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Vegetation Type is an Important Predictor of the Arctic Terrestrial Summer Surface Energy Budget

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The terrestrial Arctic is subject to extreme climatic changes including increases in temperature and changes in precipitation patterns. At the heart of these developments lie changes in the land surface energy budget (SEB), which couples important earth system processes including the carbon and water cycles. However, despite the importance of the SEB, uncertainties in predictions of high-latitude SEBs persist, specifically for the SEB-components sensible and latent heat fluxes.

These uncertainties have in part been attributed to insufficient representation of Arctic vegetation in land surface components of Earth system models. However, to date, a quantitative understanding of the relative importance of Arctic vegetation for the SEB compared to other important SEB-drivers is missing.

Here we harmonize *in situ* observations from regional and global monitoring networks and provide a quantitative, circumpolar assessment of the magnitude and seasonality of observed SEB-components over treeless land >60°N in the time period 1994-2021. Using a variance partitioning analysis, we identify vegetation type as an important predictor for SEB-components during Arctic summer, in comparison with other SEB-drivers including meteorological conditions, snow cover duration, topography, and permafrost extent. Differences among vegetation types are especially high for mean summer magnitudes of sensible and latent heat fluxes, where they reach up to 8% and 9% of the potential incoming shortwave radiation, respectively. Our comparison with SEB-observations across glacier sites show that importantly, these differences among vegetation types are of similar magnitude as differences between vegetation and glacier surfaces. In our seasonality synthesis we find that net radiation (Rnet), sensible (H) and ground (G) heat fluxes have

an unexpected early start of summer-regime (when daily mean values > 0 Wm^{-2}), preceding the end of snowmelt by 56, 33, and 39 days, respectively. An elevated variability among vegetation types in the estimated onset (and end) dates of net positive Rnet and H (and G) relative to snowmelt (and onset) date, suggests that vegetation types differentially affect the distribution, trapping and density of snow cover, with important consequences for the cumulative energy fluxes from and to the atmosphere. Finally, we find that long-term, year-round SEB data series of Arctic tundra are still very scarce, especially in the Arctic regions of Eastern Canada and Western Russia.

In conclusion, we provide quantitative evidence of the importance of vegetation types for predicting Arctic surface energy budgets at circumpolar scale. We highlight that substantial differences among vegetation types are not only found for mean magnitudes but also the seasonality of surface energy fluxes. We contend that the land surface components of Earth system models should account for Arctic vegetation types to improve climate projections in the rapidly changing terrestrial Arctic.

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