Appendix F
ICSI Classification for Seasonal Snow on the Ground

Morphological classification					Additional information on physical processes and strength		
Basic classification	Subclass	Shape	Code	Place of formation	Physical process	Dependence on most important parameters	Common effect on strength
Precipitation Particles			**PP**				
	Columns	Prismatic crystal, solid or hollow	PPco	Cloud; temperature inversion layer (clear sky)	Growth from water vapour at –3 to –8 °C and below–30 °C		
	Needles	Needle-like, approximately cylindrical	PPnd	Cloud	Growth from water vapour at high supersaturation at –3 to –5 °C and below –60 °C		
	Plates	Plate-like, mostly hexagonal	PPpl	Cloud; temperature inversion layer (clear sky)	Growth from water vapour at 0 to –3 °C and –8 to –70 °C		
	Stellars, Dendrites	Six-fold star-like, planar or spatial	PPsd	Cloud; temperature inversion layer (clear sky)	Growth from water vapour at high supersaturation at 0 to –3 °C and at –12 to –16 °C		
	Irregular crystals	Clusters of very small crystals	PPir	Cloud	Polycrystals growing in varying environmental conditions		
	Graupel	Heavily rimed particles, spherical, conical, hexagonal, or irregular in shape	PPgp	Cloud	Heavy riming of particles by accretion of supercooled water droplets Size: ≤ 5 mm		
	Hail	Laminar internal structure, translucent or milky glazed surface	PPhl	Cloud	Growth by accretion of supercooled water Size: > 5 mm		
	Ice pellets	Transparent, mostly small spheroids	PPip	Cloud	Freezing of raindrops or refreezing of largely melted snow crystals or snowflakes (sleet) Graupel or snow pellets encased in thin ice layer (small hail) Size: both ≤ 5 mm		
	Rime	Irregular deposits or longer cones and needles pointing into the wind	PPrm	Onto surface as well as on freely exposed objects	Accretion of small, supercooled fog droplets frozen in place. Thin breakable crust forms on snow surface if process continues long enough	Increase with fog density and exposure to wind	

Notes: Diamond dust is a further type of precipitation often observed in polar regions (see Appendix E).
Hard rime is more compact and amorphous than soft rime and may build out as glazed cones or ice feathers (AMS, 2000).
The above subclasses do not cover all types of particles and crystals one may observe in the atmosphere. See the references below for a more comprehensive coverage.

References: Magono & Lee, 1966; Bailey & Hallett, 2004; Dovgaluk & Pershina. 2005; Libbrecht, 2005

Basic classification	Subclass	Shape	Code	Place of formation	Physical process	Dependence on most important parameters	Common effect on strength
	Morphological classification				*Additional information on physical processes and strength*		
Machine Made snow			**MM**				
	Round polycrystalline particles	Small spherical particles, often showing protrusions, a result of the freezing process; may be partially hollow	MMrp	Atmosphere, near surface	Machined snow, i.e., freezing of very small water droplets from the surface inward	Liquid water content depends mainly on air temperature and humidity but also on snow density and grain size	In dry conditions, quick sintering results in rapid strength increase
	Crushed ice particles	Ice plates, shard-like	MMci	Ice generators	Machined ice, i.e., production of flake ice, subsequent crushing, and pneumatic distribution	All weather safe	

References: Fauve *et al.*, 2002

Decomposing and Fragmented precipitation particles			**DF**				
	Partly decomposed precipitation particles	Characteristic shapes of precipitation particles still recognizable; often partly rounded.	DFdc	Within the snowpack; recently deposited snow near the surface, usually dry	Decrease of surface area to reduce surface free energy; also fragmentation due to light winds lead to initial break up	Speed of decomposition decreases with decreasing snow temperatures and decreasing temperature gradients	Regains cohesion by sintering after initial strength decreased due to decomposition process
	Wind-broken precipitation particles	Shards or fragments of precipitation particles	DFbk	Surface layer, mostly recently deposited snow	Saltation particles are fragmented and packed by wind, often closely; fragmentation often followed by rounding	Fragmentation and packing increase with wind speed	Quick sintering results in rapid strength increase

Morphological classification				Additional information on physical processes and strength			
Basic classification	Subclass	Shape	Code	Place of formation	Physical process	Dependence on most important parameters	Common effect on strength
Rounded Grains			**RG**				
	Small rounded particles	Rounded, usually elongated particles of size < 0.25 mm; highly sintered	RGsr	Within the snowpack; dry snow	Decrease of specific surface area by slow decrease of number of grains and increase of mean grain diameter. Small equilibrium growth form	Growth rate increases with increasing temperature; growth slower in high density snow with smaller pores	Strength due to sintering of the snow grains [1]. Strength increases with time, settlement and decreasing grain size
	Large rounded particles	Rounded, usually elongated particles of size ≥ 0.25 mm; well sintered	RGlr	Within the snowpack; dry snow	Grain-to-grain vapour diffusion due to low temperature gradients, i.e., mean excess vapour density remains below critical value for kinetic growth. Large equilibrium growth form	Same as above	Same as above
	Wind packed	Small, broken or abraded, closely-packed particles; well sintered	RGwp	Surface layer; dry snow	Packing and fragmentation of wind transported snow particles that round off by interaction with each other in the saltation layer. Evolves into either a hard but usually breakable wind crust or a thicker wind slab. (see notes)	Hardness increases with wind speed, decreasing particle size and moderate temperature	High number of contact points and small size causes rapid strength increase through sintering
	Faceted rounded particles	Rounded, usually elongated particles with developing facets	RGxf	Within the snowpack; dry snow	Growth regime changes if mean excess vapour density is larger than critical value for kinetic growth. Accordingly, this transitional form develops facets as temperature gradient increases	Grains are changing in response to an increasing temperature gradient	Reduction in number of bonds may decrease strength

Notes: Both wind crusts and wind slabs are layers of small, broken or abraded, closely packed and well-sintered particles. The former are thin irregular layers whereas the latter are thicker, often dense layers, usually found on lee slopes. Both types of layers can be represented either as sub-class RGwp or as RGsr along with proper grain size, hardness and/or density. If the grains are smaller than about 1 mm, an observer will need to consider the process at work to differentiate RGxf from FCxr.

References: [1] Colbeck, 1997

Morphological classification				Additional information on physical processes and strength			
Basic classification	Subclass	Shape	Code	Place of formation	Physical process	Dependence on most important parameters	Common effect on strength
Faceted Crystals			**FC**		Grain-to-grain vapour diffusion driven by large enough temperature gradient, i.e., excess vapour density is above critical value for kinetic growth		
□	Solid faceted particles □	Solid faceted crystals; usually hexagonal prisms	FCso	Within the snowpack; dry snow	Solid kinetic growth form, i.e., a solid crystal with sharp edges and corners as well as glassy, smooth faces	Growth rate increases with temperature, increasing temperature gradient, and decreasing density; may not grow to larger grains in high density snow because of small pores	Strength decreases with increasing growth rate and grain size
	Near surface faceted particles	Faceted crystals in surface layer	FCsf	Within the snowpack but right beneath the surface; dry snow	May develop directly from Precipitation Particles (PP) or Decomposing and Fragmented particles (DFdc) due to large, near-surface temperature gradients [1] Solid kinetic growth form (see FCso above) at early stage	Temperature gradient may periodically change sign but remains at a high absolute value	Low strength snow
	Rounding faceted particles	Faceted crystals with rounding facets and corners	FCxr	Within the snowpack; dry snow	Trend to a transitional form reducing its specific surface area; corners and edges of the crystals are rounding off	Grains are rounding off in response to a decreasing temperature gradient	

Notes: Once buried, FCsf are hard to distinguish from FCso unless the observer is familiar with the evolution of the snowpack.
FCxr can usually be clearly identified for crystals larger than about 1 mm. In case of smaller grains, however, an observer will need to consider the process at work to differentiate FCxr from RGxf.

References: [1] Birkeland, 1998

Morphological classification				Additional information on physical processes and strength			
Basic classification	Subclass	Shape	Code	Place of formation	Physical process	Dependence on most important parameters	Common effect on strength
Depth Hoar			**DH**		Grain-to-grain vapour diffusion driven by large temperature gradient, i.e., excess vapour density is well above critical value for kinetic growth.		
	Hollow cups	Striated, hollow skeleton type crystals; usually cup-shaped	DHcp	Within the snowpack; dry snow	Formation of hollow or partly solid cup-shaped kinetic growth crystals [1]	See FCso.	Usually fragile but strength increases with density
	Hollow prisms	Prismatic, hollow skeleton type crystals with glassy faces but few striations	DHpr	Within the snowpack; dry snow	Snow has completely recrystallized; high temperature gradient in low density snow, most often prolonged [2]	High recrystallization rate for long period and low density snow facilitates formation	May be very poorly bonded
	Chains of depth hoar	Hollow skeleton type crystals arranged in chains	DHch	Within the snowpack; dry snow	Snow has completely recrystallized; intergranular arrangement in chains; most of the lateral bonds between columns have disappeared during crystal growth	High recrystallization rate for long period and low density snow facilitates formation	Very fragile snow
	Large striated crystals	Large, heavily striated crystals; either solid or skeleton type	DHla	Within the snowpack; dry snow	Evolves from earlier stages described above; some bonding occurs as new crystals are initiated [2]	Longer time required than for any other snow crystal; long periods of large temperature gradient in low density snow are needed	Regains strength
	Rounding depth hoar	Hollow skeleton type crystals with rounding of sharp edges, corners, and striations	DHxr	Within the snowpack; dry snow	Trend to a form reducing its specific surface area; corners and edges of the crystals are rounding off; faces may lose their relief, i.e., striations and steps disappear slowly. This process affects all subclasses of depth hoar	Grains are rounding off in response to a decreasing temperature gradient	May regain strength

Notes: – DH and FC crystals may also grow in snow with density larger than about 300 kg m^{-3} such as found in polar snowpacks or wind slabs. These may then be termed ‘hard’ or ‘indurated’ depth hoar [3].

References: [1] Akitaya, 1974; Marbouty, 1980; Fukuzawa & Akitaya, 1993; Baunach *et al.*, 2001; Sokratov, 2001; [2] Sturm & Benson, 1997; [3] Akitaya, 1974; Benson & Sturm, 1993

Basic classification	Subclass	Shape	Code	Place of formation	Physical process	Dependence on most important parameters	Common effect on strength
	Morphological classification			Additional information on physical processes and strength			
Surface Hoar			**SH**				
	Surface hoar crystals	Striated, usually flat crystals; sometimes needle-like	SHsu	Usually on cold snow surface relative to air temperature; sometimes on freely exposed objects above the surface (see notes)	Rapid kinetic growth of crystals at the snow surface by rapid transfer of water vapour from the atmosphere toward the snow surface; snow surface cooled to below ambient temperature by radiative cooling	Both increased cooling of the snow surface below air temperature as well as increasing relative humidity of the air cause growth rate to increase. In high water vapour gradient fields, e.g., near creeks, large feathery crystals may develop	Fragile, extremely low shear strength; strength may remain low for extended periods when buried in cold dry snow
	Cavity or crevasse hoar	Striated, planar or hollow skeleton type crystals grown in cavities; orientation often random	SHcv	Cavity hoar is found in large voids in the snow, e.g., in the vicinity of tree trunks, buried bushes [1] Crevasse hoar is found in any large cooled space such as crevasses, cold storage rooms, boreholes, etc.	Kinetic growth of crystals forming anywhere where a cavity, i.e., a large cooled space, is formed or present in which water vapour can be deposited under calm, still conditions [2]		
	Rounding surface hoar	Surface hoar crystal with rounding of sharp edges, corners and striations	SHxr	Within the snowpack; dry snow	Trend to a form reducing its specific surface area; corners and edges of the crystals are rounding off; faces may loose their relief, i.e., striations and steps disappear slowly	Grains are rounding off in response to a decreasing temperature gradient	May regain strength

Notes: It may be of interest to note more precisely the shape of hoar crystals, namely plates, cups, scrolls, needles and columns, dendrites, or composite forms [3]. Multi-day growth may also be specified.
Surface hoar may form by advection of nearly saturated air on both freely exposed objects and the snow surface at subfreezing temperatures. This type of hoarfrost deposit makes up a substantial part of accumulation in the inland of Antarctica. It has been termed 'air hoar' (see [2] and AMS, 2000).
Crevasse hoar crystals are very similar to depth hoar.

References: [1] Akitaya, 1974; [2] Seligman, 1936; [3] Jamieson & Schweizer, 2000

	Morphological classification			Additional information on physical processes and strength			
Basic classification	Subclass	Shape	Code	Place of formation	Physical process	Dependence on most important parameters	Common effect on strength
Melt Forms			MF	.			
	Clustered rounded grains	Clustered rounded crystals held by large ice-to-ice bonds; water in internal veins among three crystals or two grain boundaries	MFcl	At the surface or within the snowpack; wet snow	Wet snow at low water content (pendular regime), i.e., holding free liquid water; clusters form to minimize surface free energy	Meltwater can drain; too much water leads to MFsl; first freezing leads to MFpc	Ice-to-ice bonds give strength
	Rounded polycrystals	Individual crystals are frozen into a solid polycrystalline particle, either wet or refrozen	MFpc	At the surface or within the snowpack	Melt-freeze cycles form polycrystals when water in veins freezes; either wet at low water content (pendular regime) or refrozen	Particle size increases with number of melt-freeze cycles; radiation penetration may restore MFcl; excess water leads to MFsl	High strength in the frozen state; lower strength in the wet state; strength increases with number of melt-freeze cycles
	Slush	Separated rounded particles completely immersed in water	MFsl	Water saturated, soaked snow; found within the snowpack, on land or ice surfaces, but also as a viscous floating mass in water after heavy snowfall.	Wet snow at high liquid water content (funicular regime); poorly bonded, fully rounded single crystals – and polycrystals – form as ice and water are in thermodynamic equilibrium	Water drainage blocked by capillary barrier, impermeable layer or ground; high energy input to the snowpack by solar radiation, high air temperature or water input (rain)	Little strength due to decaying bonds
	Melt-freeze crust	Crust of recognizable melt-freeze polycrystals	MFcr	At the surface	Crust of melt-freeze polycrystals from a surface layer of wet snow that refroze after having been wetted by melt or rainfall; found either wet or refrozen	Particle size and density increases with number of melt-freeze cycles	Strength increases with number of melt-freeze cycles

Notes: Melt-freeze crusts MFcr form at the surface as layers at most a few centimetres thick, usually on top of a subfreezing snowpack. Rounded polycrystals MFpc will rather form within the snowpack. MFcr usually contain more refrozen water than MFpc and will not return to MFcl.
Both MFcr and MFpc may contain a recognizable minority of other shapes, particularly large kinetic growth form FC and DH. See the guidelines (Appendix C) for examples on the use of the MFcr symbol.

Basic classification	Subclass	Shape	Code	Place of formation	Physical process	Dependence on most important parameters	Common effect on strength
	Morphological classification				Additional information on physical processes and strength		
Ice Formations			**IF**				
	Ice layer	Horizontal ice layer	IFil	Within the snowpack	Rain or meltwater from the surface percolates into cold snow where it refreezes along layer-parallel capillary barriers by heat conduction into surrounding subfreezing snow, i.e., snow at T < 0 °C; ice layers usually retain some degree of permeability	Depends on timing of percolating water and cycles of melting and refreezing; more likely to occur if a stratification of fine over coarse-grained layers exists	Ice layers are strong but strength decays once snow is completely wetted
	Ice column	Vertical ice body	IFic	Within snowpack layers	Draining water within flow fingers freezes by heat conduction into surrounding subfreezing snow, i.e., snow at T < 0 °C	Flow fingers more likely to occur if snow is highly stratified; freezing enhanced if snow is very cold	
	Basal ice	Basal ice layer	IFbi	Base of snowpack	Melt water ponds above substrate and freezes by heat conduction into cold substrate	Formation enhanced if substrate is impermeable and very cold, e.g., permafrost	Weak slush layer may form on top
	Rain crust	Thin, transparent glaze or clear film of ice on the surface	IFrc	At the surface	Results from freezing rain on snow; forms a thin surface glaze	Droplets have to be supercooled but coalesce before freezing	Thin breakable crust
	Sun crust, Firnspiegel	Thin, transparent and shiny glaze or clear film of ice on the surface	IFsc	At the surface	Melt water from a surface snow layer refreezes at the surface due to radiative cooling; decreasing shortwave absorption in the forming glaze enhances greenhouse effect in the underlying snow; additional water vapour may condense below the glaze [1]	Builds during clear weather, air temperatures below freezing and strong solar radiation; not to be confused with melt-freeze crust MFcr	Thin breakable crust

Notes: In ice formations, pores usually do not connect and no individual grains or particles are recognizable, contrary to highly porous snow. Nevertheless, some permeability remains, in particular when wetted, but to much a lesser degree than for porous melt forms.
Most often, rain and solar radiation cause the formation of melt-freeze crusts MFcr.
Discontinuous ice bodies such as ice lenses or refrozen flow fingers can be identified by appropriate remarks (see Appendix C.2).

References: [1] Ozeki & Akitaya, 1998