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PAGE21

CHANGING PERMAFROST IN THE ARCTIC AND ITS GLOBAL EFFECTS IN THE 21ST CENTURY

Submission of Milestones

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1. EXECUTIVE SUMMARY

Here we present the catalogue of permafrost physical parameters and processes for implementation in global models. The catalogue contains input from all WP2 partners, who have included detailed information about their primary PAGE21 sites.

2. Samoylov Island (72.4°N, 126.5°E, 20m asl)

Site description:

Samoylov Island belongs to an alluvial river terrace of the Lena River Delta. The island is elevated about 20 m above the normal river water level and covers an area of about 3.4 km². The western part of the island constitutes a modern floodplain which is lowered compared to the rest of the island and is often flooded during ice break-up of the Lena River in spring. The eastern part of the island belongs to the elevated river terrace which is mainly characterized by moss and sedge vegetated tundra. In addition, several lakes and ponds occur which make up about 25% of the surface area of Samoylov. The land surface of the island is characterized by the typical micro-relief of polygonal patterned ground caused by frost cracking and subsequent ice-wedge formation. The polygonal structures usually consist of depressed centers which are surrounded by elevated rims. The polygonal structures often occur in different stages of degradation with partly to completely collapsed rims. The soil in the polygonal centers usually consists of water saturated sandy peat with the water table standing a few centimeters below or above the surface. The elevated rims are usually covered with a dry moss layer underlain by wet sandy soils with massive ice wedges underneath. The cryogenic soil complex of the river terrace reaches depths of 10 to 15 m and is underlain by sandy to silty river deposits. The deposits of the Lena River reach depths of at least 1 km in the delta region.

Information for model parameterization:

Land surface properties	Basic surface classes of river terrace (floodplain not included)	Dry tundra	Wet tundra	Water	Spatial average
	Aerial fraction	58%	17%	25%	
	Dominate vegetation	Hylocomium splendens – Dryas punctata community	Drepanocladus revolvens - Meesia triquetra - Carex chordorrhiza community	Partly overgrown water (Carex) at shallow lakes and ponds	
	Albedo	0.20	0.15		0.20
Active layer properties	Type	Typic Aquiturbels, Glacic Aquiturbels	Typic Historthels Typic Aquiturbels Typic Aquorthels	Unspecified lake sediments	
	Soil composition	Ice: 50-70vol% Solid: 10-40vol%	Ice: 60-90vol% Solid: 10-40vol%		
	Heat capacity $MJm^{-3} K^{-1}$	thawed 0.9±0.5 frozen 0.7±0.3	thawed 3.4±0.5 frozen 1.8±0.3		
	Thermal conductivity $Wm^{-1} K^{-1}$	thawed 0.14±0.08 frozen 0.46±0.25	thawed 0.60±0.17 frozen 0.95±0.23		
Deep ground properties	Type				Unspecified river deposits sand / fine sand
	Composition				Sand/ fine sand, Ice: 60-80vol% (1-5m) Ice: 30-50vol% (> 5m) estimated

	Heat capacity $MJm^{-3} K^{-1}$				2.1±0.05
	Thermal conductivity $Wm^{-1} K^{-1}$				1.9±0.4
Snow cover properties	Type	Wind crust, compacted snow, partly snow free	Depth hoar covered by wind crust and compacted snow	Snow free on larger lakes, depth hoar with wind crust on smaller lakes	Snow cover is determined by wind drift, snow depth is strongly related to polygonal surface structures
	Average density kgm^{-3}	~160	~230		190±10
	Heat capacity $MJm^{-3} K^{-1}$				0.4±0.04
	Thermal conductivity $Wm^{-1} K^{-1}$				0.22±0.03
Important processes	Strong spatial differences in surface energy balance due to highly fractionated surface and subsurface properties. Expansion of thermokarst lakes and small ponds due to thermo-erosion. Soil water drainage is strongly related to active layer dynamics; Lateral water flow occurs from late summer to autumn. Strong snow-micro-topography, snow-vegetation interactions due to wind drift.				

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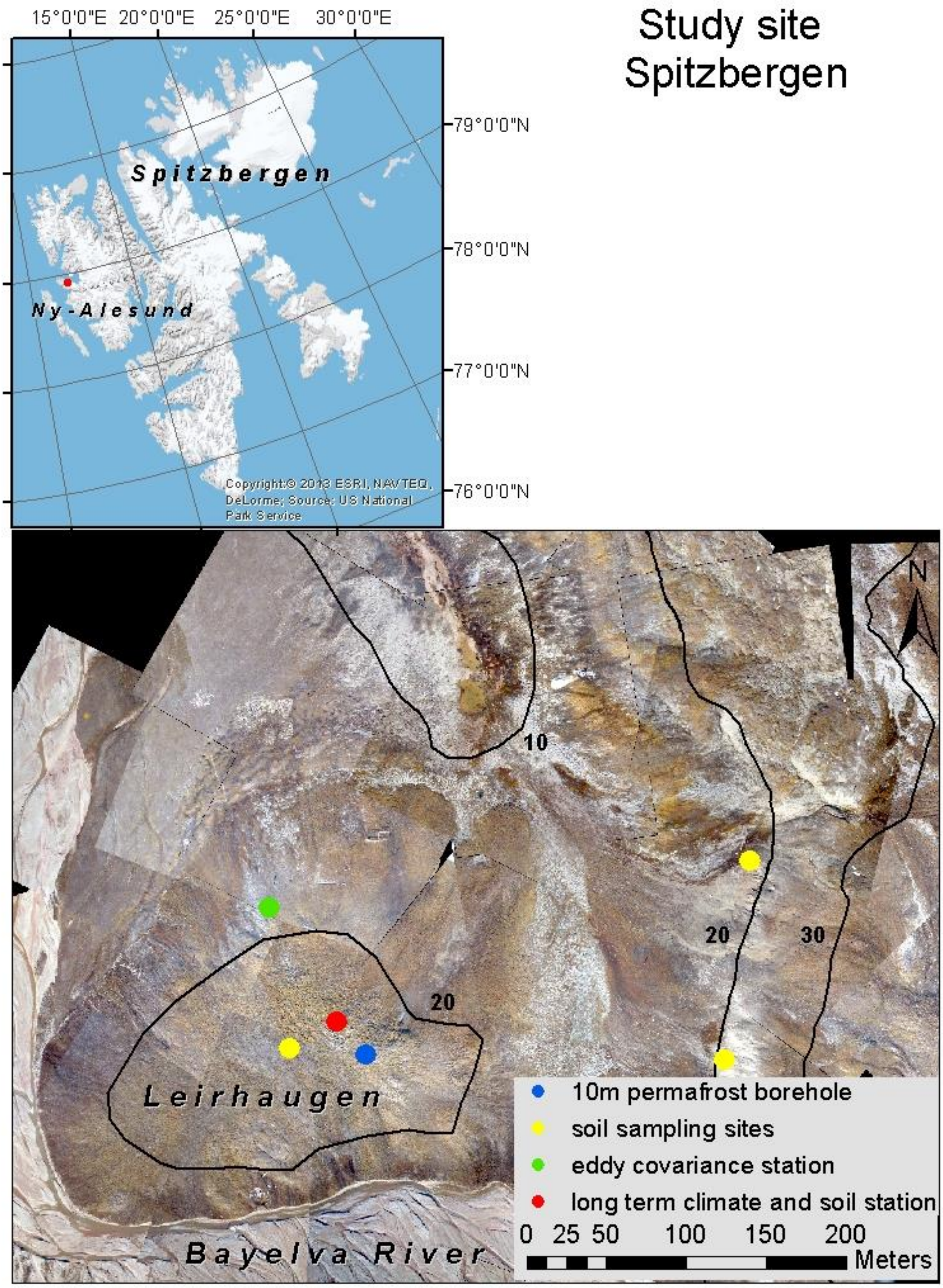
3. Bayelva, Spitsbergen (78°55'N, 11°57’E)

Site description:

The Bayelva climate and soil monitoring site is located in the Kongsfjord region at the west coast of the Svalbard Island. The North Atlantic Current warms this area to an average air temperature of about –13 °C in January and +5 °C in July, and provides about 400 mm precipitation annually, falling mostly as snow between September and May. The observation site located in the Bayelva River catchment on the Brøgger peninsula, about 3 km from the village of Ny-Ålesund. The Bayelva catchment is bordered by two mountains, the Zeppelinfjellet and the Scheteligfjellet, between which the glacial Bayelva River originates from the two branches of the Brøggerbreen glacier moraine rubble. To the north of the study site the terrain is flattening and at about 1 km distance the Bayelva River reaches the shore line of the Kongsfjorden (Arctic Ocean). In the catchment area, sparse vegetation alternates with exposed soil and sand and rock fields. Typical permafrost features, such as mud boils and non-sorted circles, are found in many parts of the study area. The Bayelva permafrost site itself is located at 25 m a.s.l., on top of the small Leirhaugen hill. The dominant ground pattern at the study site consists of non-sorted soil circles. The bare soil circle centers are about 1 m in diameter and are surrounded by a vegetated rim consisting of a mixture of low vascular plants of different species of grass and sedges (*Carex* spec., *Deschampsia* spec., *Eriophorum* spec., *Festuca* spec., *Luzula* spec.), catchfly, saxifrage, willow and some other local common species (*Dryas octopetala*, *Oxyria digyna*, *Polegonum viviparum*) and unclassified species of mosses and lichens. The vegetation cover at the measurement site was estimated to be approximately 60%, with the remainder being bare soil with a small proportion of stones. The silty clay soil has a high mineral content, while the organic content is low, with organic fractions below 10%. In the study period, the permafrost at Leirhaugen hill had a mean annual temperature of about −2 °C at the top of the permafrost at 1.5 m depth.



Information for model parameterization:

Land surface properties	Basic surface classes of river terrace (floodplain not included)	Vegetated	Bare	Spatial average
	Aerial fraction	60%	40%	
	Dominate vegetation	*Carex* spec., *Deschampsia* spec., *Eriophorum* spec., *Festuca* spec., *Luzula* spec.), catchfly, saxifrage, willow and some other local common species (*Dryas octopetala*, *Oxyria digyna*, *Polegonum viviparum*) and unclassified species of mosses and lichens.		
	Albedo			0.15
Active layer properties	Type			Soil material generally consists of silty clay with some larger stones. The silt content decreases from over 50 % at the top of the profile to less than 30 % at the bottom, concomitant with an increase of clay content to over 50 %. Volumetric liquid water content in frozen soils ranges between 4-9 %
	Soil composition*			Thawed: 60% mineral, 30% water, 10% air Frozen (below active layer): 60% mineral, 40 % ice
	Heat capacity $MJm^{-3} K^{-1}$			thawed 2.3 (±0.5) frozen 1.95
	Thermal conductivity $Wm^{-1} K^{-1}$			thawed 1.30 (±0.4) frozen 2.5
Deep ground properties	Type			Unspecified glacier deposits
Snow cover properties	Type			Basal ice layer and several internal ice layers; depth hoar
	Average density kgm^{-3}			350
	Heat capacity $MJm^{-3} K^{-1}$			0.75±0.1
	Thermal conductivity $Wm^{-1} K^{-1}$			0.45±0.15
Important processes	The seasonal thaw of the active layer after snow melt is driven by short-wave radiation; ~ 15% of the total net radiation during the summer season is consumed by the ground heat flux The energy is mainly supplied by short-wave radiation, but is mediated through conduction in the snow pack or percolating and			

	refreezing melt water; snow melt must be considered crucial for both monitoring and modeling schemes in permafrost areas. During winter, the most important factor for the permafrost is the incoming long-wave radiation, as it determines the general magnitude of the surface temperature During winter, the strong near-surface temperature inversion limits the use of air temperatures as surrogate for the temperature of the snow surface During arctic winter and especially polar night conditions the parameterization of energy exchange between surface and atmosphere remains one of the major deficiencies in current models. *Large spatial variability !

4. Kytalyk (70.82973N, 147.48897E, 55 m asl)

Site description:

Shrub tundra on continuous permafrost. The subsoil consists of ice-rich clay and sand, with a thin cover of peat. The station is situated in a drained thaw lake basin. Landscape elements are river floodplain, drained thaw lake basins, remnants of Pleistocene 'yedoma', actively expanding thaw lakes. Dominant vegetation on dry sites is Betula nana / Salix dwarf shrubs, on intermediate sites Eriophorum tussock tundra, on wet sites Eriophorum/Carex meadows and Sphagnum-dominated vegetation. Outside the river floodplain the vegetation is generally oligotrophic, on the river floodplain a more nutrient rich vegetation occurs dominated by grasses.

Information for model parameterization:

Land surface properties	Basic land surface types	Drained thaw lake basins	Yedoma surface	Floodplain	Lakes	Spatial average
	Aerial fraction	50%	20%	20%	10%	
	Dominate vegetation	Dwarf shrubs, Carex meadows, Shagnum	Tussock tundra, dwarf shrubs	Grass/Carex meadows, low Arctica fulva grass, channels and lakes, tall shrubs	Open water	Tussock tundra, dwarf shrubs, Carex/Eriophorum/grass medows, Sphagnum hummocks
	Microrelief	Low centered ice wedge polygons, high centered polygons, low palsas	Tussocks, polygons, erosion channels	Mostly flat, developing polygons		Dominated by various types of ice wedge polygons
Active layer properties	Soil type	Cryic histosols	Cryosols and cryic histosols	Cryosols and cryic histosols		
	Soil composition	Silt wit peat cover, ice content 40-80%	Silt wit peat cover, ice content 40-90%	Silt wit peat cover, ice content 30-50%		
	Active layer thickness	25-60 cm	30-60 cm	40-100 cm		
Deep ground properties	Soil type	Ice-rich silt	Ice-rich silt	Ice-rich silt and fine sand		silts
Snow cover properties	Type	Continuous between October and May	Continuous between October and May	Continuous between October and May	Ice > 1.5 m	

Important processes		Periglacial features vary strongly with age of drained thaw lake basins Development of ponds in ice-rich spots of the landscape increased strongly Active thaw lake bank erosion				

5. Zackenberg (74.30'N, 20.30'E)

Site description:

The Zackenberg research station is situated in central Northeast Greenland. The climate is high arctic and the main the study area is a 2-3 km wide valley, called Zackenbergdalen, where the research station is located. Around the valley there the landscape is mountainous with several peaks reaching 1000-1400 m asl. The Zackenberg river, which flows though the valley, has a catchment area of approximately 514 km^2, of which approximately 20% is covered by glaciers.

Zackenberg valley to the right and Young Sund to the left. Photo taken from Nansen blokken on Zackenberg mountain

Information for model parameterization:

Land surface properties	Basic land surface types	Dry tundra	Dry to wet tundra	Dry and wet tundra	Spatial average
	Aerial fraction	5.7%	30.2%	64.1%	
	Dominate vegetation	*Cassiope tetragona* heath	Grassland (domination specie *Arctagrostis latifolia*)	*Dryas intergrifolia* 9.3%, *Salix arctica* 10.9%, Fen(4.0%), bare ground and mosses	
	Albedo				60-90% on snow covered surfaces, 10-20% on dry tundra
Active layer properties	Soil type				Sandy fluvial sediments
	Soil composition	Porosity not measured	Porosity not measured		
	Bulk density	Ranges between 0.92 - 1.81 g/cm³	Ranges between 0.76 - 1.40 g/cm³		
	Rooting depth	Majority of the roots is found within the upper 30 cm	Majority of the roots is found within the upper 30 cm	Majority of the roots is found within the upper 30 cm	
Deep ground properties	Soil type	Bedrock starts below 20m.	Bedrock starts below 20m.		

	Composition				West side of river is dominated by granite and gneiss. East side of river sedimentary rocks.
Snow cover properties	Type				Wind packed snow covers the area.
	Average density kgm-3				Average density 496 kgm-3
	Average depth				0.80 m maximum snow depth on heath
Important processes	The landscape in Zackenberg is dominated by continuous permafrost. The landscape is primarily being formed by periglacial processes, and thus frost thaw processes affect the ecosystem dynamics. The amount of snow and thickness of the snowpack has a large effect on soil, vegetation and gas flux between land and atmosphere in the area.				

6. Adventdalen (78.203 N, 15.828 E, 15 m asl)

Site description:

The 35 km-long Adventdalen valley is an east-west oriented, 3 km wide U-shaped valley located in northeastern Nordenskiöld Land, centrally on the island Spitsbergen, Svalbard. It spans 78°09'-78°14'N and 15°41'-17°02'E, and drains westwards into Isfjorden. In the lowermost 15 km the valley bottom is covered by fluvial sediments with braided river plains and terraces along the sides (Tolgensbakk et al., 2001). The river Adventelva runs along the entire valley. Only smaller glaciers exist in the mountains surrounding the valleys draining in summer to the river Adventelva. Permafrost is continuous in the high arctic periglacial landscapes of Svalbard (Humlum et al., 2003). Ice-wedge polygons are widespread in the valley bottoms (Sørbel & Tolgensbakk, 2002), and are today active (Christiansen, 2005). The inner parts of Adventdalen became ice-free shortly before 10 ka, when the upper marine limit at around 64 m asl. was formed at the study site in Adventdalen (Lønne, 2005). The permafrost is the warmest this far north in the Arctic, with ground temperatures from -3˚C to -6˚C (Romanovsky et al, 2010; Christiansen et al., 2010). Geologically, the Adventdalen area comprises flat-lying, sedimentary rocks of Early Permian to Eocene age, with increasingly younger rocks containing sandstones, siltstones and shales exposed towards the southwest (Dallmann et al., 2001). Large plateaux dominate around Adventdalen, caused to a large degree by the near horizontal bedding of the sedimentary rocks (Dallmann et al., 2001). Coal is being mined from the Tertiary sandstones along the south side of Adventdalen, just as natural erosion and deposition of this coal occurs in the valley.

The Adventdalen area is one of the driest parts of Svalbard, with an average annual precipitation of only 190 mm, and a mean annual air temperature around -6°C at Svalbard Airport, located 6 km west of the mouth of Adventdalen (1961-1990) (Førland et al., 1997). Strong winds blowing down valley in Adventdalen from the SE are dominant in winter, causing a generally shallow snow cover in the valley (Christiansen et al., 2013). The dominant regional airflow in wintertime is also from the SE, as measured at a meteorological station on the Gruvefjellet plateau 1 km south of Adventdalen at 470 m asl. Therefore, the influence of the wind on the geomorphological activity in Adventdalen is determined by the regional air flow, not local conditions.

Information for model parameterization:

Land surface properties ENTIRE Adventdalen mapped area (Sørbel et al., 2000)	Basic land surface types	Weathering material autochothonous+ allochthonous+ exposed bedrock+ colluvium			Lowland sediments (solifluction, tills, fluvial, marine, Aeolian, org)			Anthropo genic, lakes and other
	Aerial fraction	65.9 %			32.9%			1.2 %
	Dominate vegetation				Grass, Cassiope, Dryas			
Active layer properties	Thickness	2-4 m			60-120cm (55-205 cm)			
					Gravimetric ice (%) in the AL; average 74 %		Volumetricice (%) *est in the AL; average 43 %	
Permafrost properties	Ice content	Excess ice (%) in the top 1 m of permafrost; average 25 %	Gravimetric ice (%)in the top 1 m of permafrost; average 68%	Volumetric* ice (%) *est. in the top 1 m of permafrost; average 51%	Excess ice (%) in the top 1 m of permafrost; average 17 %	Gravimetric ice (%)in the top 1 m of permafrost, average 137 %	Volumetric* ice (%) *est. in the top 1 m of permafrost, average 55 %	
Deep ground properties	Lithology	Sediment cover app. 1-3 m, bedrock below			Sediment infilling the valley typically 1-70 m thick sediment cover			
	Composition							
	Permafrost temperatures	-3 to -6C			-3 to -6C			
Snow cover properties	Type	Hard wind packed snow			Hard wind packed snow			
	Snow depths	0-100 cm			0-100 cm			
	Snow temp	-3 to – 30C			-3 to -30C			
	Duration	From Sep to July			From Oct to June			
Important processes	Winter warm spells often once or several times during each winter bring rain and snow melting to the area, causing ice layers to form in the snow pack or on the ground surface. High interannual and interseasonal variability due to extreme maritime climate in both air temperature values and precipitation amounts. Relatively dry site, with around 200 mm precipitation only, so snowdrifting is rather important for the ground thermal regime. Polar night from end of October to mid February.							

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2.6 Abisko (68°21'20''N, 18°49'14''E, 385 m a s l)

Site description:

Abisko is located in northernmost Sweden in an area of sporadic permafrost. In the lowlands, permafrost can mainly be found in peat mires (Johansson *et al*., 2006) and in the mountains, permafrost can be found from ca 850 m a s l (Ridefelt *et al*., 2008). Lowland permafrost is 15-30 m thick and warm (MAGT -0.5°C) (Johansson M. *et al*., 2011). Abisko is located in the Torneträsk catchment where Lake Torneträsk is the dominating water body covering 330 km^2 (Ekman, 1957). The elevation in the area ranges from 340 to 1750 m a s l. The catchment has a very strong climatic gradient. Abisko is located in a rain shadow, with a total annual precipitation of 303 mm (1913-2006) whereas 35 km west of Abisko the total annual precipitation is 900 mm. The mean annual air temperature is -0.6ºC (1913-2006) and has increased by 2.5 ºC during the period of measurements. This has resulted in mean annual air temperatures above 0ºC during the last decade (Callaghan *et al*., 2010).

Information for model parameterization:

Land surface properties	Basic land surface types	Mountain birch forest	Tundra (above treeline vegetation)	Peat mires	Lakes	Glaciers	Spatial average
	Aerial fraction	25% (Lantmäteriet, 1997)	ca 50% (Lantmäteriet, 1997)	2% (Lantmäteriet, 1997)	10% (Lantmäteriet, 1997)	<1% (Lantmäteriet, 1997)	
	Dominate vegetation	*Betula pubescens* ssp. *Czerepanovii* (Carlsson *et al*., 1999)		*Andromeda polifolia, Vaccinium uliginosum, Empetrum nigrum, Betula nana,Dicranum scoparium, Sphagnum fuscum Sphagnum balticum Cetraria cucullata, Cetraria nivalis Cladonia* spp. *Eriophorum vaginatum Rubus chamaemorus* (Johansson *et al*., 2013)	-	-	
	Albedo	11% (Chapin et al., 2005)	17% (Chapin et al., 2005)	~18% (Rydén, 1978)	6%(Duguay *et al*., 2003)	67% (Jonsell *et al*., 2003)	
	Permafrost existence	No	Yes	Yes	No	No (possible under coldbased glaciers though)	
Active layer properties	Soil type	-		Peat 60-90 cm (Klaminder *et*	-	-	Akerman and Johansson, 2008

				al., 2008)			
	Soil composition	-		Up to 35% ice content (Akerman and Johansson, 2008)	-	-	
Deep ground properties	Soil type						
	Composition			Average 7-8% ice content (Akerman and Johansson, 2008)			
Snow cover properties							Johansson C. *et al*.,2011 Kohler *et al*., 2006
Important processes	The catchment has a very strong climatic gradient ranging from Abisko with a total annual precipitation of 303 mm to Riksgränsen with a total annual precipitation of 900 mm.						

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