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Isaksen, K., P. Holmlund, et al. (2001). "Three deep alpine permafrost boreholes in Svalbard and Scandinavia." Permafrost and Periglacial Processes **12**(1): 13-26.

Isaksen, K., J. L. Sollid, et al. (2007). "Recent warming of mountain permafrost in Svalbard and Scandinavia." Journal of Geophysical Research-Earth Surface **112**(F2): -.

[1] Three deep boreholes (≥ 100 m) in mountain permafrost were recently drilled in Svalbard (Janssonhaugen) and in Scandinavia (Tarfalaryggen and Juvvasshoe) for long-term permafrost monitoring. These holes form part of a latitudinal transect of boreholes in permafrost through Europe, established by the Permafrost and Climate in Europe (PACE) project. Six-year thermal time series data collected from the three boreholes are presented. These data provide the first opportunity for temporal trends in permafrost temperatures in Svalbard and Scandinavia to be analyzed. Results show that the permafrost has warmed considerably at all three sites. Significant warming is detectable down to at least 60 m depth, and present decadal warming rates at the permafrost surface are on the order of 0.04 degrees-0.07 degrees C yr⁻¹, with greatest warming in Svalbard and in northern Scandinavia. The present regional trend shows accelerated warming during the last decade.

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Juliussen, H. and O. Humlum (2008). "Thermal Regime of Openwork Block Fields on the Mountains Elgåhogna and Sjølen, Central-eastern Norway." Permafrost and Periglacial Processes 19(1): 1-18.

The lack of simple mountain permafrost distribution models taking snow depth and site-specific factors into consideration led us to test the regional Canadian temperature at the top of the permafrost or at the bottom of the seasonally frozen layer (TTOP)-model in mountain terrain in central-eastern Norway. The TTOP-model uses seasonal n-factors (nt and nf) and air temperature to model the mean annual ground-surface temperature (MAGST), and a ratio of thawed to frozen thermal conductivity to model the average TTOP.

This study presents 28 and 36 values of nt and nf, respectively. The potential incoming solar radiation, derived in a Geographical Information System (GIS), was used to parameterise nt, and average snow depth was used to parameterise nf. Due to limited information on the subsurface component of the model, only MAGST was modelled. The model was run for the 1961-90 normal period, the Little Ice Age and the year 2050. The model was evaluated against existing model predictions based on bottom temperature of winter snow (BTS) and geophysical soundings. Finally, critical values of snow depth, potential incoming solar radiation and thermal conductivity ratio that constrain negative MAGST and thus permafrost were determined. Copyright © 2007 John Wiley & Sons, Ltd.

Lie, O., S. O. Dahl, et al. (2004). "Holocene fluctuations of a polythermal glacier in high-alpine eastern Jotunheimen, central-southern Norway." Quaternary Science Reviews 23(18-19): 1925-1945.

Bukkehammarbreen is a polythermal cirque glacier lying in the permafrost zone of eastern Jotunheimen, central-southern Norway. In the proglacial lake Bukkehammartjorna, sediment analyses of loss-on-ignition (LOI), magnetic susceptibility and analyses of grain-size distribution have been used to reconstruct Holocene variations in glacier activity and other catchment processes. The glacier has low-sediment production, hence a low signal-to-noise ratio of minerogenic sediment flux is found. Grain-size analyses are used to enhance the glacial signal and to detect glacier variations and other changes in sediment input. The sedimentological record from Bukkehammartjorn is compared with three other lake records from the same region in order to separate the glacial signal from variations in organic production and episodes of enhanced non-glacial minerogenic sedimentation. Subsequent to the deglaciation after the Younger Dryas, a preboreal glacial advance culminated before 10,100 cal. BP. This was followed by a prolonged period with no glaciers in the catchment until 7500 cal. BP, after which there is evidence of limited glacier activity lasting until 6800 cal. BP. Between 6700 and 6000 cal. BP the catchment was deglaciated. After 6000 cal. BP Bukkehammarbreen reformed, increasing in size towards similar to 3800 cal. BP, with evidence for reduced glacier activity around 5200 cal. BP. A glacier with approximately similar size as at present has existed after similar to 3800 cal. BP. The investigation has demonstrated the usefulness of multi-site and multi-parameter lacustrine investigations in reconstructing glacier fluctuations and for testing and validating the results. The investigations have shown that grain-size variations in sediment cores located at increasing distance from the meltwater inlet of a lake may provide an indicator of paraglacial activity in the catchment during the Holocene. The results also suggest that the lower altitudinal limit

of permafrost in eastern Jotunheimen remained below about 1800 m during the Holocene.
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Matsuoka, N. (2001). "Solifluction rates, processes and landforms: a global review." Earth-Science Reviews 55(1-2): 107-134.

Field data on the rates of solifluction and associated parameters are compiled from the literature, in an attempt to evaluate factors controlling the spatial variability in solifluction processes and landforms, with special attention on the climate-solifluction relationship. The analyzed data originate from 46 sites over a wide range of periglacial environments, from Antarctic nunataks to tropical high mountains. Solifluction, broadly defined as slow mass wasting resulting from freeze-thaw action in fine-textured soils, involves several components: needle ice creep and diurnal frost creep originating from diurnal freeze-thaw action; annual frost creep, gelifluction and plug-like flow originating from annual freeze-thaw action; and retrograde movement caused by soil cohesion. The depth and thickness of ice lenses and freeze-thaw frequency are the major controls on the spatial variation in solifluction processes. Near the warm margin of the solifluction-affected environment, diurnal freeze-thaw action induces shallow but relatively rapid movement of a superficial layer 5 - 10 cm thick on average, often creating the thin stone-banked lobes typically seen on tropical high mountains. In addition to diurnal movement, annual frost creep and gelifluction may occur on slopes with soil climates of seasonal frost to warm permafrost, dislocating a soil layer shallower than 60 cm at a rate of centimeters per year and eventually producing medium-size solifluction lobes. In High-Arctic cold permafrost regions, two-sided freezing can induce plug-like flow of a soil mass 60 cm or thicker. The correlation between process and landform suggests that the riser height of lobes is indicative of the maximum depth of movement and prevailing freeze-thaw type. Climate change may result in new different ground freezing conditions, thereby influencing the surface velocity and maximum depth of soil movement. Soil moisture and topography also control solifluction. High moisture availability in the seasonal freezing period enhances diurnal freeze-thaw action and subsequent seasonal frost heaving. The latter contributes to raising the moisture content of the thawed layer and promotes gelifluction during the thawing period. The slope angle defines the upper limit of the surface velocity of solifluction. A diagram correlating the potential frost creep with the actual surface velocity permits an inter-site comparison of the relative magnitude of solifluction components. Physically based modelling of periglacial slope evolution requires synthetic and more detailed field monitoring and laboratory simulations of solifluction processes. (C) 2001 Elsevier Science B.V. All rights reserved.

Matthews, J., S. Dahl, et al. (2000). "Holocene glacier variations in central Jotunheimen, southern Norway based on distal glaciolacustrine sediment cores." Quaternary Science Reviews 19(16): 1625-1647.

Sediment cores from two glacier-fed lakes are used to reconstruct a continuous record of glacier variations since about 10,000 cal. BP in the Smorstabbtinden massif of central Jotunheimen, southern Norway. Particular attention is paid to the century- to millennial-scale, pre-little Ice Age glacial signal based on an estimated temporal resolution of less than or equal to 55 and less than or equal to 25 yr cm⁻¹ for Bovertunsvatnet and Dalsvatnet, respectively. Visible lithostratigraphic variations, organic content/loss-on-ignition, calcium carbonate content, magnetic susceptibility and grain-size fractions (especially the fine silt) are used as proxy indicators of glacier presence and extent in the lake catchments. Following deglaciation, the early Holocene was characterized by generally small glaciers until a major advance (the Finse Event) peaking at approximately 8200 cal. BP. From 7900 to at least 5300 cal. BP glaciers appear to have been absent from central Jotunheimen. There is evidence of glacier expansion between about 2400 and 1600 cal. BP (the Bovertun I Event) and between about 1400 and 800 cal. BP (the Bovertun II Event) before reduced glacier extent during the

Mediaeval Warm Period. Finally, the most extensive Neoglacial maximum occurred during the Little Ice Age after 500 cal. BP. In addition to providing a record of the broad pattern of climatically forced Holocene glacier variations, periodicities at 110-140, 200-285 and about 500 yr have been identified. Uncertainties remain concerning the precise timing of events, glacierization and deglaciation detection thresholds, a possible mid-to late-Holocene (5300-2500 cal. BP) Neoglacial build-up of small glaciers, and shorter-term; decadal- to century-scale variations in glacier size, for which more proximal sites are required. (C) 2000 Elsevier Science Ltd. All rights reserved.

Matthews, J. A. (2005). "'Little Ice Age' glacier variations in Jotunheimen, southern Norway: a study in regionally controlled lichenometric dating of recessional moraines with implications for climate and lichen growth rates." *Holocene* **15**(1): 1-19.

A new approach to regional lichenometric dating is developed and applied to ' Little Ice Age ' moraine- ridge sequences on 16 glacier forelands in Jotunheimen, southern Norway. Lichenometric- dating curves, based on the *Rhizocarpon* subgenus, are constructed independently for west, central and east Jotunheimen. Although there are differences between the subregions, a composite regional moraine chronology for Jotunheimen identifies 12 episodes of moraine formation in AD 1743 - 1750 (the regional ' Little Ice Age ' glacier maximum), 1762 - 1771, 1782 - 1790, 1796 - 1802, 1811 - 1818, 1833 - 1838, 1845 - 1854, 1860 - 1868, 1871 - 1879, 1886 - 1898, 1915 - 1922 and 1927 - 1934. Spatial and temporal patterns in glacier behaviour between the subregions and between Jotunheimen and the neighbouring Jostedalbreen are explained in terms of the interaction of annual to decadal variations in summer temperature and winter precipitation: glacier advances and moraine- formation events driven primarily by winter- precipitation variations exhibit subregional patterns while summer- temperature forcing affects more synchronous glacier behaviour across the region. Regionally controlled lichenometric dating improves the accuracy of dating by up to about +/- 20 years on relatively old moraines and is dependent on regional patterns in the rate of lichen growth. On relatively young surfaces, mean cumulative growth rate declines from about 0.75 mm yr⁻¹ in maritime west Jotunheimen to about 0.55 mm yr⁻¹ in continental east Jotunheimen (though the differential in growth rate is less on older surfaces).

Matthews, J. A., M. S. Berrisford, et al. (2005). "Holocene glacier history of Bjornbreen and climatic reconstruction in central Jotunheimen, Norway, based on proximal glaciofluvial stream-bank mires." *Quaternary Science Reviews* **24**(1-2): 67-90.

Holocene variations of Bjornbreen, Smorstabttinden massif, west-central Jotunheimen are reconstructed from the lithostratigraphy of two alpine stream-bank mires flooded episodically by meltwater. The approach uses multiple sedimentological indicators (weight loss-on-ignition, mean grain size, grain-size fractions, bulk density, moisture content and magnetic susceptibility), an a priori model of overbank deposition of suspended glaciofluvial sediments, a detailed chronology based on 56 radiocarbon dates, and a Little Ice Age sedimentological analogue. Rapid, late-Preboreal deglaciation was indicated by immigration of *Betula pubescens* by 9700 cal. BP. An interval of at least 3000 years in the early Holocene when glaciers were absent was interrupted by two abrupt episodes of, glacier expansion around the time of the Finse Event, the first at ca 8270-7900 cal. BP (Bjornbreen I Event) and the second at ca 7770-7540 cal. BP (Bjornbreen II Event). Neoglaciation began shortly before ca 5730 cal. BP with gradual build-up to the maximum of the Bjornbreen III Event at ca 4420 cal. BP. Later maxima occurred at ca 2750 cal. BP (Bjornbreen IV Event) and at 1300, 1260, 1060 and 790 cal. BP (all within the Bjornbreen V Event). Glaciers were smaller than today and possibly melted away on several occasions in the late Holocene (ca 3950, 1410 and 750 cal. BP). Minor maxima also occurred at ca 660 and 540 cal. BP, within the late Mediaeval Warm Period and the early Little Ice Age, respectively. The Little Ice Age maximum was dated

to 213 25 BP (ca 205 cal. BP). The relative magnitudes of the main glacier maxima were determined: Erdalen Event > Little Ice Age Event (Bjornbreen VI) > Bjornbreen I (Finse Event) approximate to Bjornbreen II > Bjornbreen V greater than or equal to Bjornbreen IV > Bjornbreen III. These episodic events of varying magnitude and abruptness were used in conjunction with an independent summer-temperature proxy to reconstruct variations in equilibrium-line altitude (ELA) and a Holocene record of winter precipitation. Since the Preboreal, ELA varied within a range of about 390 m, and winter precipitation ranged between 40 and 160% of modern values. Winter precipitation variations appear to have been the main cause of these century- to millennial-scale Holocene glacier variations. (C) 2004 Elsevier Ltd. All rights reserved.

Nesje, A., S. O. Dahl, et al. (2000). "The lacustrine sedimentary sequence in Syngneskardvatnet, western Norway: a continuous, high-resolution record of the Jostedalsbreen ice cap during the Holocene." Quaternary Science Reviews 19: 1047-1065.

Ridefelt, H., B. Etzelmuller, et al. (2008). "Mountain permafrost distribution in the Abisko region, sub-Arctic northern Sweden " Norwegian Journal of Geography 67: 276-289.

Riseborough, D., N. Shiklomanov, et al. (2008). "Recent advances in permafrost modelling." Permafrost and Periglacial Processes 19(2): 137-156.

This paper provides a review of permafrost modelling advances, primarily since the 2003 permafrost conference in Zurich, Switzerland, with an emphasis on spatial permafrost models, in both arctic and high mountain environments. Models are categorised according to temporal, thermal and spatial criteria, and their approach to defining the relationship between climate, site surface conditions and permafrost status. The most significant recent advances include the expanding application of permafrost thermal models within spatial models, application of transient numerical thermal models within spatial models and incorporation of permafrost directly within global circulation model (GCM) land surface schemes. Future challenges for permafrost modelling will include establishing the appropriate level of integration required for accurate simulation of permafrost-climate interaction within GCMs, the integration of environmental change such as treeline migration into permafrost response to climate change projections, and parameterising the effects of sub-grid scale variability in surface processes and properties on small-scale (large area) spatial models. Copyright (c) 2008 John Wiley & Sons, Ltd.

Smith, M. W. and D. W. Riseborough (1996). "Permafrost monitoring and detection of climate change." Permafrost and Periglacial Processes 7(4): 301-309.

Ground temperature monitoring has been proposed as a means of detecting climate change in permafrost regions, although it is well known that the relationship is not simple. This paper presents a functional model of the permafrost-climate relationship, which accommodates the geographical variations of climatic, surface and soil factors that control ground thermal regime. The model is used to analyse the impacts of climate change on ground temperatures and to assess the design and interpretation of ground temperature monitoring programs. The model suggests that lithologic conditions form the primary local influence on permafrost temperatures, followed by snowcover and vegetation. Results using the model suggest that simple monitoring of active layer depth does not provide a reliable indicator of changes in permafrost temperature conditions, and that monitoring at exposed bedrock sites will produce the most direct signal of climate change on the ground thermal regime.

Smith, M. W. and D. W. Riseborough (2002). "Climate and the limits of permafrost: A zonal analysis." Permafrost and Periglacial Processes 13(1): 1-15.

This paper defines the climatic and environmental conditions that determine the limits and continuity of permafrost occurrence, in the Canadian context. The analysis utilizes a functional model that links air, surface and permafrost temperature through seasonal surface transfer functions and subsurface thermal properties. The temperature of permafrost (TTOP) results from the interplay between the air temperature, the nival (snow) offset and the thermal offset. These offset values vary systematically and geographically with freezing and thawing indices, snow cover conditions and ground thermal properties. These effects are analysed by calculating offset and TTOP values using Canadian climate station data for air temperature and snowfall. Whilst permafrost is ultimately a climatic phenomenon, the ground thermal conductivity ratio, via the thermal offset, is shown to be the critical factor in determining the southernmost extent of (discontinuous) permafrost. In contrast, snow cover, via the nival offset, is the critical factor in determining the northern limit of discontinuous permafrost (i.e. southern limit of continuous permafrost). Calculated TTOP values increase gradually southwards towards the limit of permafrost occurrence, as the effect of a rising mean annual air temperature (MAAT) is counteracted by an increasing thermal offset. This results in a diffuse geographical transition in the disappearance of permafrost. In contrast, there is a more abrupt transition to continuous permafrost at the northern limit of the discontinuous zone, associated with geographical changes in snow cover and the associated nival offset. The transition from discontinuous to continuous permafrost occurs between a MAAT of -6degrees to -8degreesC. This may explain the air temperature limit for continuous permafrost cited by previous authors. Copyright (C) 2002 John Wiley Sons, Ltd.

Williams, P. J. and M. W. Smith (1989). The Frozen Earth: Fundamentals of geocryology. Cambridge, Cambridge University press.