers crossing hydroclimatic zones such as the Nile, the Mississippi and the large rivers flowing into the Arctic. Overall, our model results show great promise for future projection of global fresh surface water temperature under global change.