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Patterns of North American ground surface warming from well temperature logs and comparison with observational and proxy surface temperature histories

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North American precise well temperature logs, sampled from 30 - 82º N, show evidence of extensive ground surface temperature (GST) warming ($>$1º C) beginning in some regions as early as the 18^{th} century (central-eastern Canada and eastern U.S.A) while in other regions as late as the 20^{th} century (mid-western Canada and U.S.A. Great Plains, Canadian Arctic and Alaska) However, patterns of cooling or change less than 0.5º C are typical for large regions of the south western U.S.A. and some eastern coastal areas of the continent. There is large variability in GST warming and cooling patterns. The average amplitude of GST warming is 0.95º C (standard error 0.05º C, N = 504 wells) beginning 230 years ago (SE = 8.5 years). Average GST warming, as derived from well temperatures, is approximately 0.4º C greater than surface air temperature (SAT) warming as derived from published proxy sources as well as observational records over the same period. This confirms published discrepancies found between well temperature and tree-ring temperature reconstructions. When GST warming magnitudes are combined into latitudinal groups (70 - 82º N, 60 - 70º N, 50- 60º N and south of 50º N), warming in the most southerly group is significantly less than that observed to the north. The initiation of GST warming began between 100 and 300 years ago, depending on region. There is a significant spatial trend to later warming onset in the north. A comparison of SAT warming patterns from observations with GST warming patterns from well temperature logs for the most recent 80 years shows that spatial correlation exists in some regions. This strongly suggests the influence of other forcing factors on GST change, such as changes in snow cover, latent heat, and

land-use. However, the close association between GST and SAT warming magnitudes in regions of exceptionally high warming (Canadian Prairies and U.S.A.Great Plains) indicates that surface temperature is the forcing responsible for the majority of the observed deviation of temperature with depth.