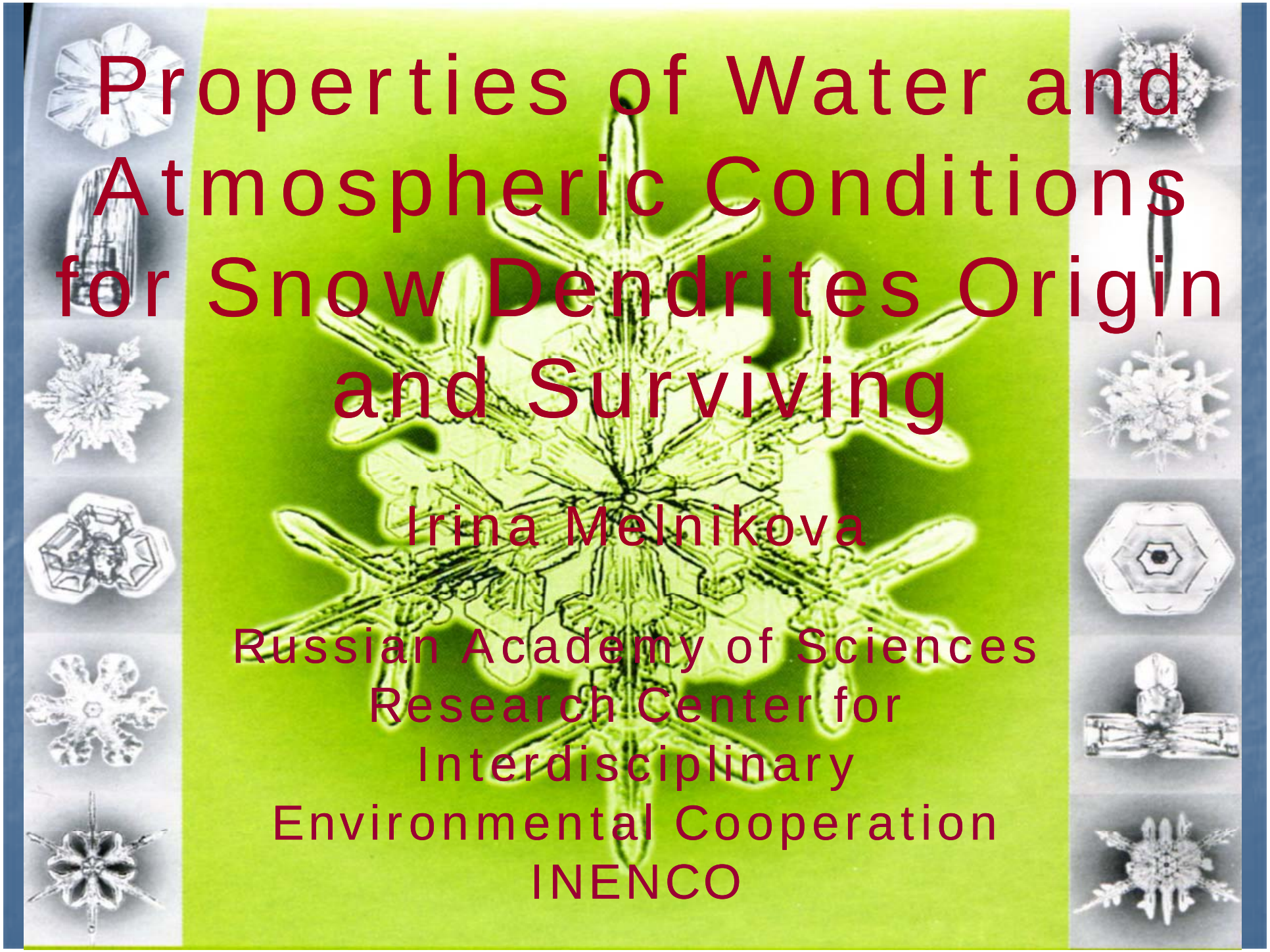
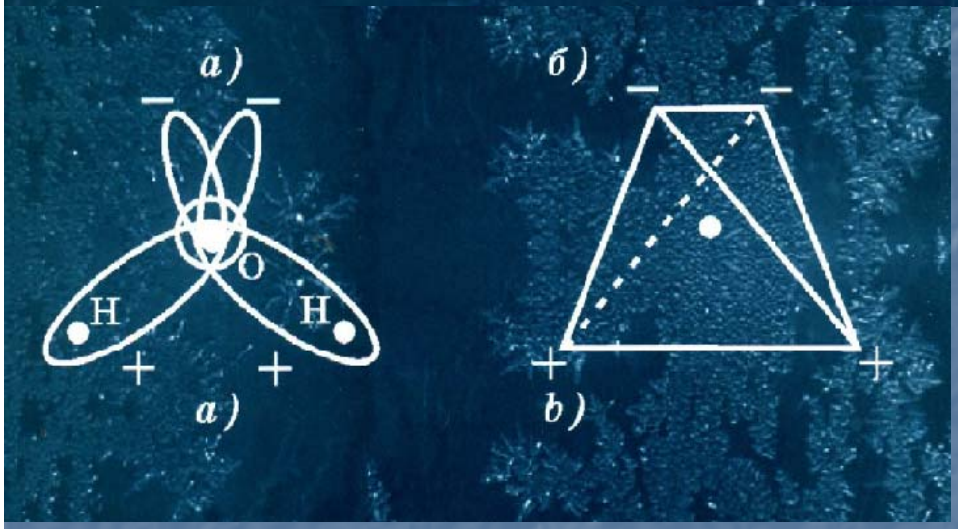


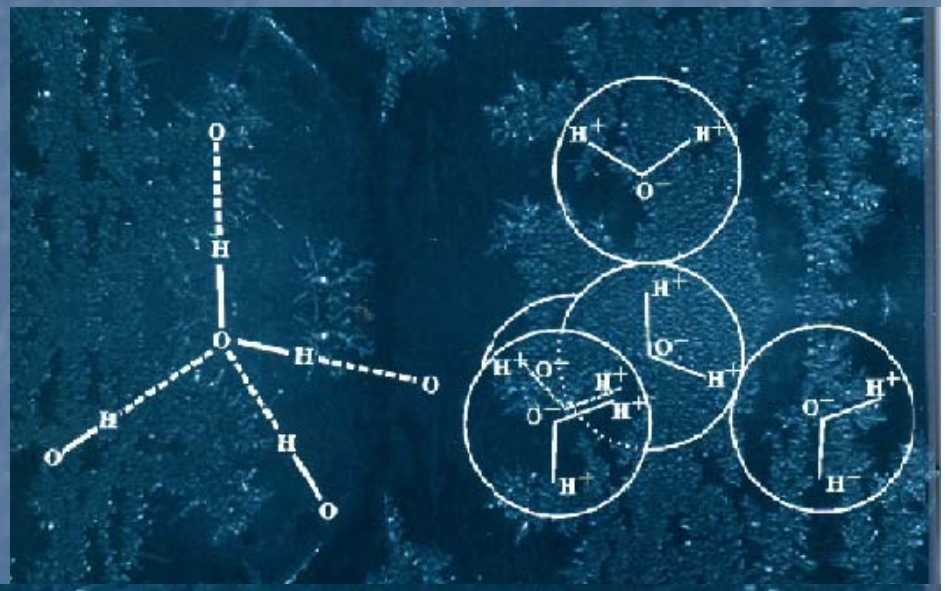
Properties of Water and Atmospheric Conditions for Snow Dendrites Origin and Surviving

Irina Melnikova

Russian Academy of Sciences
Research Center for
Interdisciplinary
Environmental Cooperation
INENCO

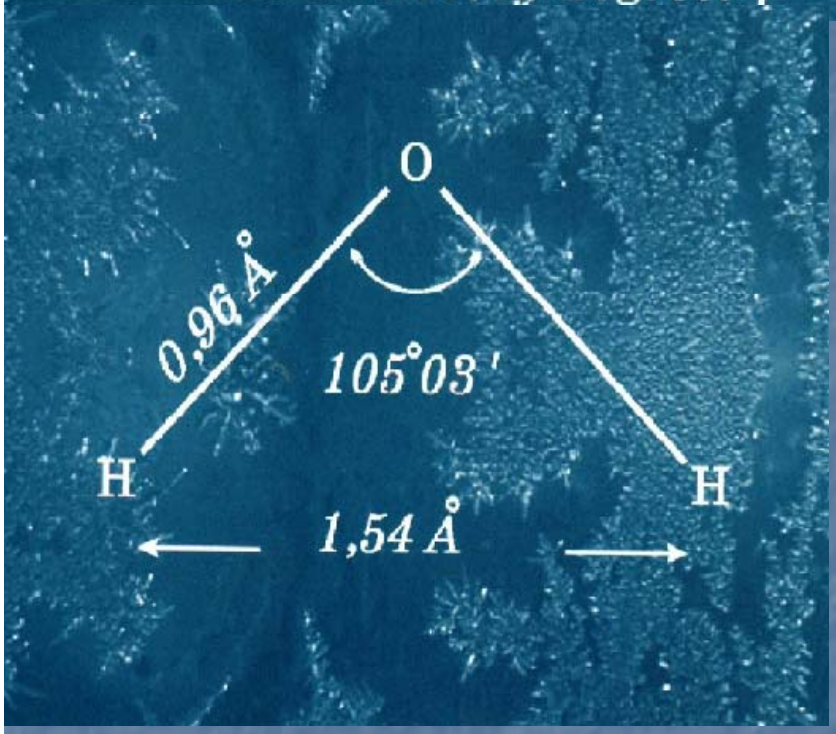
Water molecule is a polar molecule. It has constant polar moment which is equal to 1.87 D. Three nuclei in water molecule form isosceles triangle with two protons in the base and oxygen nucleus in the peak (a). Electrostatic water model looks like regular tetrahedron. Tetrahedron center is located in the center of molecule mass, two peaks have positive charge (+0.3e), and the other two negative (−0.6e) (b). First such model was proposed by D. Bernal and R. Fauler (1933).



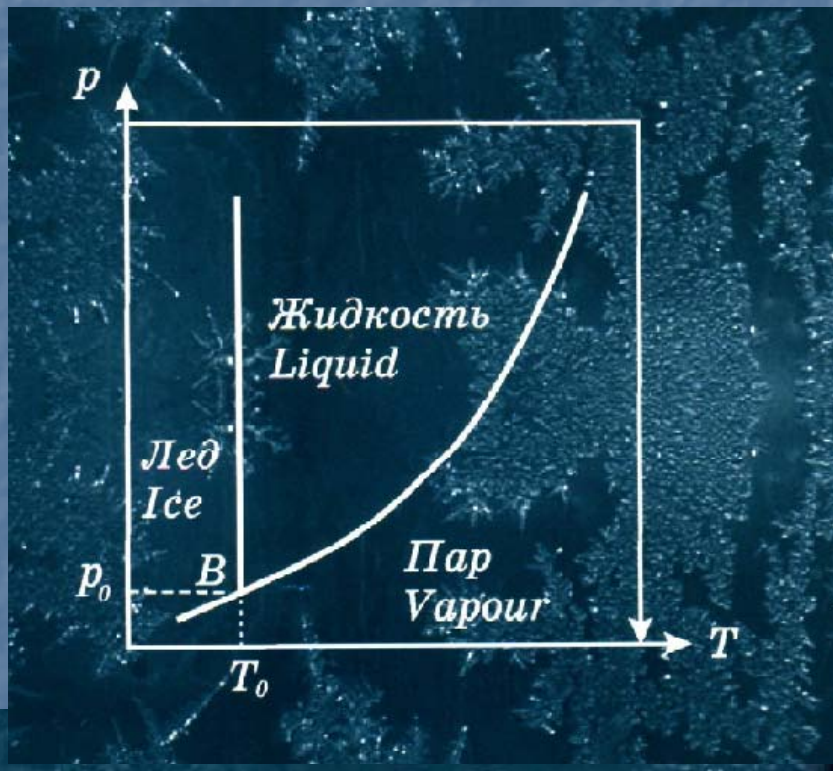


Ice has strictly determined structure. Each water molecule within ice is connected by hydrogen bonds with nearest molecule

Properties of different water phases are determined by peculiarities of it molecule structure. Sizes and form of molecule can be changed due to excitation of rotational oscillation and electron liberty degree.

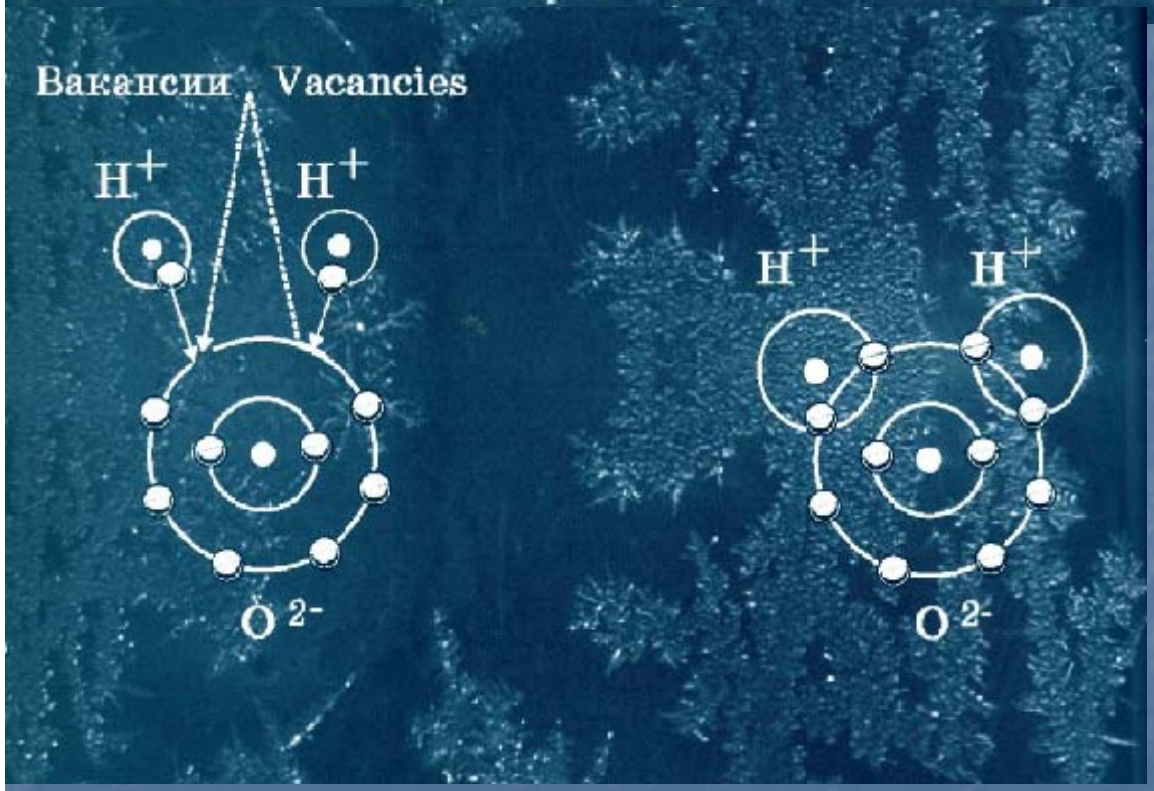


T_{cr} =100° The temperature in the atmosphere is always <T_{cr} and often <0° and vapor can transform to water and ice



There is so called triple point of water B. Here water can be in vapour, liquid and solid phase at the same time (T_0 = 0.0075 °C, p_0 = 6.1 hPq).

Electrons of oxygen and hydrogen take part in formation of chemical (covalent) bonds. Hydrogen atoms have only one electron shell with the only one electron, oxygen atom has two shells, first is inner with two electrons and the second one is exterior with six electrons. Two electrons of hydrogen atoms fill vacancies of two missed (to eight) electrons of exterior shell of oxygen atom in order exterior shell to be stable.

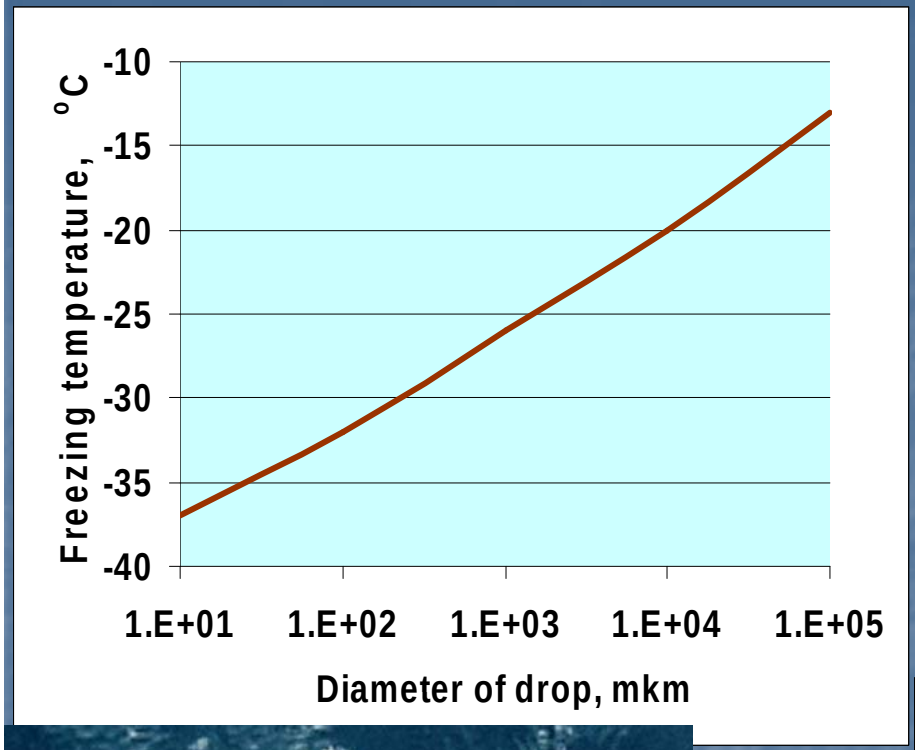


What are the **key parameters** in the atmosphere?
Temperature (T), Water vapor density (W),
Humidity $q=q_0 10^{-0.159z}$ – decreasing with altitude from analysis observational data at Alpine stations (Gann)

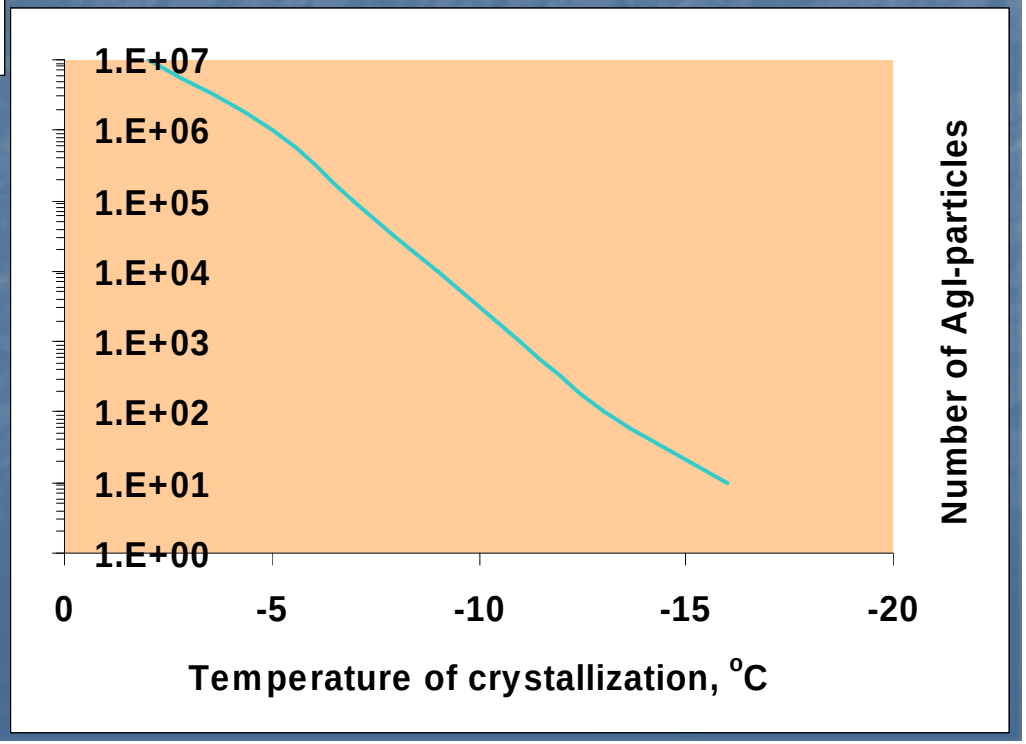
Key Processes: 1. Condensation – Vaporization: vapor ⟷ water
2. Sublimation: vapor ⟷ ice
3. Melting – freezing: water ⟷ ice

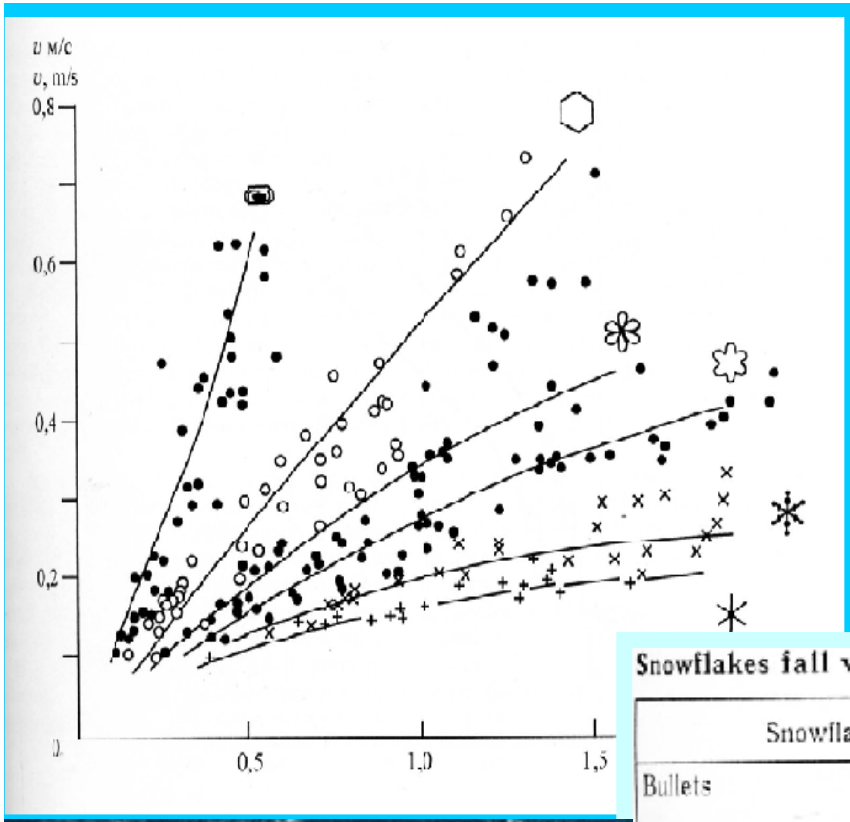
Thermodynamic parameters of WATER, VAPOR, ICE

	Density kg m^{-3}	Specific heat J deg^{-1} kg-1	Transition latent heat kg^{-1}	Surface tension m^{-2}
Ice	0.917	2106	I–W 3.34 x 10^5 I–V 2.83 x 10^6	Ice–air 8.0x10^4
Water	1.000	1007	W–V(T=0°) 2.50x10^6 W–V(T=100°)2.25x10^6	
Water vapour	0.622xρ_{air}	c_p = 1952 c_v = 1463		Water–air 7.5x10^4
Dry Air	1.275	c_p = 1004 c_v = 717		



Temperature of freezing and crystallization





Dependence

of plate-like crystals fall velocity on their

size *d* (Fig)

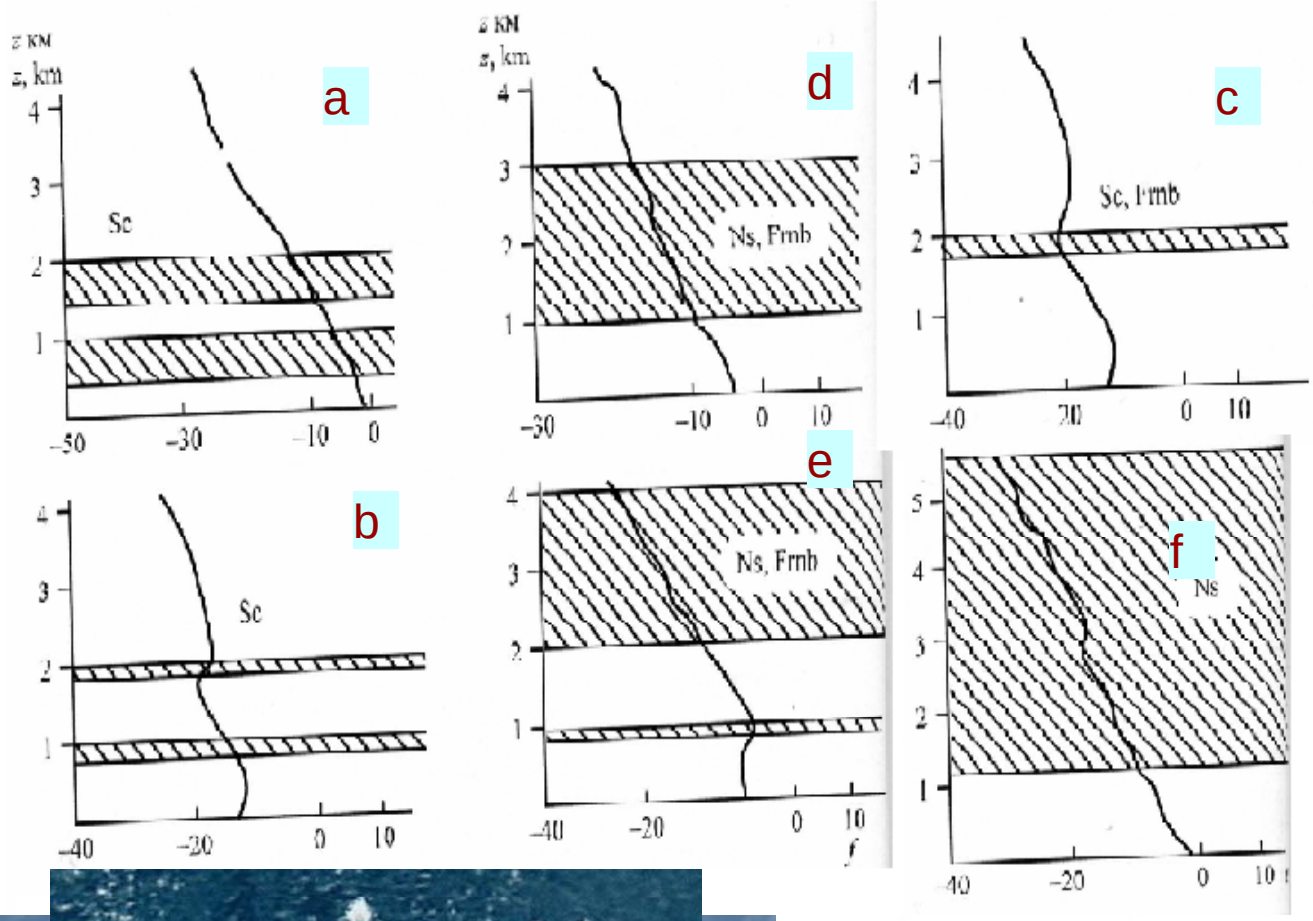
and types (Table)

Snowflakes fall velocity data [2]

Snowflakes form	Snowflake sizes, mm	Snowflake fall velocity, cm/s
Bullets	0.32—0.55	77.0—106.3
	0.39—0.56	58.7—80.7
capped with plates	0.48—0.85	51.0—91.7
Clusters	0.54—0.86	75.8—106.3
capped with plates	0.53—1.23	70.0—118.2
Columns capped with plates on both ends	0.61—1.36	59.4—113.1
Thick plates (or spatial hexagonals)	0.28—0.43	32.2—48.0
Hexagonals thin	0.32—0.65	20.8—41.0
Stellar crystals		
dendritic with branched beams	0.91—3.08	12.5—46.3
dendritic with branched beams originating from center and finishing by small plates	0.57—3.42	21.7—67.9
plate-like	0.42—1.30	21.0—61.0
Graupel	0.28—1.35	34.4—113.6

Cloud properties and types of snowflakes

CLOUG FORM	Heights, km		CLOUD THICKNESS, m	Temperature, °C					Snowflake type							TEMP. PROFILE
	BASE	TOP		within		Near surface 0.3-0.5km		AT the SURFACE	NEEDLES	THIN HEXAGONALS	STELLARS	IRREGULAR PLATES	COLUMNS	SPATIAL HEXAGONALS	SNOW FLAKES	
				FROM	UP TO	FROM	UP TO									
Sc	0.45 1.50	1.1 2.1	650 600	-3.4 -9.4	-6.5 -14.5	-1.0	-2.0	-0.4	X	X	X	X	X		X	a
Sc	0.7 1.7	1.0 1.9	300 200	-11.5 -17.4	-13.5 -20	-10.0	-10.7	-10.7		X	X	X			X	b
Sc Frnb	1.7	2.15	450	-20.4	-21.2	-10.0	-10.9	-10.9		X	X	X			X	c
Ns Frnb	0.85 0.6	3.05	2200	-9.0 -5.5	-19.1 -7.0	-3.2	-2.6	-2.6		X	X	X	X		X	d
Ns Frnb	1.8 0.7	4.0 0.75	2200 50	-11.7 -7.0	-27.0 -8.0	-7.8	-7.3	-7.3		X	X	X	X	X	X	e
Ns	1.1	5.5	4400	-10.0	-33.0	-5.5	-3.8	-3.8		X	X	X	X	X	X	f



Temperature profiles

in clouds from

airborne data

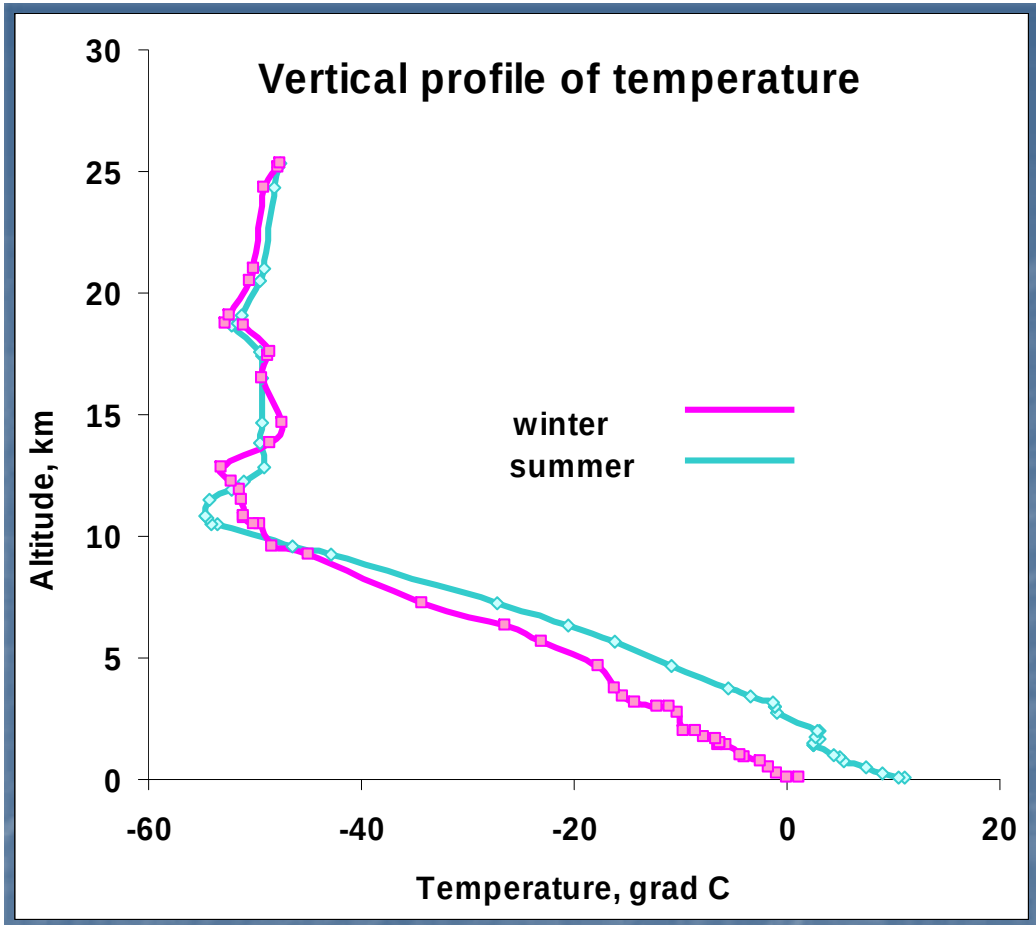
Frequency (%)

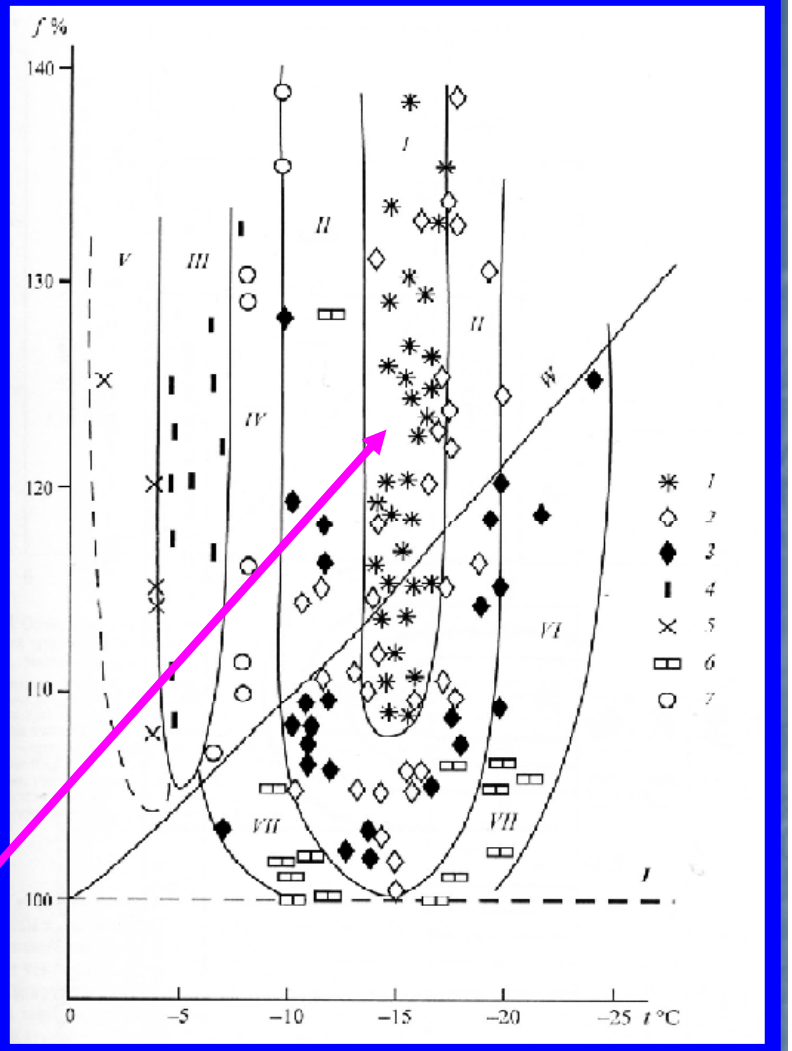
of snow flake

types

owflake types
falls

Type of particles	Center of Russia European part	Verkho-yansk
Clusters	38.5	26
Stellar crystals	28.0	—
Plates	17.0	34
Needles	9.3	6
Capped columns	2.0	—
Columns	1.8	34
Snow graupel	3.4	—





Snow quality for ski is regulated by type and shape of snowflakes.

Snowflake shape depend on

1) T-W – diagram;
2) nuclei composition (reagents)

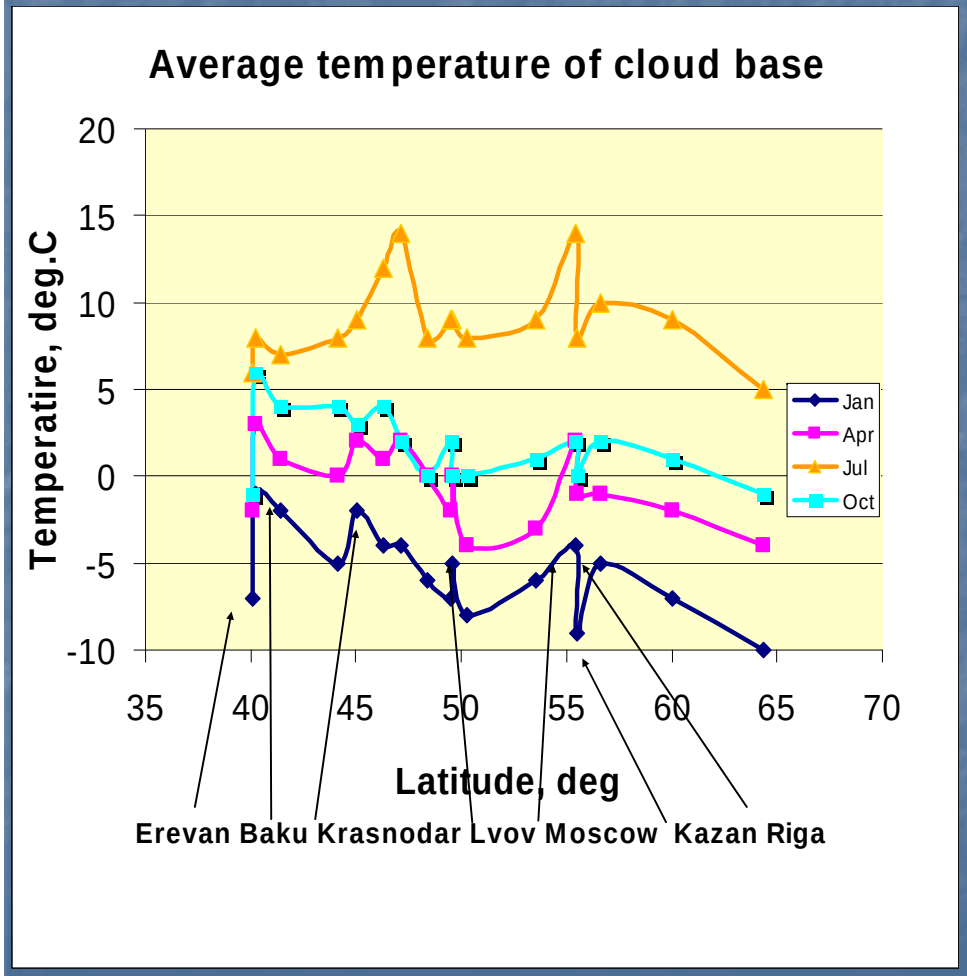
(This property is used for reagent identification)

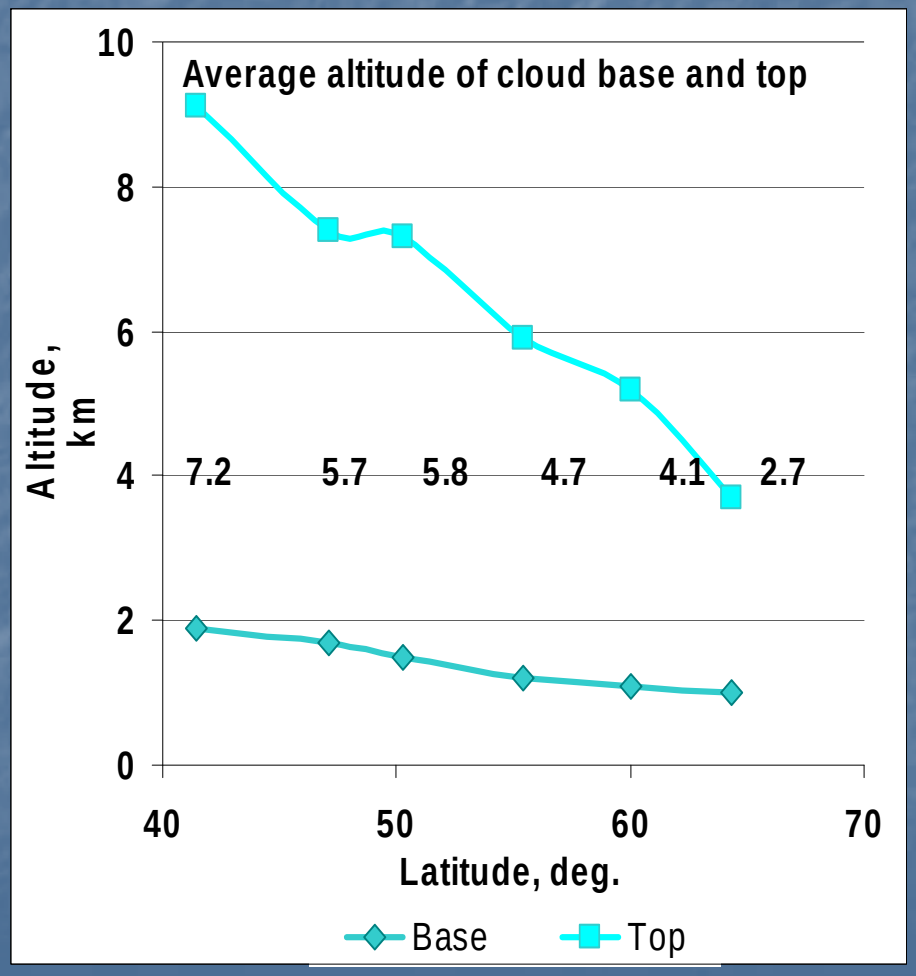
f >108%, T~12-16 ºC

Dependence of snow crystals form on air temperature (t) and water vapour density excess (f) (the diagram of U. Nakaya).

1 — dendrites; *2* — sector stellar crystals and plates; *3* — thick plates, spatial plates; *4* — needles; *5* — irregular needles; *6* — columns; *7* — cups;
I—*VII* — regions with predominant crystal form.
W — water saturation; *I* — ice saturation.

Temperature and altitude of cloud

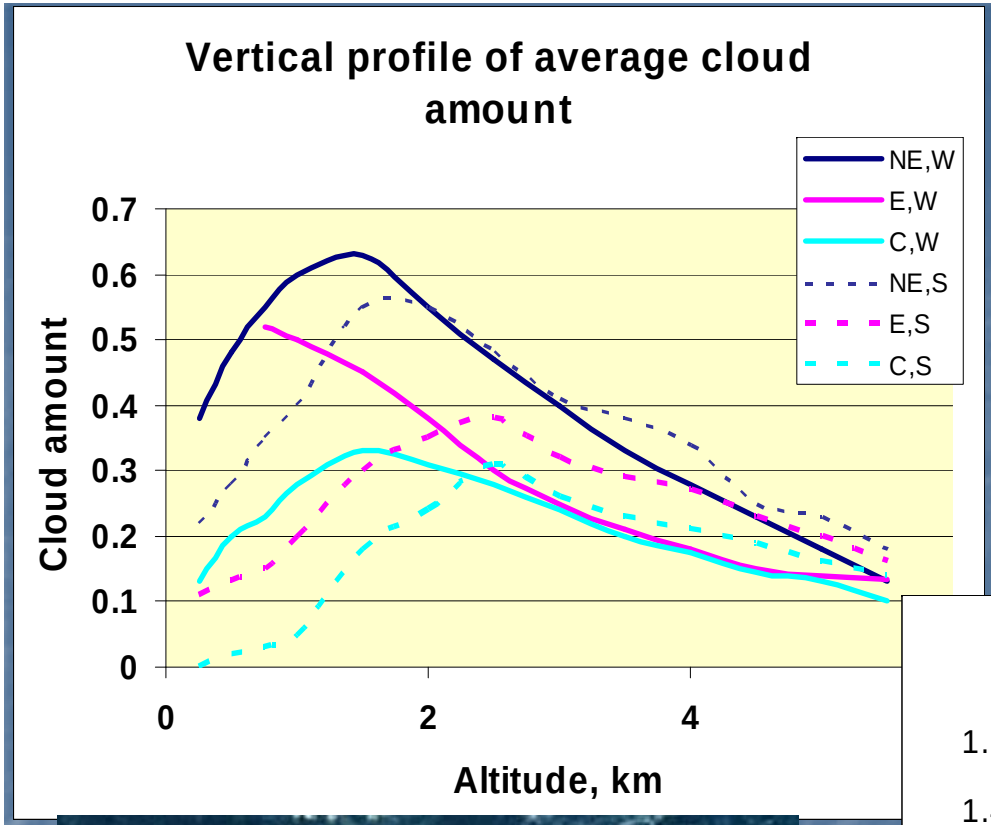


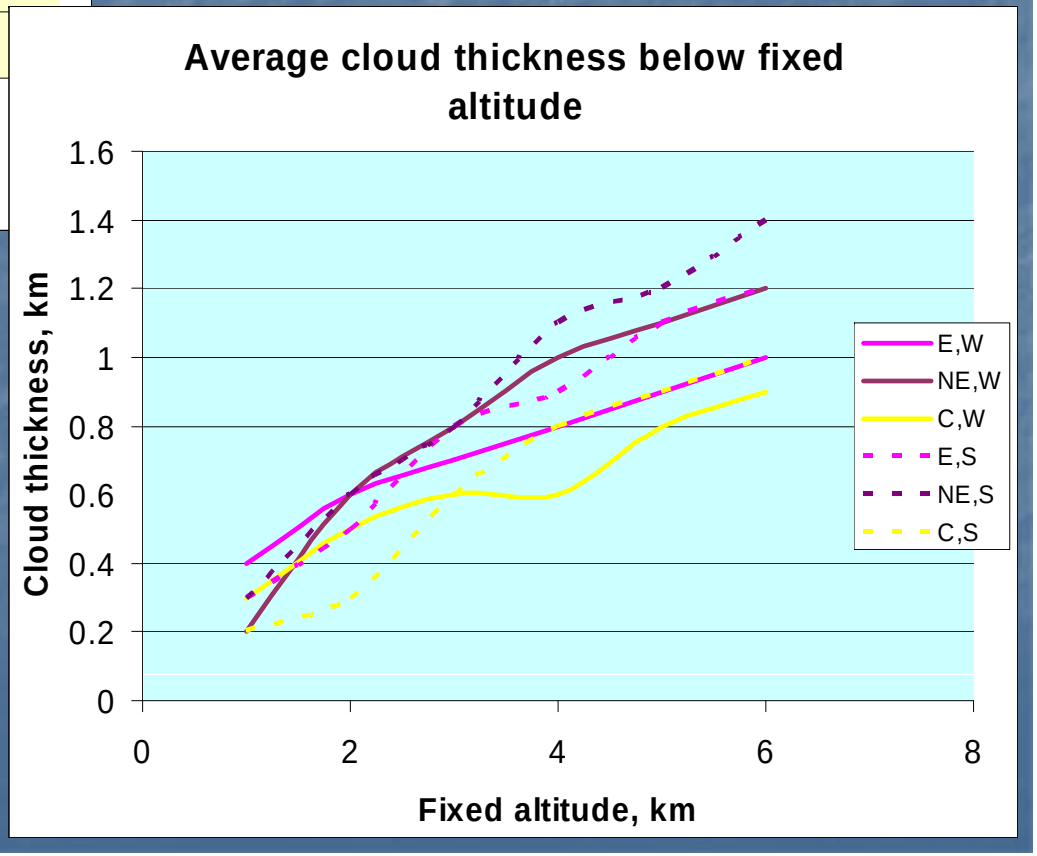


How high are the Clouds: Types, Altitudes, Temperatures, Precipitation

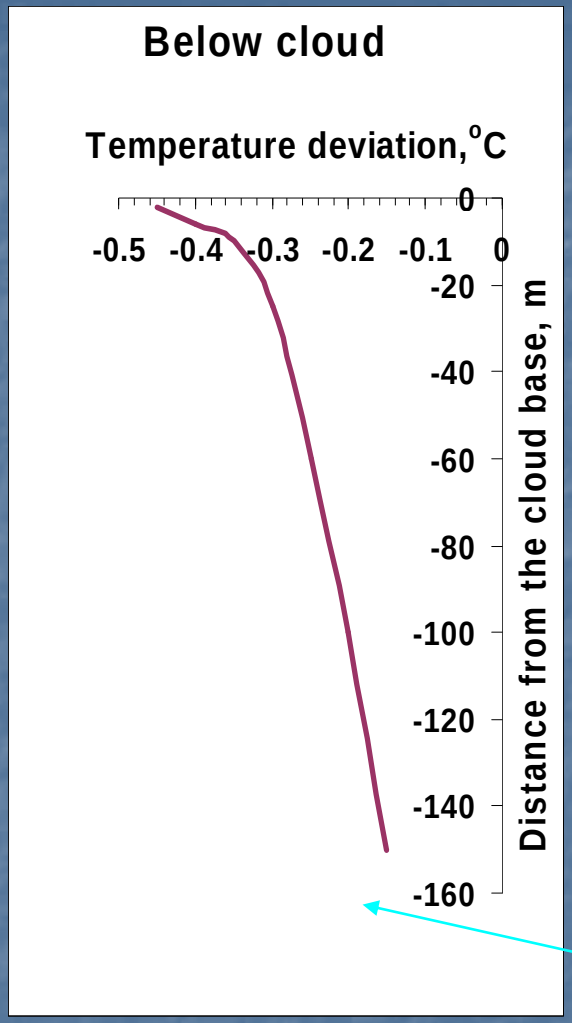
Base altitude, km	Thickness km	Cloud type	Precipitation	Winter Temperature Base	Top	Gradient
High level >6	0.2	Cirrus (Ci)	No			
	0.4	Cirrocumulus	No			
	0.1-2.0	Cirrostratus	No			
Middle level 2–6	0.2-0.7	Altocumulus	Weak			
	1.0	Altostratus	Weak			
Low level				summer, Cb Ttop=-15; Tbase=-1		
0.1-0.7	0.2-0.8	Stratus (St)	Weak	-7	-10	0.66
0.5-1.5 <2	0.2-0.8	Stratocumulus Sc	Weak	-7	-12	0.74
0.1-1.0	1.0-5.0	NIMBOSTRATUS Ns	Heavy, long duration	-10	-25	0.55

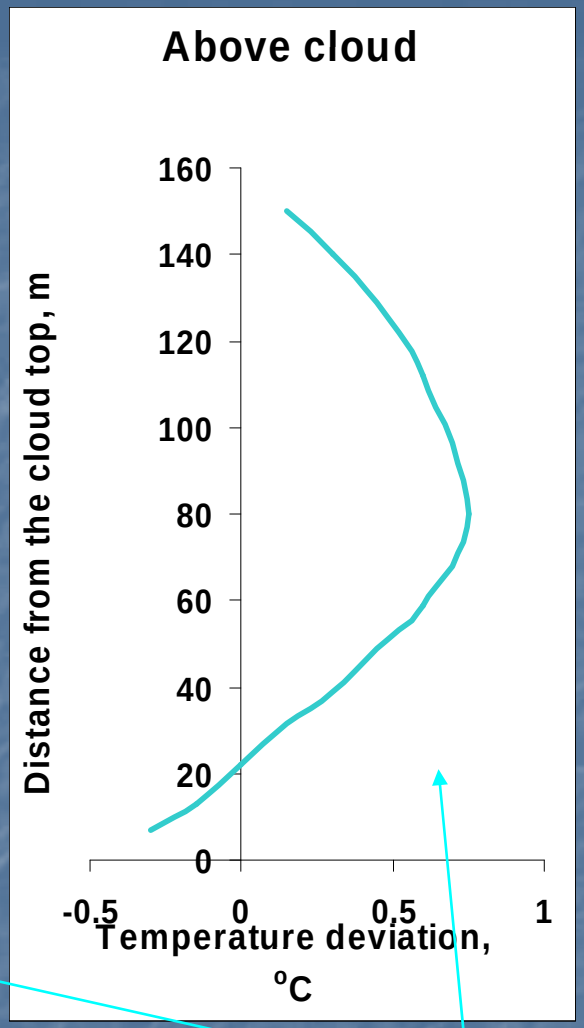
Cloud amount and thickness

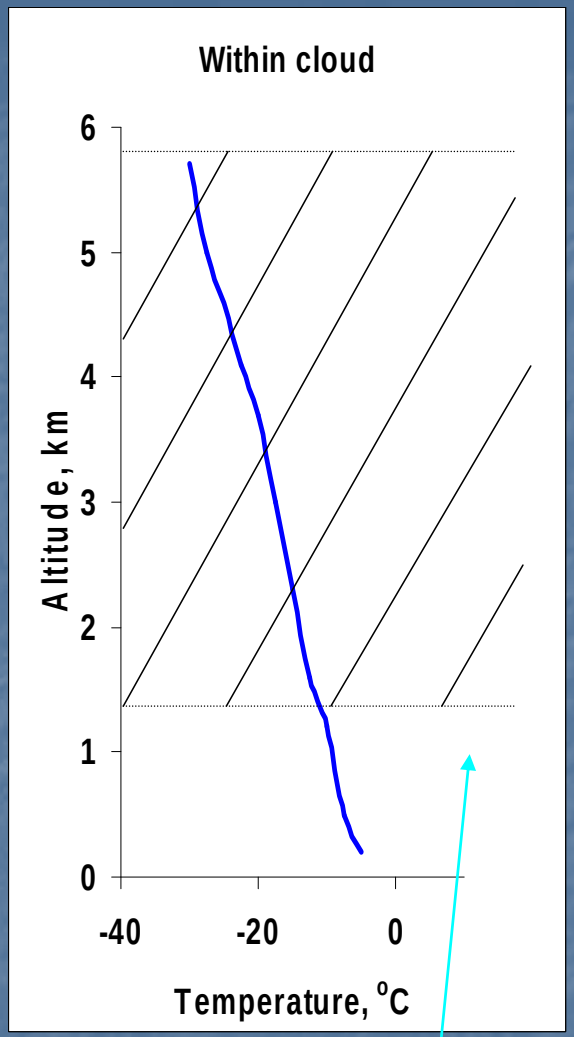




Temperature out and within clouds







Appeared that it is not important for dendrite shape

It is important!

Aerosol nucleus impact: How the snowflake starts to grow and how we can enhance this growth?

Snow quality for ski is regulated by type and shape of snowflakes.
Snowflake shape depend on 1) T-W – diagram 2) nuclei composition (reagents)

Particles of AgI and PbI_2 are the most effective for freezing cooling droplets.

1. Negative ions better stimulate the process of nuclei origin
2. External electric field impacts (depending on the sense)
3. Freezing of the cloud containing large droplets (5 - 500mkm) is happen during several seconds, **-T=-10 – -15°C** – droplets size influence
4. The probability of the ice nuclei origin with aerosol particle has max for **-T=10 – -12°C**

What turbulences can occur within the cloud?

1. Average velocity pulsation is 0.2 – 0.3 m/s with Gauss distribution in St
2. Turbulence coefficient is 10 – 15m^2/s
3. Water content average Q_w=0.33(T=5) – 0.15(T= – 15) g/m^3
4. Water column $P = Q_w\Delta z$ = 0.04 – 0.15 kg/m^2
5. Average velocity pulsation is 1 – 4 m/s Cu, Cb, max = 10 – 15m/s
6. Turbulence coefficient is 50 – 150 m2/s
7. Water content average Q_w= 0.6(T=5) – 0. 4(T=-15) g/m^3 max: 2g/m^3
8. Ice content is in one order less
9. $P = Q_w\Delta z$ = 0.08 – 0.28 kg/m^2 , $P=0.3\Delta z^2$

What ground conditions are needed that the snow survives

1) surface temperature
2) type of the surface (roughness)
3) declination of the surface (governs sliding of snow mass, melting water run-off)
4) vegetation
5) shadowing
6) orientation

What are the atmospheric parameters that make snow surviving?

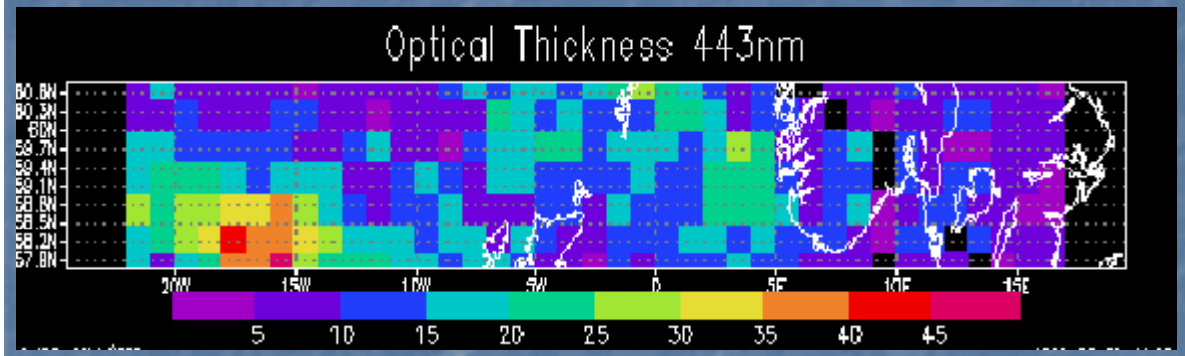
1) temperature profile (regulates cloudiness, precipitation, humidity)
2) water vapour density profile (regulates cloudiness, precipitation)
3) wind velocity (cooling factor)
4) declination of the surface (solar illumination)
5) cloud amounts (governs shadowing by clouds - cooling, greenhouse warming)

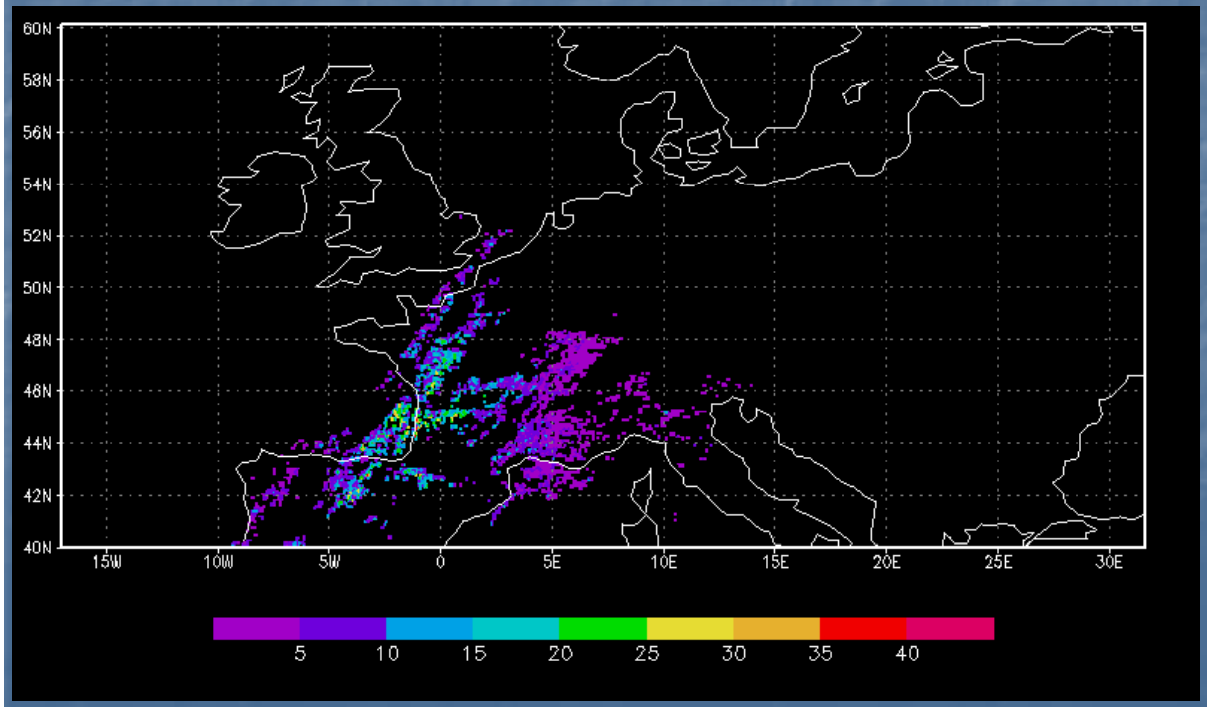
$$S_S = F_0 \frac{\exp\left(-\tau_0 / \sin h\right)}{\left(1 - A_s A(0)\right)} \mathrm{x}$$

$$\mathrm{x}\left\{\begin{array}{l}\cos\alpha\left(\sin\varphi\sin\delta + \cos\varphi\cos\delta\cos\Omega\right) + \sin\alpha\cos\psi_n tg\varphi\left(\sin\varphi\sin\delta + \cos\varphi\cos\delta\cos\Omega\right) - \\ -\sin\alpha\cos\psi_n\sin\delta\sec\varphi + \sin\psi_n\cos\delta\sin\Omega\end{array}\right\}$$

RETRIEVAL OF CLOUD OPTICAL PARAMETERS FROM SATELLITE OBSERVATION

for precipitation forecast





$$\tau = 1{,}5\,\frac{W}{\rho\, r}$$

Precipitation amount

$$J = W\rho^{-1}$$

$$\sim \tau \Delta t$$

Surface Albedo impact:

$$R_S(\mu_0) = (1 - A_S)\frac{F^{\downarrow}(\tau_0, \mu_0)}{1 - A_s A(\tau_0)},$$

$F^{\downarrow}(\tau_0, \mu_0)$ = 0.025 fresh snow

= 0.160 old snow

=0.8 clear sky

=0.4 clouds

Albedo: fresh snow A=0.98, old snow A=0.85

$$\frac{(1 - A_S)}{(1 - A_S A(\tau_0))}$$

=0.03 clear sky, fresh snow

=0.05 clouds, fresh snow

=0.2 clear sky, old snow

=0.4 clouds, old snow

REFERENCES:

1. John M. Wallace, Peter V. Hobbs Atmospheric Science (an introductory survey). Academic Press. 1977, 470 pp.

2. Handbook of Clouds and Cloudy Atmosphere, ed. I.P.Mazin, A.Kh. Khrgian, Leningrad, Hydrometeoizdat, 1989, (in Russian).

3. Yu. A. Dovgalyuk, L. S. Ivlev. Physics of Water and other Atmospheric Aerosols St.Petersburg, St.Petersburg University, 1998, 324 pp. (in Russian).

4. L. S. Ivlev, Yu. A. Dovgalyuk. Physics of Atmospheric Aerosols Systems St.Petersburg, NIIH, 1999, 258 pp. (in Russian).

5. Atlas of Snowflakes. ed. Yu. A. Dovgalyuk, T. A. Pershina St.Petersburg, Hydrometeoizdat, 2005, 140 pp. (Bilingual).

6. Melnikova I., A. Vasilyev, Short-wave solar Radiation in the Earth Atmosphere. Calculation. Observation. Interpretation. Heidelberg, Springer-Verlag GmbH&Co.KG, 2004, 310 pp.

7. L.G.Kachurin. Physical Basement of Influence to Atmospheric Processes. Leningrad, Hydrometeoizdat. 1973, 366 pp. (in Russian).

8. G.F. Prikhotko. Artificial Preciptation from Convective Clouds. Leningrad, Hydrometeoizdat, 1968, 175 pp. (in Russian).

Thank you for attention