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Subsurface hydro-thermal regime and the atmospheric hydroclimate by a climate model

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The phase change process (freezing/ thawing) under the ground surface is an important element of the climate system in the cold regions. Using the modeled process of different complexity, the representation and impacts of the freezing/thawing ground on large scales have been evaluated extensively since the late 1990s in the Global Climate Models or, more recently, Earth System Models. One of the motivations for those studies lied in more plausible evaluation of the projected change of the climate in the context of global warming, and its impact. At an earlier stage, freezing/thawing process was expressed indirectly (e.g. via empirical or analytical relationship with the surface air temperature), but later on, the physically more realistic implementation in both thermal and hydrological perspective were used to enable more quantitative examination of the effects. Those considerations included physical processes (unfrozen water below the freezing point), and snow and soil physical characteristics (thermal conductivity, heat capacity; inclusion of organic layers, deeper soil column). The impacts of those improvements in the subsurface processes, values and settings on the modeled atmospheric hydroclimate were examined, with a special focus on their seasonality and geographical characteristics.

The used numerical model is the atmospheric component of the CCSR/NIES/FRCGC MIROC4.0 coupled Atmosphere-Ocean global climate model (AOGCM), and the physical terrestrial scheme, MATSIRO. On-line atmospheric experiments were performed at the horizontal resolution of Triangular 42 truncation (T42; ca. 2.5° by 2.5°), and forced by the monthly climatological sea surface temperature and sea ice concentrations derived from the observations for the period 1981-2000.

The controlled factors in the set of the experiments were 1) hydro-thermal parameterizations, 2) soil column depth (5-layer 4-m vs. 12-layer 100-m), and 3) presence or absence of top organic layers (TOL). All the model experiments were run for 20 years, forced by the climatological sea surface temperature and sea ice concentrations derived from the 1981-2000 period, after 150-year spin-up for the subsurface regime. The last 9 years were taken for the analysis.

Different complexity of the subsurface hydro-thermal physics simulated different near-surface thermal states and seasonality. The refined physics showed warmer summer and cooler winter. The difference was most apparent in high latitudes; surface air temperature increased about 2°C in summer (zonal average, only over land), and decreased by about 5°C in winter. The improved physics and the presence of the top organic layer kept more ground ice during the warmer seasons. The total amount of soil moisture (i.e. soil wetness), however, did not change by the change of the physics. This helped mitigating the unrealistically fast and large flux of heat within the ground and at the interface between the atmosphere and the land surface, and fed back to the change in the subsurface thermal regime (e.g., active layer depth, or length of ground freezing), and affected the seasonality. It also led to improvement of the cumulative temperature indices for the atmospheric forcing in the warm and cold season (e.g. Thaw and Freezing Index).

. The difference in the near-surface thermal state in high latitudes also affected snow accumulation in winter[U+FF0C]earlier and larger for the finer physics, although precipitation did not vary largely except in the lower latitudes, at the southern flank of the Tibetan Plateau, where large precipitation differences were found during the summer monsoonal period, leading to a contrast between wetter Tibetan Plateau and drier coastal China.

Land-average total annual runoff did not vary greatly between integrations at all latitudes; however, its seasonal distribution showed large difference. During the melting season, high-latitude runoff was greater for the finer physics due to shallower active layer, whereas it was smaller in summer because of a larger amount of soil moisture removed to the atmosphere by stronger evapotranspiration. Surface heat fluxes were also affected: both sensible and latent heat fluxes to the atmosphere were stronger from spring to early summer for the refined physics, due to larger near-surface water storage by ground ice and less penetration of heat to the ground by organic layer, resulting in a warmer near-surface air. From autumn to winter, higher heat conductivity of ice enhanced downward sensible heat flux (i.e., from the atmosphere to the ground), leading to a cooler air.

Seasonality (the seasonal amplitudes) of the near-surface hydroclimate showed sensitive to the subsurface hydro-thermal regimes, whose reproduction depends highly on employment of the realistic physics and physical property values. One of the implications is potential need for recalibration of surface heat budget in the climate models with the realistic subsurface physics. Vegetation/eco-system modeling will also need to take those into account for future development.