Snowhydrology

24.01.2006 GEO 4430

- Snow-accumulation
- Snow-distribution

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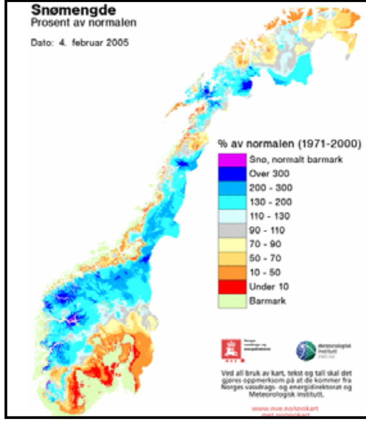


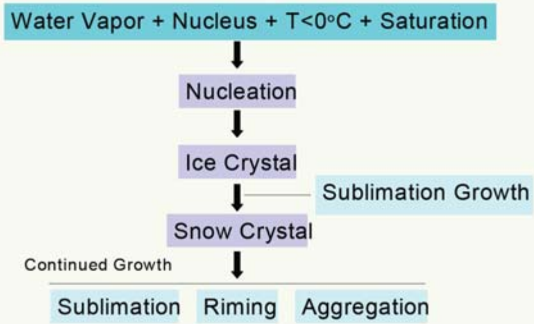
Aim: Understand principles of snow distribution

Snow precipitation

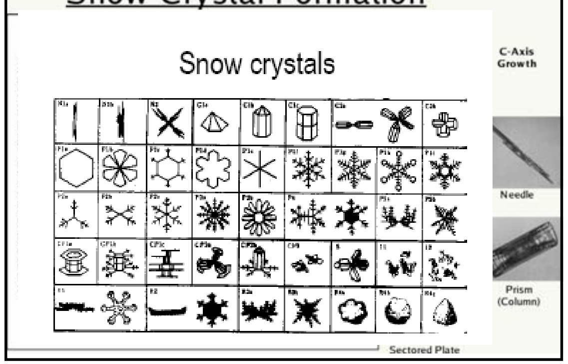
What makes it snow?

- Saturated or oversaturated air exists due to air lift
- Nuclear seeds exist
- Collisions occur between cloud drops or ice particles

Snowfall Formation



Snow Crystal Formation



Snow precipitation

- Orographic
  - Mountain barriers
    → uplift
- Cyclonal
  - Mixing of warm and cold air masses
    → advection & convection

Snowfall distribution: orographic effects

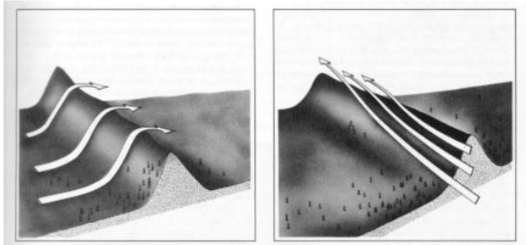


Figure 2.7. Orographic lifting is the most important winter precipitation mechanism; maximum effect is produced (left) when the wind is perpendicular to the mountain barrier.

Snowfall distribution: convergence

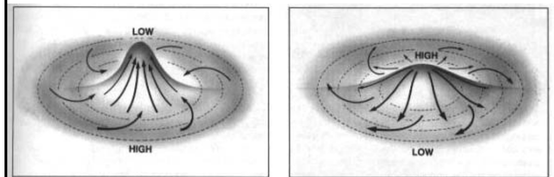
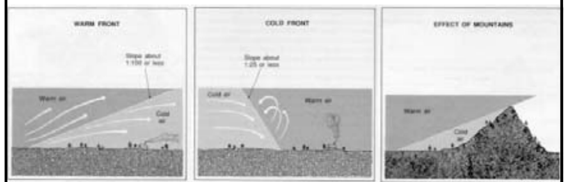


Figure 2.5. Convergence around a low-pressure area (diameter of about 1,000 km) causes widespread precipitation. Divergence (sinking) around a high causes clearing skies.

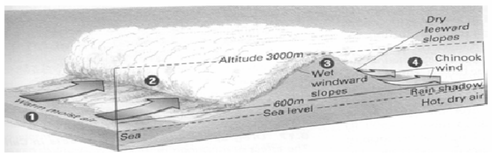
Snowfall distribution: frontal effects (advection)



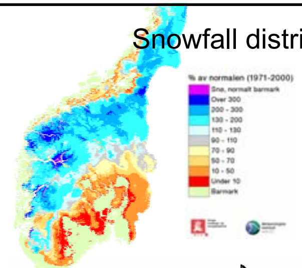
Snowfall distribution

View to Longyearbyen, Svalbard
Picture credit: Ole Humlum

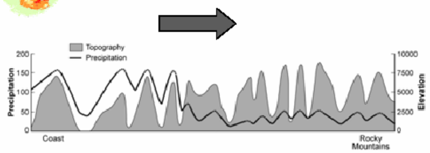
More snow with increasing elevation



Snowfall distribution



Less snow with increasing distance to the source



Snowcover distribution

Snowcover distribution

- **Open Environments**
  - Over highly exposed terrain, the effects of meso- and micro-scale differences in vegetation and terrain features may produce wide variations in accumulation patterns.

Snowcover distribution

- **Forested Environments**
  - Most studies show greater snow accumulation in clearings than in the forest
  - Most of the difference develops during storms, not between storms
  - major factors contributing to the difference ?

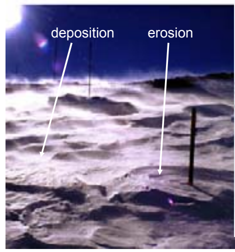
Snowcover distribution

- **Forested Environments**
  - Differences in snow accumulation between different species of conifers is usually small compared to between coniferous and deciduous stands
    - coniferous stands are all relatively efficient snow interceptors
    - Once intercepted, cohesion between snow particles helps keep snow in the canopy for extended time periods
      - snow is more susceptible to sublimation losses in the canopy than on the forest floor
        - » High surface area to mass ratio

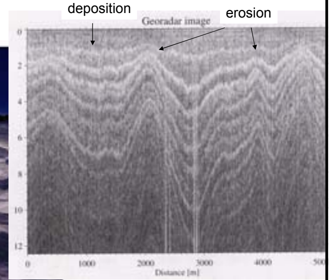
Snow (re-)distribution

Longyearbyen, Photo: Ole Humlum

Snow redistribution



Durand et al. (in press)



Richardson-Näslund, 2001

Snow drift

- **Four Factors**
  - **1. Shear Velocity**
  - **2. Threshold Wind Speed**
  - **3. Types of Transport**
  - **4. Transport Rates**

Snow drift

- **Shear Velocity**
  - **Movement of snow particles occurs when the drag force exerted on the snow surface by the wind exceeds the surface shear strength.**
  - **The total atmospheric shear stress, S, is equal to $p_a u^{*2}$, where p_a is the air density and u^* is the friction (shear) velocity.**

Snow drift

- **Shear Velocity - Wind**
  - **The friction velocity u^* is usually calculated from wind profiles, but can be estimated from a single 10-m wind speed (u_{10}):**

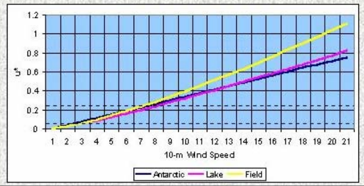
		u_{10} = 5 m/s
Antarctic Ice Sheet	$u^* = u_{10}/26.5$	u^* = 0.19
Snow-covered Lake	$u^* = u_{10}^{1.18}/41.7$	u^* = 0.16
Snow-covered Fallow Field	$u^* = u_{10}^{1.30}/44.2$	u^* = 0.18

Snow drift

- **Threshold Shear Velocity - Snow**
  - **u^*_t is the friction velocity at which snow transport begins**
    - **depends on snow characteristics**

Older, wind-hardened, dense or wet-snow: u^*_t = 0.25 - 1.0 m/s

Fresh, loose, dry snow, and during snowfall: u^*_t = 0.07 - 0.25 m/s



Snow drift

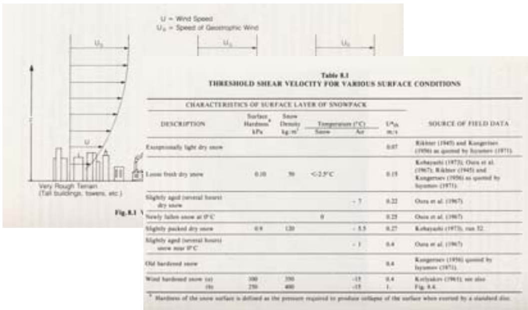


Table 8.1
THRESHOLD SHEAR VELOCITY FOR VARIOUS SURFACE CONDITIONS

DESCRIPTION	Surface Hardness* kPa	Snow Density kg/m³	Temperature (°C) Snow	Air	U^*_{t} m/s	SOURCE OF FIELD DATA
Exceptionally light dry snow					0.07	Rikhter (1945) and Kungurtsev (1956) as quoted by Iuyamov (1971)
Loose fresh dry snow	0.10	50	<-2.5°C		0.15	Kobayashi (1972); Oura et al. (1967); Rikhter (1945) and Kungurtsev (1956) as quoted by Iuyamov (1971).
Slightly aged (several hours) dry snow				-7	0.22	Oura et al. (1967)
Newly fallen snow at 0°C			0		0.25	Oura et al. (1967)
Slightly packed dry snow	0.9	120		-5.5	0.27	Kobayashi (1972), run 32
Slightly aged (several hours) snow near 0°C				-1	0.6	Oura et al. (1967)
Old hardened snow					0.6	Kungurtsev (1956) quoted by Iuyamov (1971).
Wind hardened snow (a)	300	350		-15	0.4	Kotlyakov (1961); see also
(b)	250	400		-15	1.	Fig. 8.4

* Hardness of the snow surface is defined as the pressure required to produce collapse of the surface when exerted by a standard disc.

Handbook of Snow (1981)

Snow drift

- Threshold wind speed increases with increasing temperature and humidity
- It the original deposition occurs with wind, the particles will be broken into smaller pieces → higher density pack → increase threshold wind speed
- Threshold wind speed increases with time since deposition, due to snow metamorphism

Snow drift

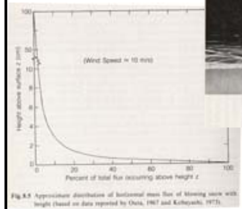
- **Three Types of Transport**

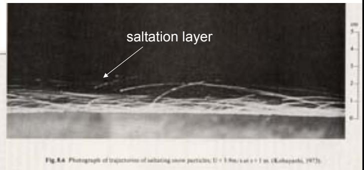
TYPE	MOTION	HEIGHT	WINDSPEED
Creep	Roll	< 1 cm	<< 5 m/s
Saltation	Bounce	1 cm - 10 cm	5 - 10 m/s
Turbulent Diffusion	Suspended	1 m - 100 m	> 10 m/s

Snow drift

- **Sublimation Losses**
  - Snow particles are more exposed to atmosphere during wind transport
  - Sublimation losses can be very high as a result
    - depends on transport rate, transport distance, temperature, humidity, wind speed, and solar radiation

Snow drift

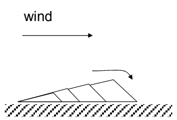




Handbook of Snow (1981)

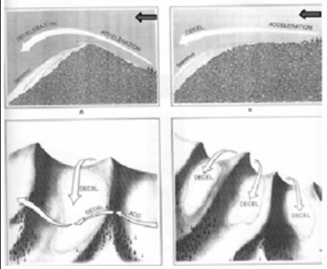
extensive redistribution of snow by wind !!

Snow drift



...a matter of scale

Snow drift



Terrain	Typical distances of snow transport (km)
Mountain topography (Kotlyakov, 1973	0.1 - 0.5
Plains in W Siberia (Dyunin et al., 1973)	1 - 3
Plateau in SE Wyoming (Tabler&Schmidt, 1973)	0.5 – 1.4
On ice domes (Kotlyakov, 1968)	Up to 5
On polar ice caps (Kotlyakov, 1968)	30 - 50

Handbook of Snow (1981)

Snow drift

Very efficient redistribution…

Picture Courtesy: SLF Davos

Accumulation by avalanche

~2500m asl

Ice-chapel at Watzmann, German Alps

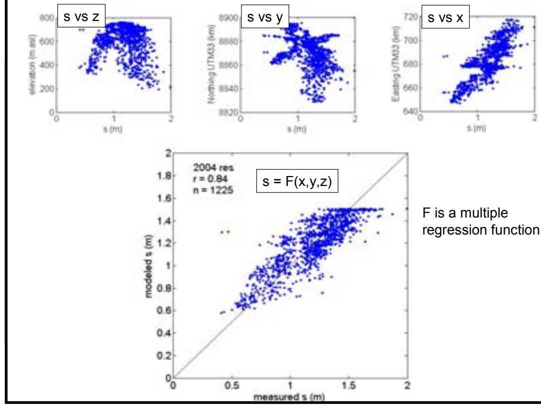
850 m asl

…is the ice-chapel a glacier?

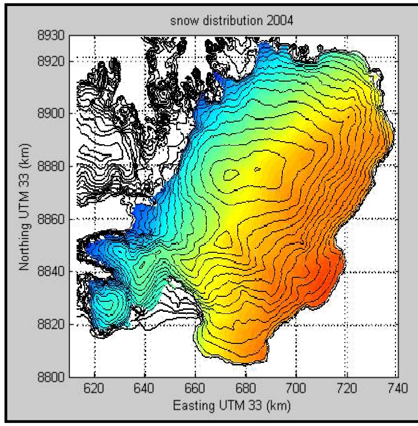
Snowcover distribution

- Quantifying snowfall is problematic.
- In practice, we are often just concerned with the snowcover distribution

  (e.g.,avalanche warning, meltwater runoff)



F is a multiple regression function



multiple regression: using x,y,z position

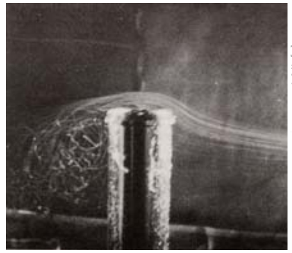
Snowcover distribution

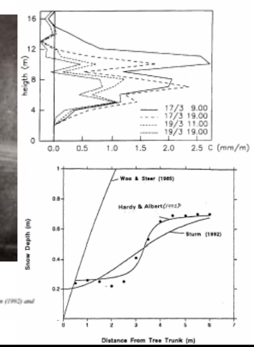
- **Topographic Effects**
  - Seasonal snow cover increases with elevation *if other influencing factors do not vary with elevation*
    - Why ?
    - Relation between snowfall and elevation may vary widely from year-to-year
    - Elevation *is not* only factor in snow cover distribution
      - slope, aspect, vegetation, wind, temperature, and characteristics of the parent weather systems

Snow at different scales

- Microscale (10-100 m)
  - Topography (slope, aspect, elevation), vegetation
- Mesoscale (0.1-1km)
  - Topography (slope, aspect, elevation), vegetation (forest)
- Macroscale (>10 km)
  - Latitude, macrotopography, distance to moisture source etc

Microscale





Mesoscale

Simulating snow transport using a turbulence-model of airflow
from: Corripio et al (in press)

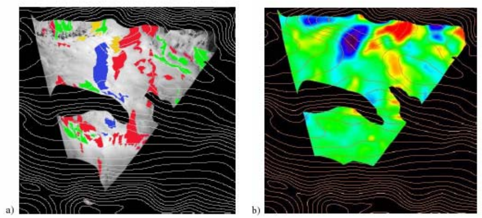
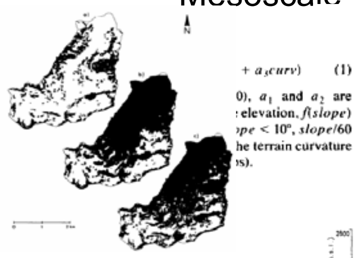
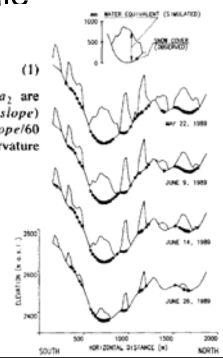


Figure 5. Comparison between manually mapped areas of snow accumulation (blue and green) and erosion (red and orange) and those modelled by SYTRON2 at the Col du Lac Blanc experimental site. Colours range from red (erosion) to blue (accumulation). North is right.

Mesoscale

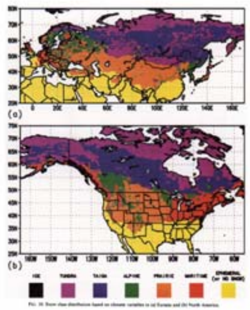




Snow distribution using terrain parameters

Blöschl et al., 1991

Macroscale



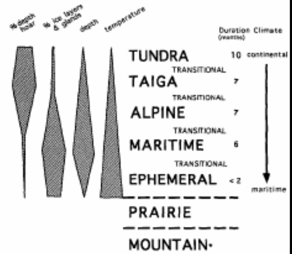


FIG. 1. Seasonal snow cover classes in the new system. Note that mountain (•) snow is a special designation for regions where the snow cover is highly variable.

Sturm et al., 1995

Macroscale

Snow classification (Sturm et al., 1995)

TABLE 2. Snow class descriptions.

Snow cover class	Description	Depth range (cm)	Bulk density (g cm⁻³)	Number of layers
tundra	A thin, cold, wind-blown snow. Max. depth approx. 75 cm. Usually found above or north of tree line. Consists of a basal layer of depth hoar overlain by multiple wind slabs. Surface sastrugi common. Melt features rare.	10–75	0.38	0–6
taiga	A thin to moderately deep low-density cold snow cover. Max. depth: 120 cm. Found in cold climates in forests where wind, initial snow density, and average winter air temperatures are all low. By late winter consists of 50% to 80% depth hoar covered by low-density new snow.	30–120	0.26	>15
Alpine	An intermediate to cold deep snow cover. Max. depth approx. 250 cm. Often alternate thick and thin layers, some wind affected. Basal depth hoar common, as well as occasional wind crusts. Most new snowfalls are low density. Melt features occur but are generally insignificant.	75–250	no data	>15
maritime	A warm deep snow cover. Max depth can be in excess of 300 cm. Melt features (ice layers, percolation columns) very common. Coarse-grained snow due to wetting ubiquitous. Basal melting common.	75–500	0.35	>15
ephemeral	A thin, extremely warm snow cover. Ranges from 0 to 50 cm. Shortly after it is deposited, it begins melting, with basal melting common. Melt features common. Often consists of a single snowfall, which melts away, then a new snow cover reforms at the next snowfall.	0–50	no data	1–3
prairie	A thin (except in drifts) moderately cold snow cover with substantial wind drifting. Max. depth approx. 1 m. Wind slabs and drifts common.	0–50	no data	<5
*mountain	A highly variable snow cover, depending on solar radiation effects and local wind patterns. Usually deeper than associated type of snow cover from the adjacent low-lands.		no data	variable

* Special class.

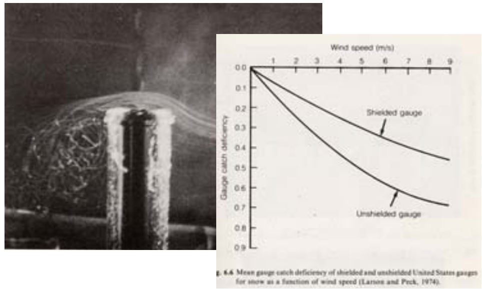
Bibliography

- **Essery et al., 1999**: A distributed model of blowing snow over complex terrain, Hydrological Processes 13, 2423 – 2438
- **Sturm et al., 1995**: A seasonal snow cover classification system for local to global applications, Journal of Climate 8, 1261 – 1283
- **Gray & Male, 1981**: Handbook of Snow, Pergamon Press
  - Snowfall pp 153-187
  - Snowdrift pp 338-358
  - Infiltration pp 398-406

Measuring snow precipitation

- Rain gauge
- snow depth sounding, ultrasonic ranger
- (snow pillow)
- (radar, GPR and SAR)

Snow measurement



Gray & Male: Handbook of Snow (1981)

Snow measurement

Pcorr = Pgauge * C
C = f (w, T, gauge type)

Hellman gauge
w = wind speed (m/s), T = air temperature (°C)

T(°C)	w (m/s) 1	3	6
0	1.28	2.01	3.98
-5	1.28	2.32	5.56
-10	1.28	2. 67	8.19

Correction factor

- Usually is just one correction factor used for entire winter
  - varies from station to station
  - depends on station wind exposure
  - larger correction for wind exposed stations
  - varies from gauge type to gauge type

Snow measurement

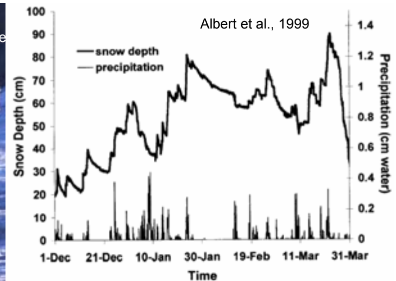
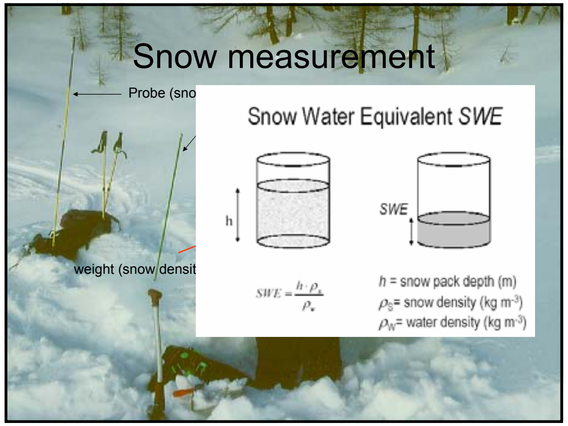
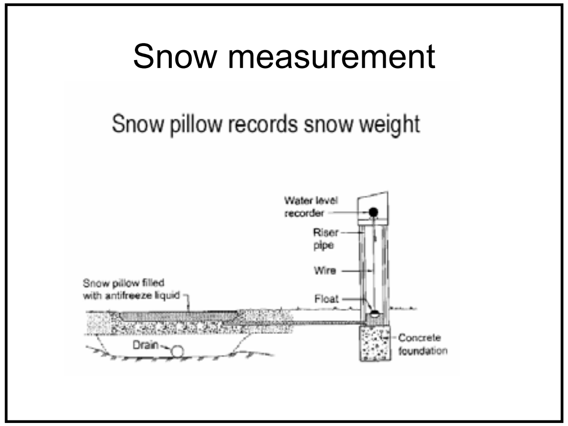


Figure 2. Snow depth and precipitation data for the season


Snow measurement
Snow Water Equivalent SWE
h
SWE
h = snow pack depth (m)
ρS= snow density (kg m-3)
ρW= water density (kg m-3)


Snow measurement
Snow pillow records snow weight
Water level recorder
Riser pipe
Wire
Float
Snow pillow filled with antifreeze liquid
Drain
Concrete foundation