
Icing on overheadlines of electrified railway lines

Meteorological Conditions

1. Basics and understands

1.1. Processes of icing on overheadline

(Fog / Precipitation)

1.2. Physical basics

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Relative Humidity

Saturation

Dew Point

Condensation Nuclei

Density of air

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(Warm front / Cold front)

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Local wind in coastal areas

Wind speed

Cloud layers

2. Ice on overheadline due to fog

2.1. Mechanism of developing fog

(Upslope fog / Advection fog / Radiation fog / Evaporation fog / Frontal fog)

3. Ice on overheadline due to precipitation

3.1. Mechanism of developing precipitation

Clouds

Precipitation

(Rain / Freezing rain / Snow / Snow pellets / Ice pellets / Hail)

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(Clear ice / Rime ice / Hear frost)

5. Summary

1. Basics and understands

1.1. Processes of icing on overheadline

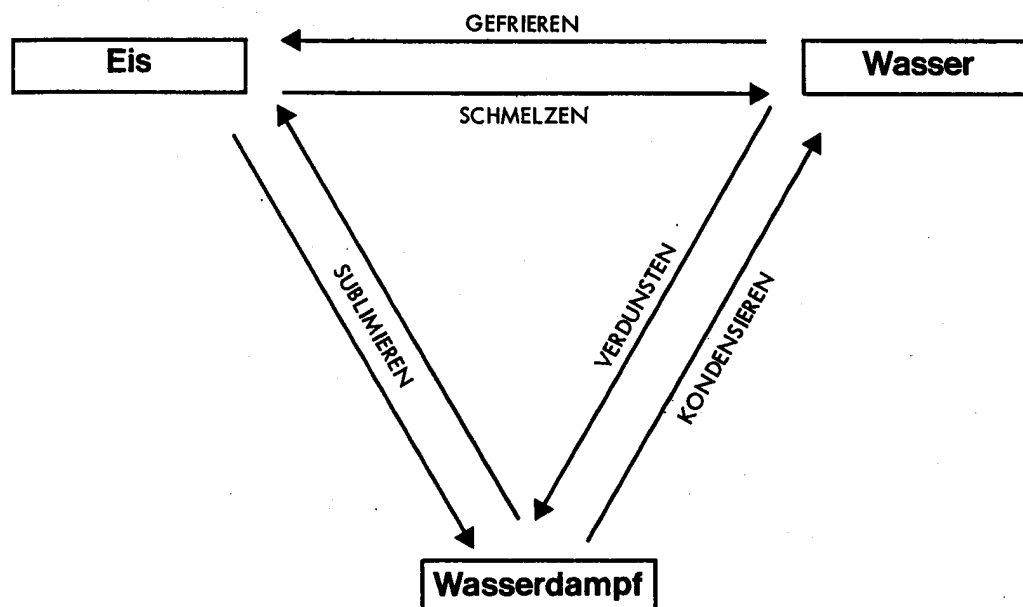
due to fog

A mass of air in the atmosphere is always containing an amount of water. If the temperature of this humid air will decrease, it will reach its point of saturation. That means, there is the beginning of condensation, so water will convert from gas to liquid state. The name of this phenomena is fog, in the mass of air there are existing very small water droplets. In case the temperature is decreasing more below 0°C, this small water droplets will convert from their liquid to their solid state (freezing). As a result, the fog may be frozen on the surface of the overheadline wire.

due to precipitation

Precipitation like rain droplets or snowflakes can fall onto the overheadline and on temperatures below 0°C it could be frozen.

1.2. Physical basics



There are three states of water (gas, liquid, solid). Changes of state are sublimation, freezing / melting and condensation / evaporation.

Absolute Humidity

In his gaz state as vapor air can contain a highly variable amount of water. The higher the temperature, the more water the air can contain.

Temperature	-20°C	-10°C	0°C	10°C	20°C	30°C
g H ₂ O per kg dry air	0.8	1.8	3.8	7.8	15	28

Conclusion:

The probability of getting ice on overheadline is the highest just at or below freezing temperature of 0°C. At lower temperatures, air can contain less water. In very low temperature conditions, the probability of icing on overheadline will be drastically reduced.

Relative Humidity

The ratio between the actual amount of water vapor held in the atmosphere compared to the amount required for saturation. Relative humidity generally is influenced by temperature and atmospheric pressure. For meteorologic purposes only the influence of the temperature is important, the atmospheric pressure don't vary so much (980 – 1'030 mbar).

$$\text{Relative Humidity} = \frac{\text{effective quantity of water in the air}}{\text{max. possible quantity of water in the air}} \quad [\text{in \%}]$$

Saturation

Atmospheric condition where water is changing its phase to liquid. At saturation relative humidity is 100 % unless there is a shortage of deposition or condensation nuclei. Generally this process is caused by the cooling of the atmosphere.

Dew Point T_{Dew}

Dew point temperature is the temperature, at which water vapor condensates from gas state into liquid. Dew point normally occurs, if there is a mass of air with a relative humidity of 100 %.

Condensation nuclei

Condensation nuleis are microscopic particles of dust, smoke or salt. Condensation normally occurs on these particles, if relative humidity becomes 100 %. The availability of condensation nuclei can lead to the situation, that water can condense at relative humidities lower than 100 %.

Density of air

The density of air changes with its temperature, the colder the temperature, the higher the density. That means, cold air is heavier than warm air, it will descend to the ground.

1.3. Meteorological basics

Air mass and weather front

An air mass is a body of air, whose temperature and humidity characteristics remain relatively constant. Air masses are classified according to their temperature and humidity characteristics.

A weather front is a transition zone between air masses with different weather characteristics. A weather front generally is a zone with meteorological activities like wind, clouds and precipitation.

Weather fronts develop in the area of northern Atlantic and then move eastwards to the European continent. You will see their position in forecast weather charts.

Warm Front

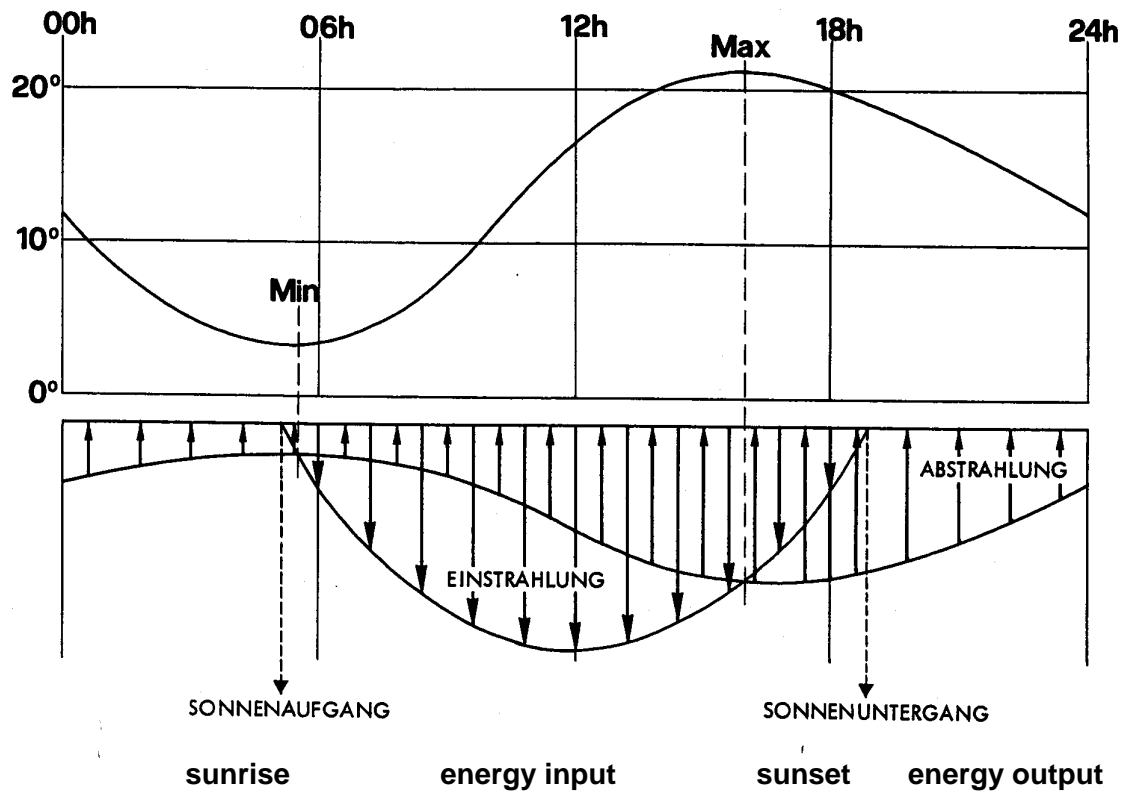
A transition zone in the atmosphere, where an advancing warm air mass displaces a cold air mass.

Cold Front

A transition zone in the atmosphere, where an advancing cold air mass displaces a warm air mass.

Daily temperature cycle

During daytime (between sunrise and sunset) there is an input of energy from sun to earth. During all the time, there is an output of energy from earth to space. As long the input is bigger than the output, the temperature on earth is increasing. It reaches its maximum value at approx. 16 h. After the output is dominating, so the temperature is decreasing during evening and night time and reaches its minimum at approx. 5 h in the early morning hours.



The lowest temperature is in the early morning hours. So during this time there is the highest probability to get fog.

Conclusion:

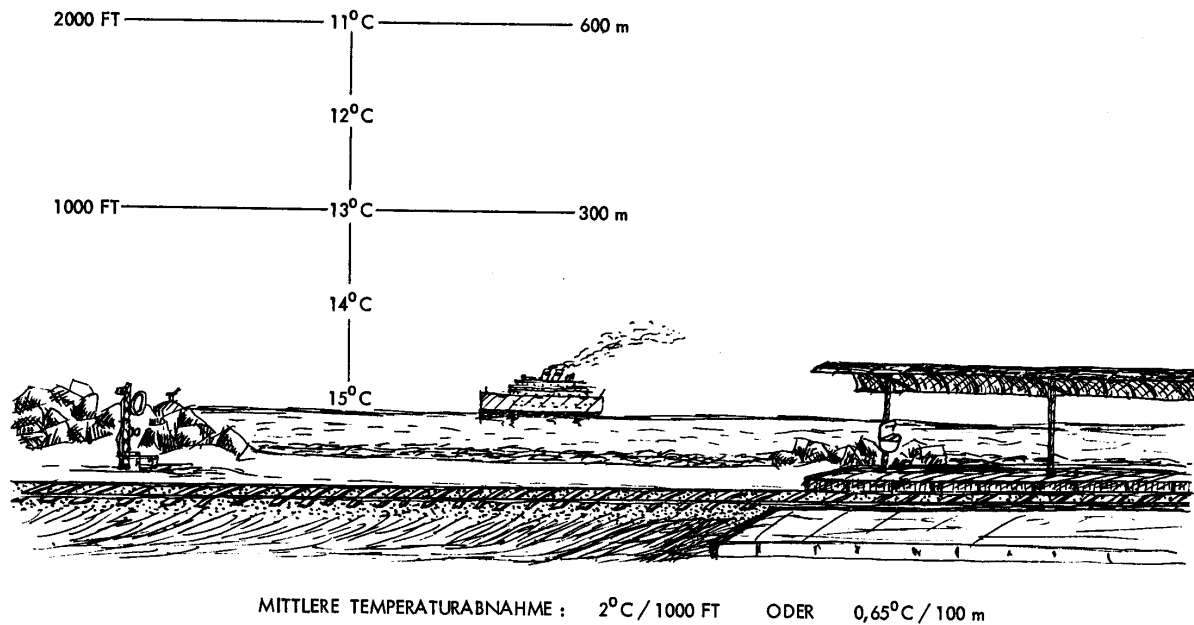
The highest probability to get ice on overheadline is during the early morning hours (at sunset) .

Temperature gradient in the atmosphere

Normally, during most of the time, the temperature gradient in the atmosphere is

- 0.65°C per 100 m

that means, the higher the altitude, the lower the temperature will be.



Extreme temperatures

Max. measured temperature	Switzerland	+39°C	Basel
	World	+58°C	Aziza, Lybia
Min. measured temperature	Switzerland	-40°C	La Brevine
	World	-91°C	Vostok Station, Antarctic

Temperature inversion

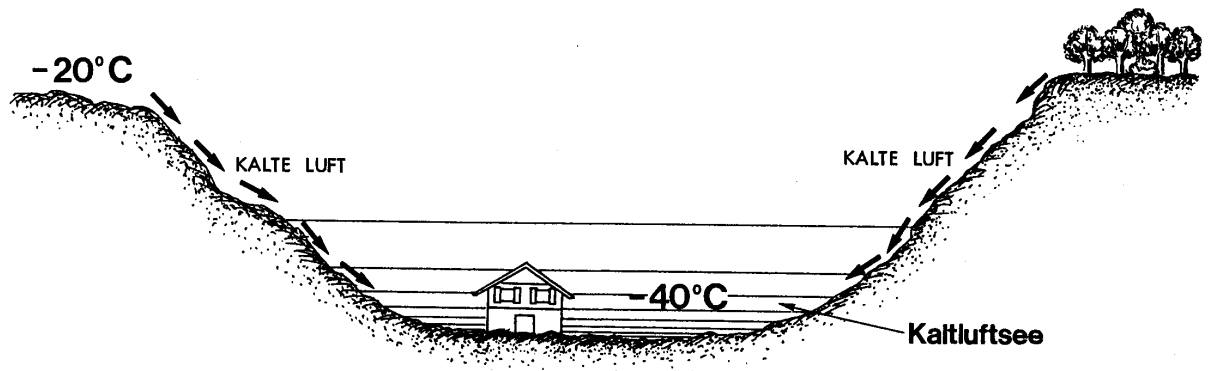
As seen before, normally the temperature gradient is negative (the higher the altitude → the lower the temperature). Generally this rule is valid over the whole atmosphere. Under some special conditions, there is also the possibility to have locally a positive temperature gradient (inversion).

During a cold, cloudless night, cold air (which is heavier than warmer air), is collecting itself at the bottom of a valley. As a result, there is a cold air layer of a few hundred meters.

Conclusion:

Into this „lake of cold air“, there is a high probability for icing on overheadline.

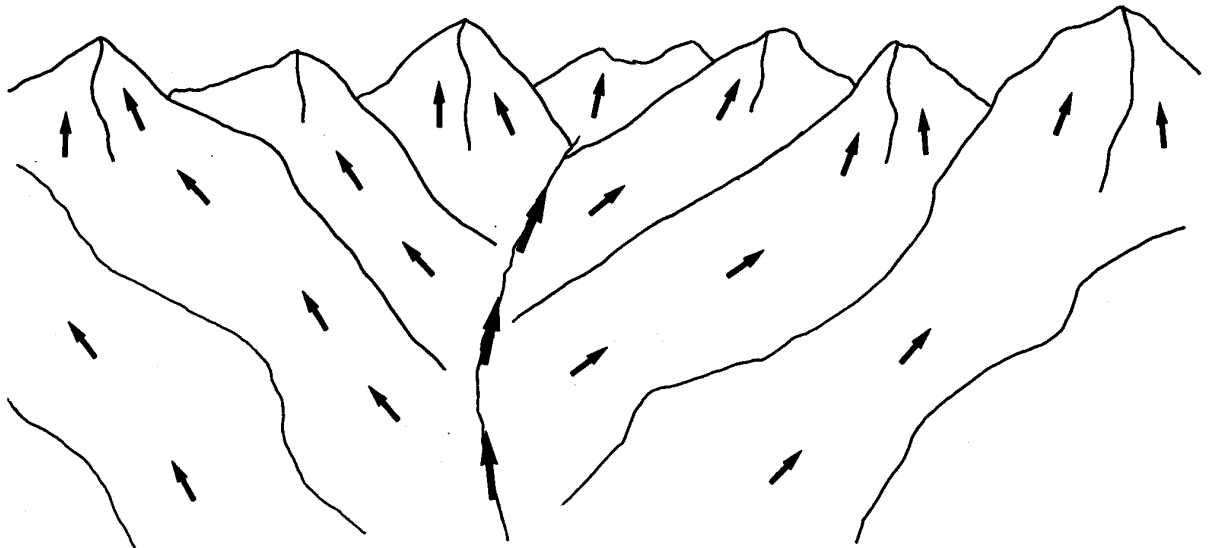
In mountain areas (like Switzerland), most problems with ice on overheadline are located inside of a cold air layer like it is described above. (into a zone of a few hundred meters above ground level, at the bottom of a lowland or valley)



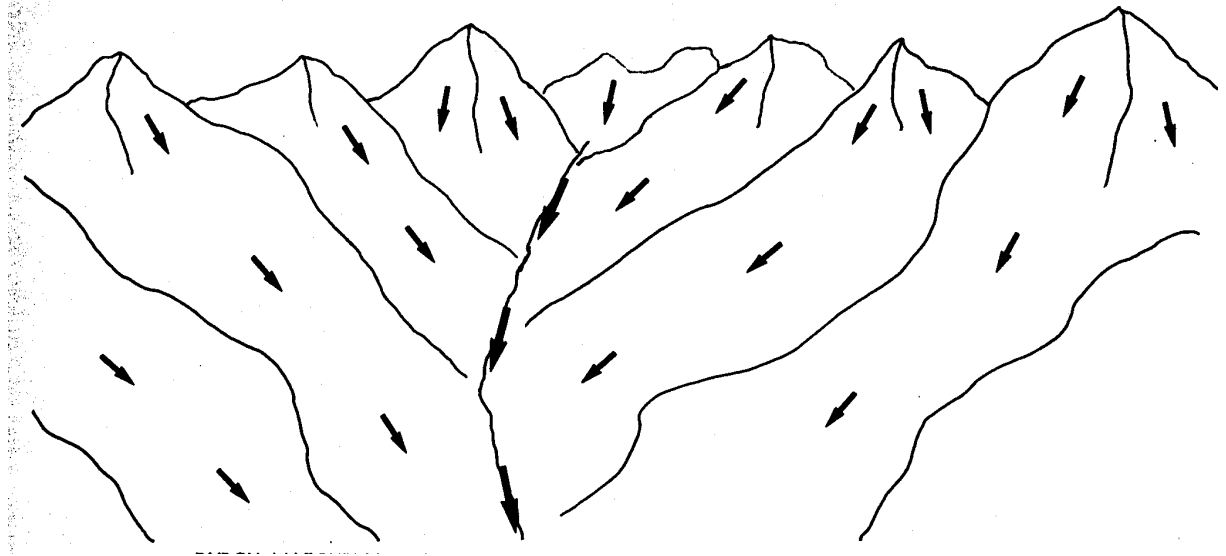
lake of cold air

Local winds in mountain areas

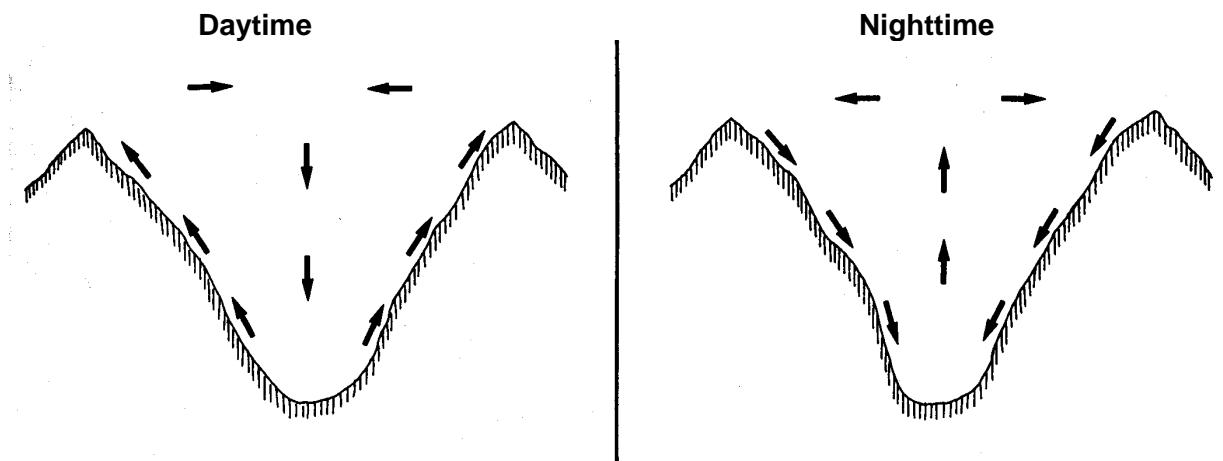
During daytime : The sun radiation is heating up the slopes of the mountains. The air near the slopes is ascending.



During nighttime : The mountain slopes are cooling, because there is radiation of energy to space. The air near the slopes is descending.

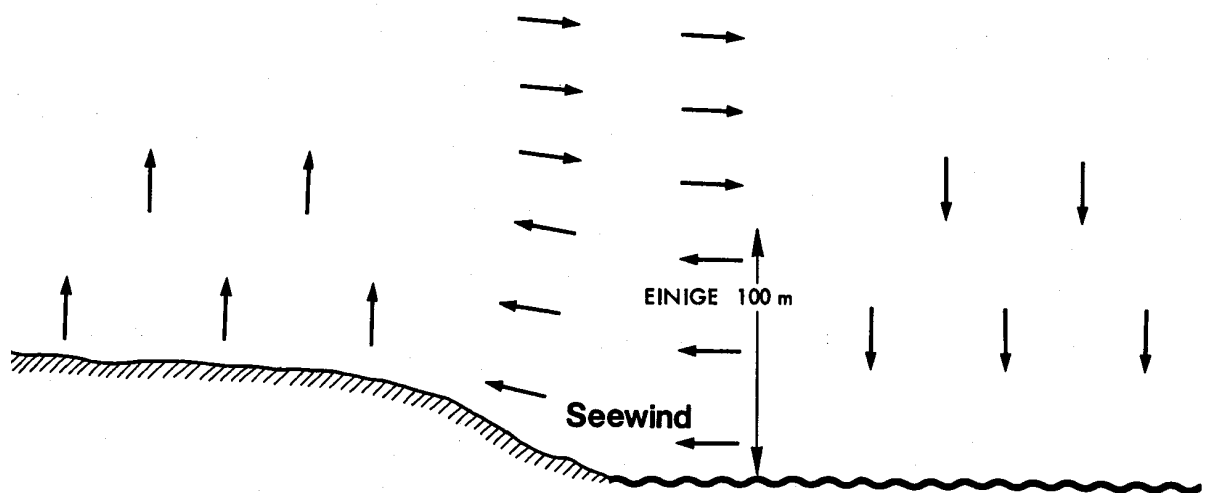


Next pictures will show the resulting wind circulation during day and night.

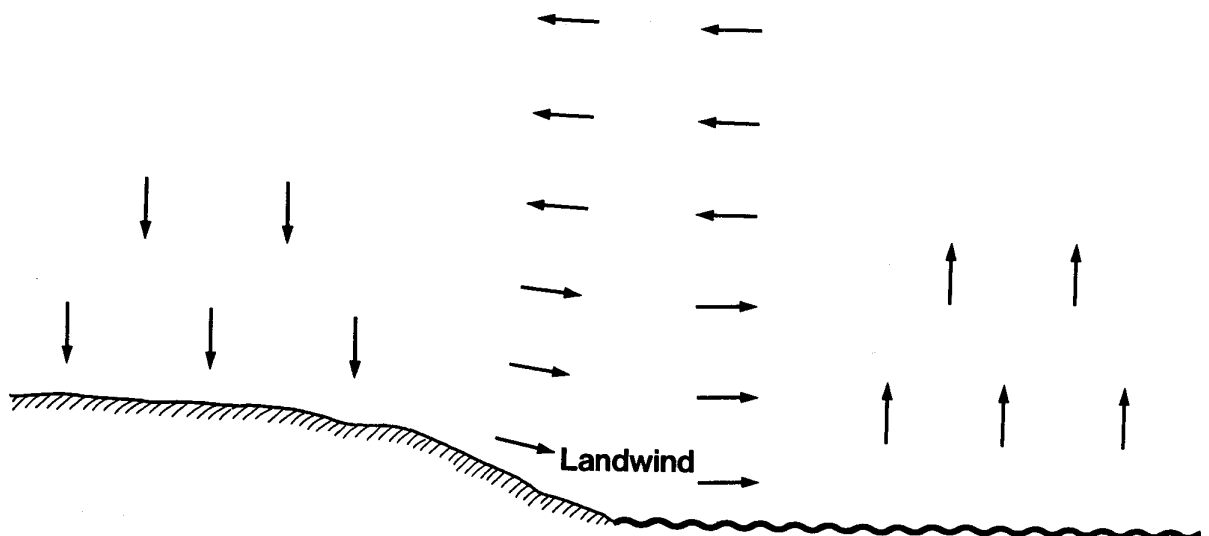


Local wind in costal areas

During daytime : The surface of the land will be heated up more by the sun radiation than the surface of the water. As a result, there will be a wind circulation from sea to land.



During nightttime : The surface of the land is cooling down more than the surface of the water. As a result, there will be a wind circulation from land to sea.

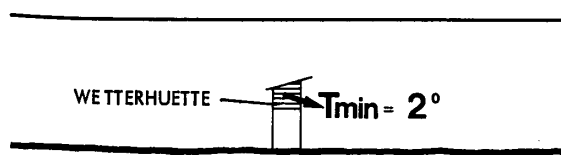


Windspeed

Influence of the windspeed to the minimal air temperature during nighttime:

- No wind

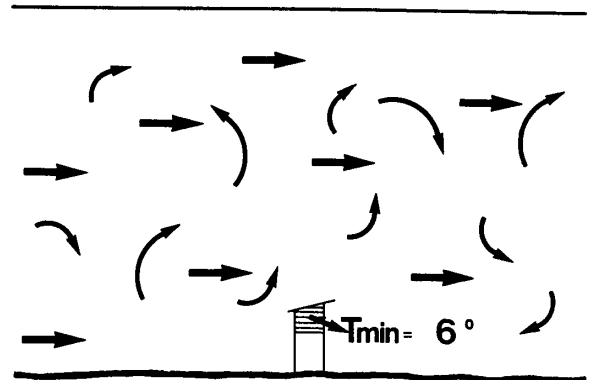
- Windstille



No mixture of the lowest, coolest airtlayer with higher airtlayers

- Strong wind

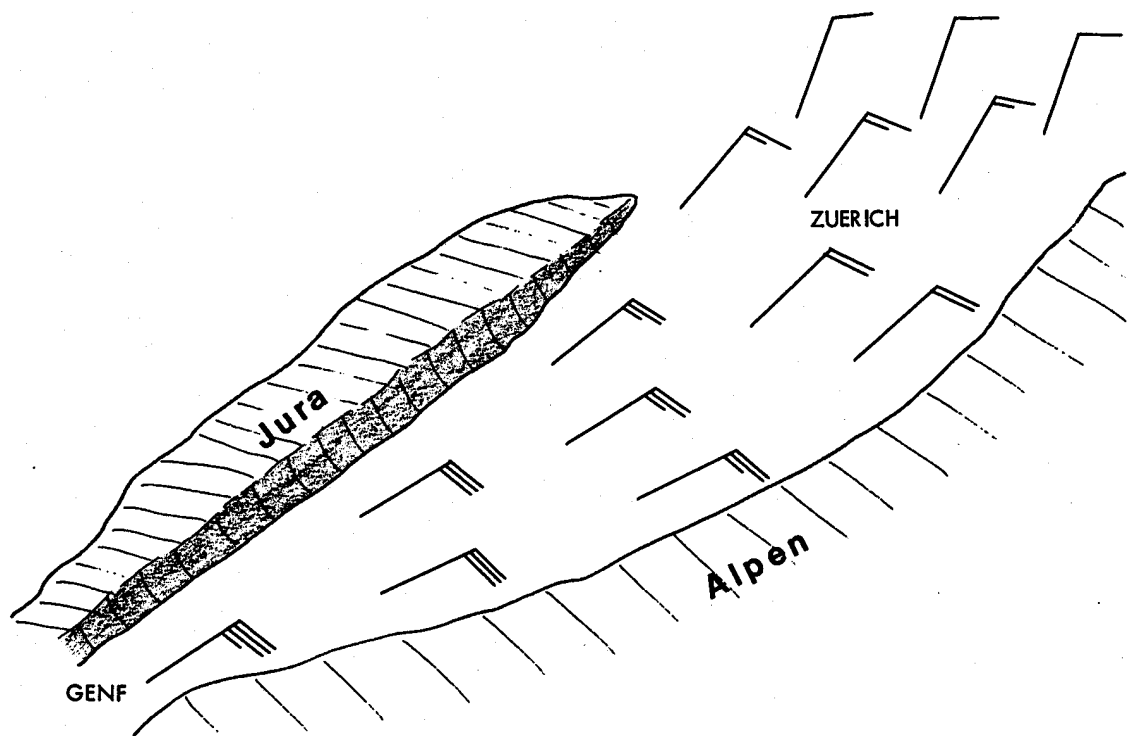
- Starker Wind



Mixture of all the airtlayers, the average mixture temperature gets higher.

Conclusion:
The highest probability to get ice on overheadline through radiation fog is in calm wind conditions.

The more narrow a valley is, the higher is the appropriate windspeed.



Conclusion:

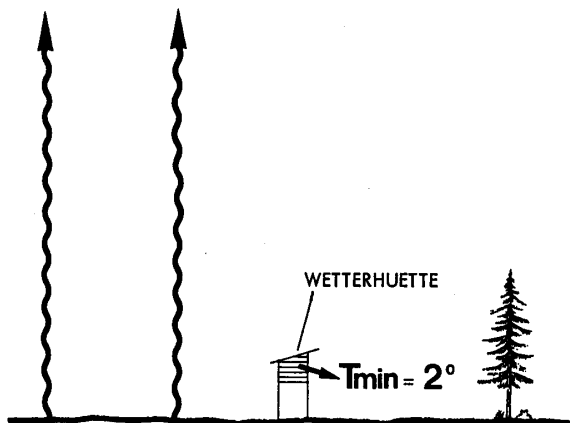
The probability of icing on overheadlines through radiation fog is higher in wide planes than in narrow valleys.

Cloud layers

Influence of cloud layers to the minimal air temperature during nighttime:

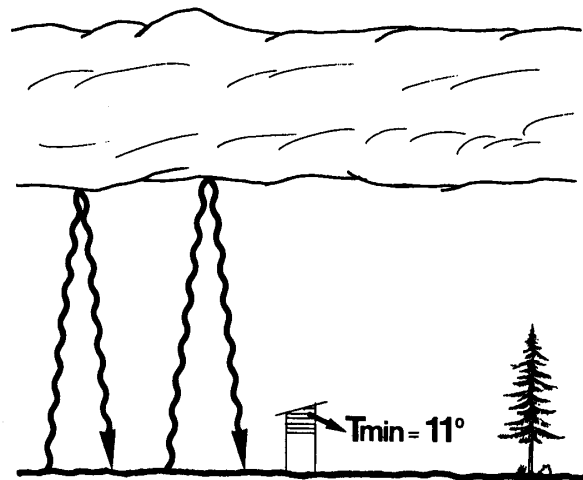
- Sky clear

- Wolkenlos



- Sky overcasted

- Bedeckt



During nighttime, there is radiation from the earth's surface to space. If there is a cloud layer, this helps to prevent from losing energy to space. The minimum air temperature will be lower in case there is no cloud layer, it means the sky is clear.

Conclusion:

The probability of icing on overheadline through radiation fog is much higher in case the sky during nighttime is clear (no cloud layers).

2. Ice on overheadline due to fog**2.1. Mechanism of developing fog**

If the air near the ground is cooled sufficiently, it becomes saturated and fog can develop. By definition, fog exists, if the atmospheric visibility near the earth's surface is reduced to 1 kilometer or less.

If there is a mass of air near saturation, there are two physical circumstances that may lead to condensation and to develop of fog.

1. Cooling down of the air

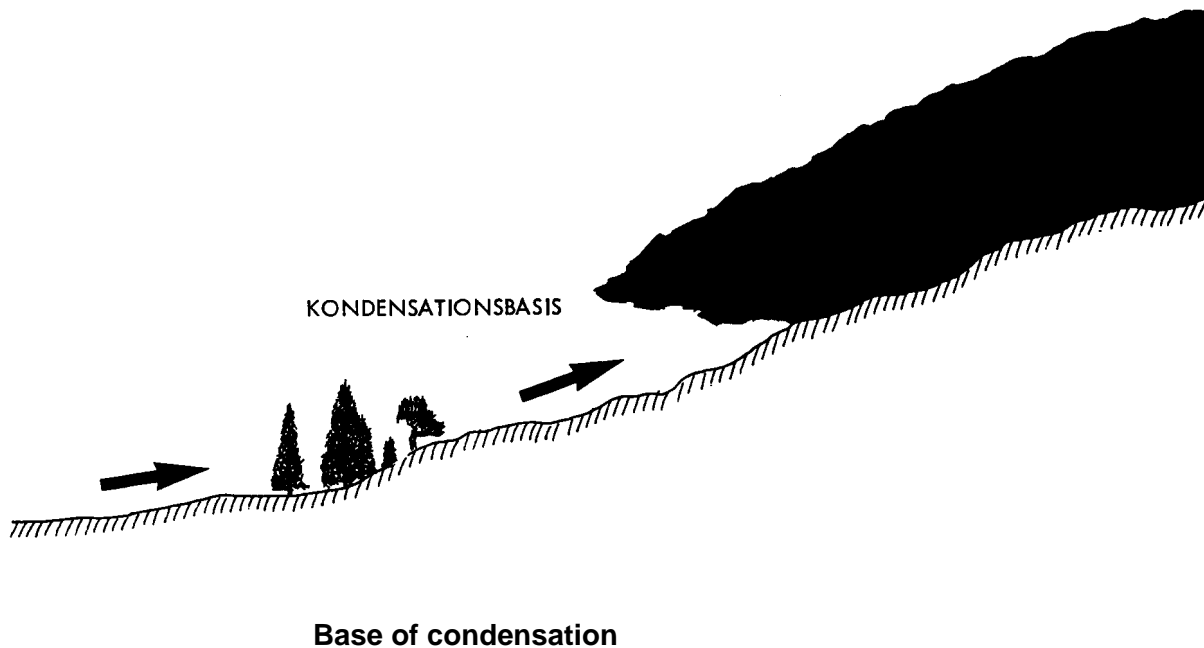
- due to moving the air upwards
- due to horizontal moving over a cold surface
- due to radiation loss during nighttime

2. Mixing the air

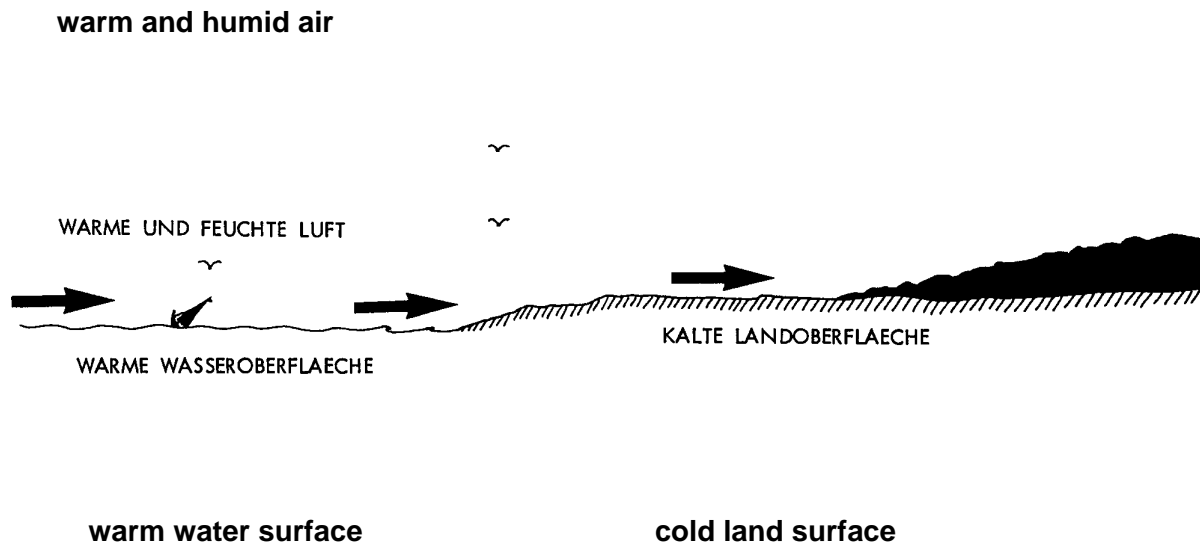
- with other air masses

Fogs composed primarily of water droplets can be classified according to the process that causes the air to cool and saturate:

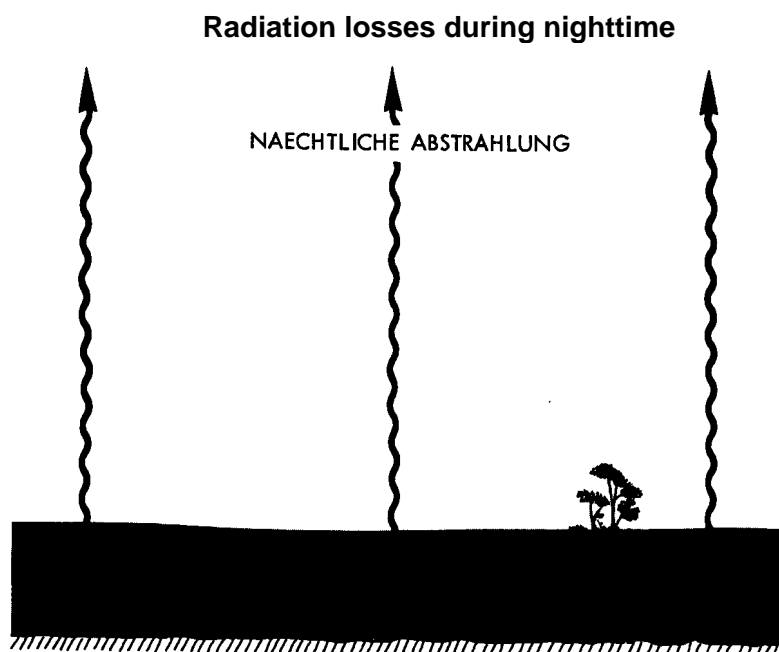
Upslope fog is generated by airflow over topographic barriers. As the air is forced to rise upward where the atmospheric pressure is less, it is cooled by expansion and produces fog on the windward slopes of hills or mountains. Icing on overheadline may develop, if there is cold enough for the freezing condition on the upper regions of the mountain.



Advection fog may be generated by winds that contrast in temperature with the earth's surface. Warm air advection can produce fog through contact cooling with a cold land surface.



Radiation fog or **ground fog**, is generated as the earth's surface cools by radiation loss at night. The fog will be formed by the movement of cooler, more dense air from higher elevations to the lowland or valley bottom. This type of fog is normally quite shallow.



Emergence of radiation fog

1. WIESENNEBEL (SHALLOW FOG)

DUENNE SCHLEIER, NICHT HOEHER ALS 2 m



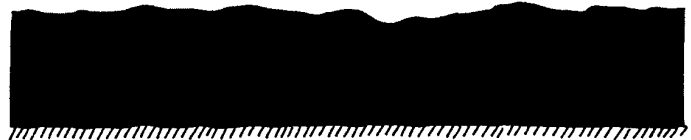
2. NEBELBAENKE (FOG PATCHES)

SICHT IN DEN BAENKEN UNTER 1 km



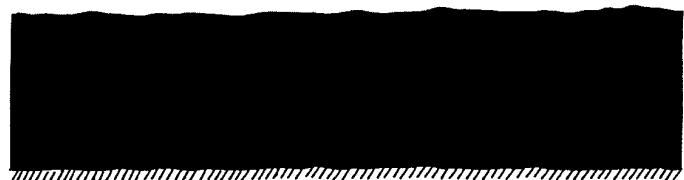
3. NEBEL (FOG)

SICHT IM GANZEN GEBIET UNTER 1 km

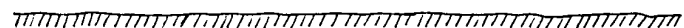
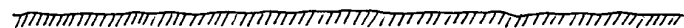


Definition: Visibility in fog areas is lower than 1 km

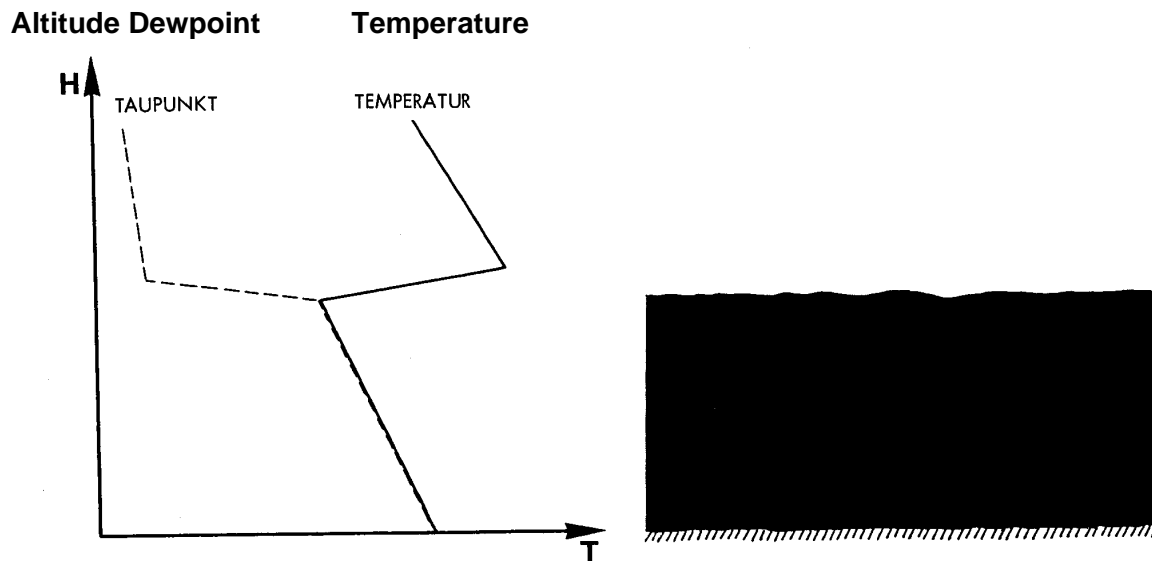
Dissolution of radiation fog



DA DIE LUFT VOM BODEN HER ERWAERMT WIRD, LOEST SICH DER NEBEL AUCH ZUERST IN DEN BODENNAHEN SCHICHTEN AUF (UEBERGANG VON NEBEL ZU HOCHNEBEL).



After sunrise the ground will be heated up by the sun. The fog disappears first in the layers near the ground.



Average upper limit of fog in the Swiss lowlands is 200 – 500 m above ground

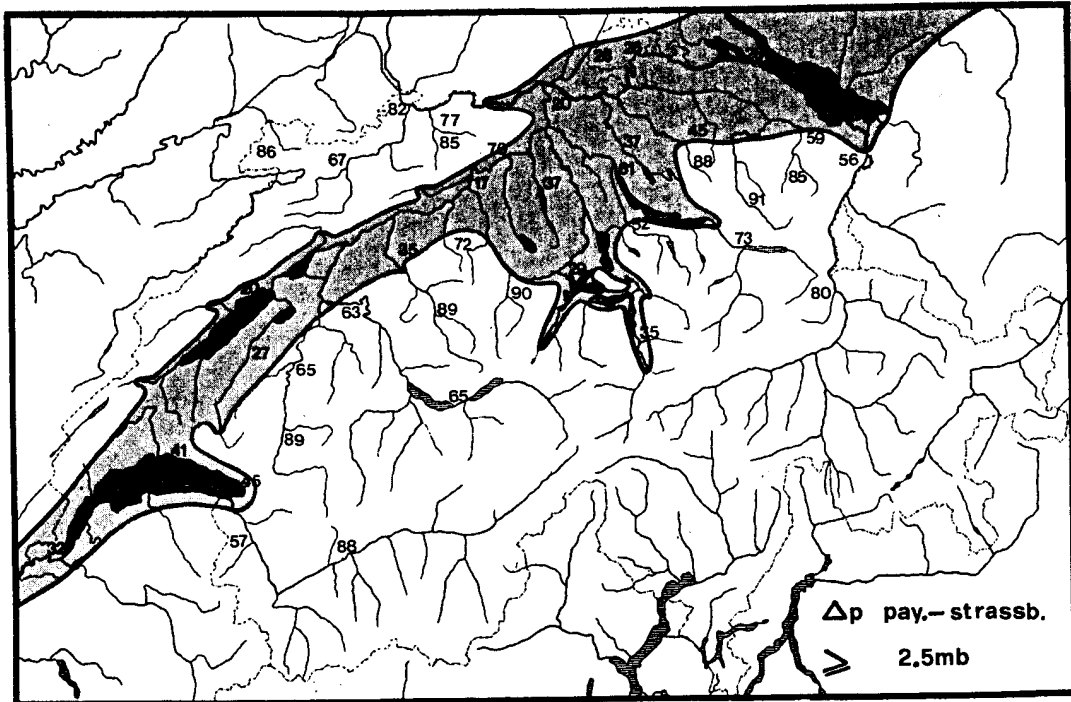
- **Evaporation fog** occurs when you get cold air advection over warm water or warm, moist land surfaces resulting in fog formation as water evaporates into the cold air. This type of fog is sometimes called steam fog or sea smoke.
- **Frontal fog** is produced as weather fronts, especially warm fronts, pass through an area. Precipitation falling into the colder air ahead of the warm front may evaporate enough water to cause the formation of small droplets as fog near the ground.

Conclusions:

- In continental european countries (with mountains and valleys or hills and lowlands), the mechanism of **radiation fog** will be dominating.
Examples: Switzerland, Middle and South of Germany, Austria, Czech etc.
- In coastal areas, the mechanism of **advection fog** is possible.
Examples: Coastal area of the north sea coast of Belgium, Netherlands, Northern Germany, Denmark etc.
- In high mountain areas, the mechanism of **upslope fog** is possible.
Examples: Sweden and Norway (maybe on the top of the „fjell“)

Important : In every case, the local conditions have to be checked carefully.

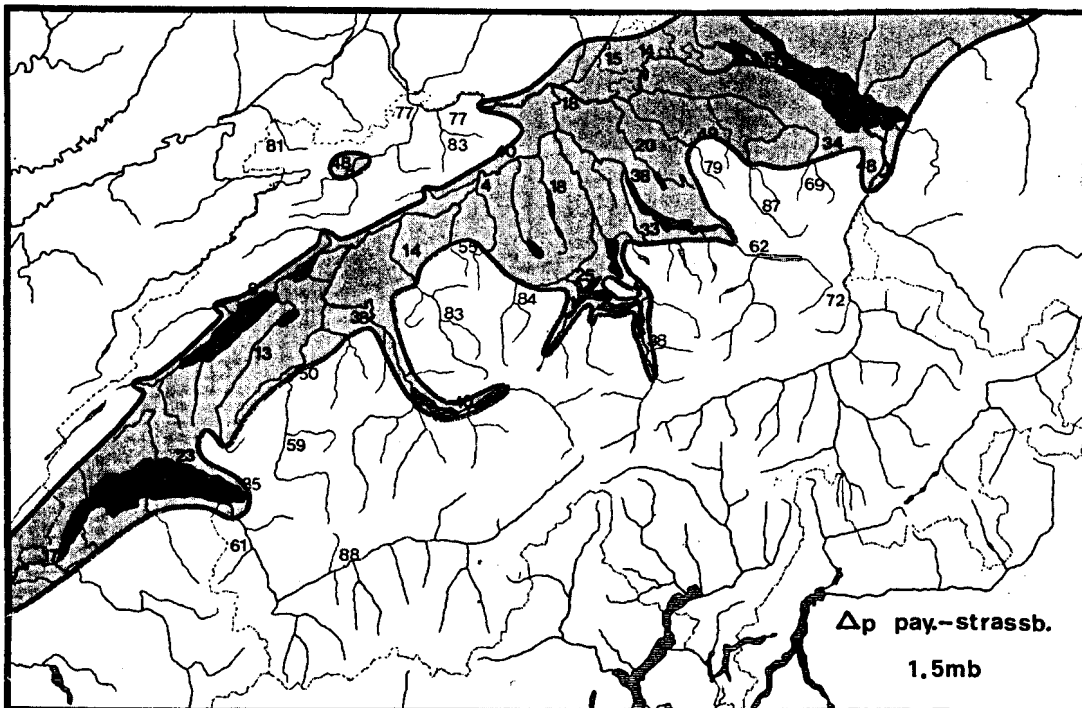
Upper limit of the fog 600 m Nebelmeer-Obergrenze um 600m



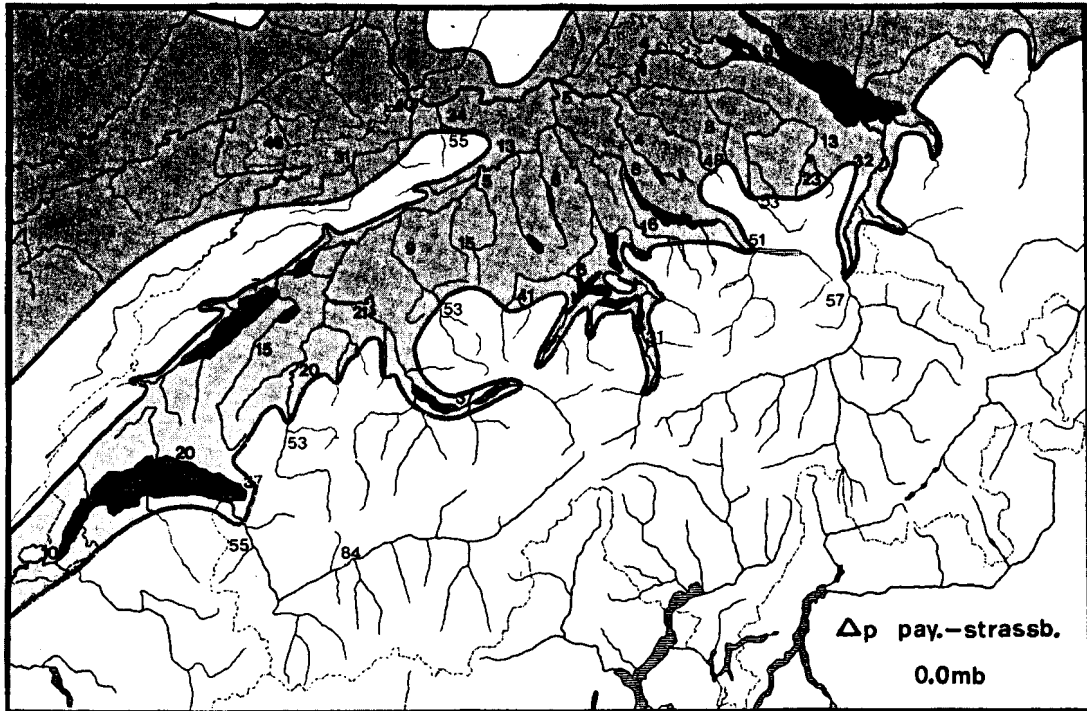
ZAHLEN : RELATIVE SONNENSCHENDAUER (IN %)

Numbers: Relative Time of sunshine (in %)

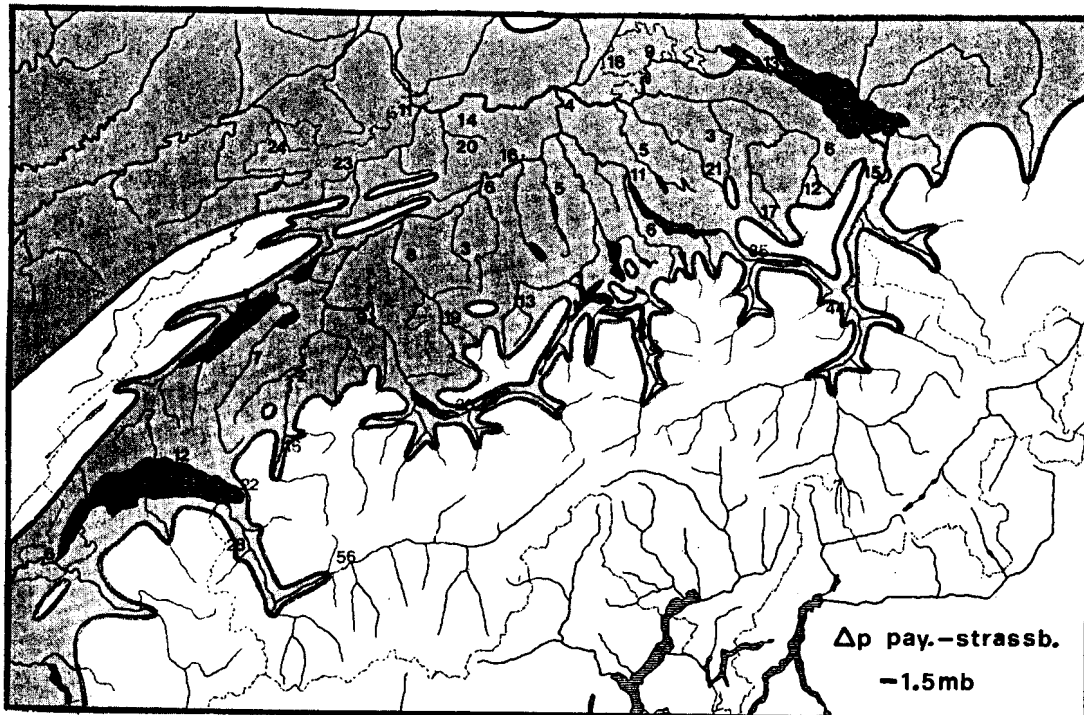
... um 760m



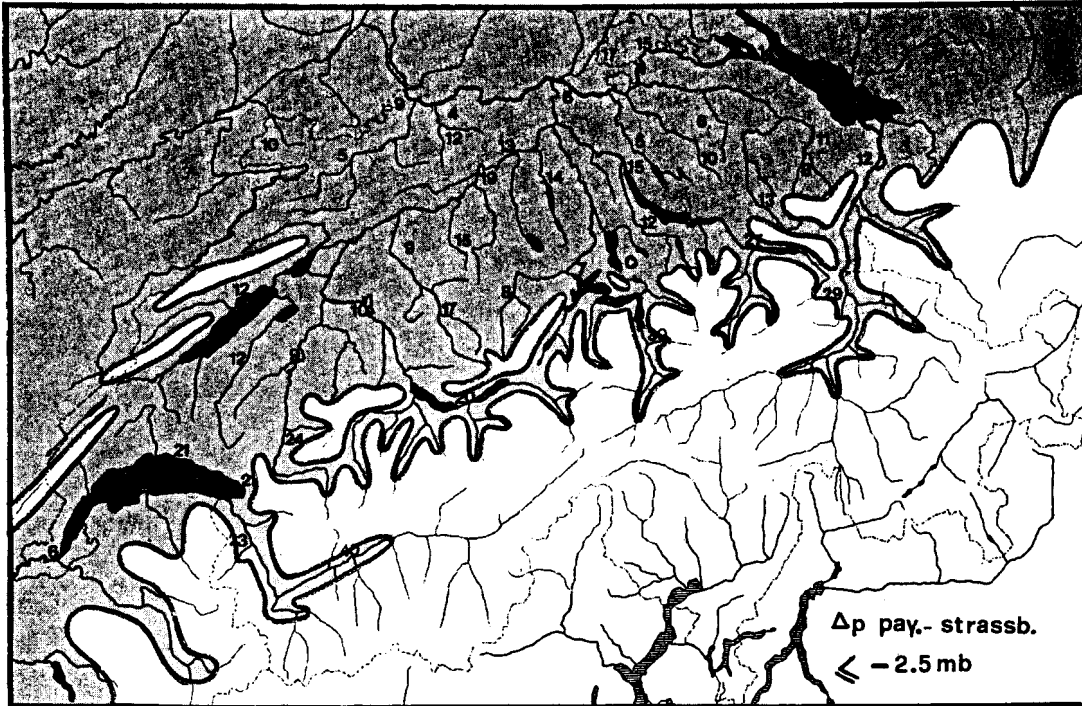
...um 920m



...um 1100m

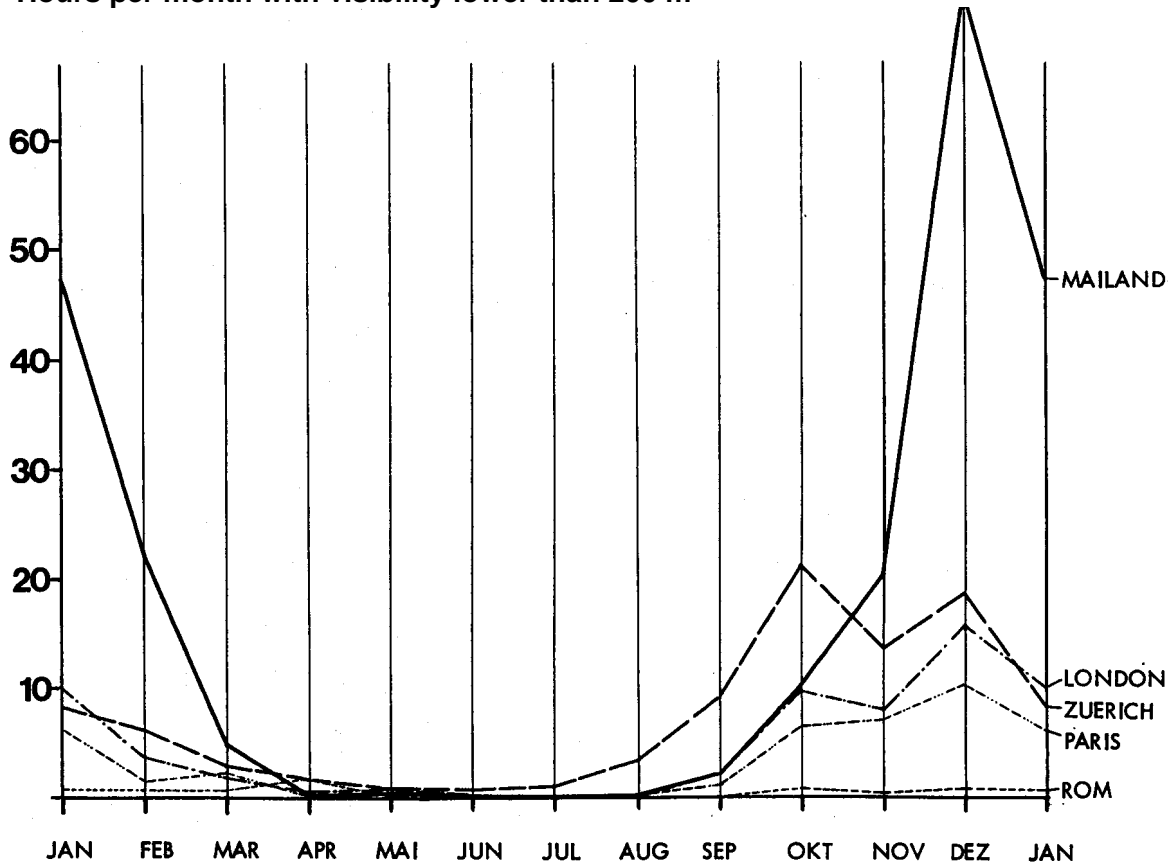


... um 1400m



Fog on airports

Hours per month with visibility lower than 200 m



3. Ice on overheadline due to precipitation

3.1. Mechanism of developing precipitation

Not only fog, but under some condition also precipitations can lead to ice on overheadline. Most important condition to get any kind of precipitation is the presence of clouds.

3.1.1. Clouds

A collection of tiny particles of liquid or solid water occurring above the earth's surface. Clouds are classified according to their height of occurrence and shape. The major types of clouds include:

Cirrus, Cirrocumulus, Cirrostratus, Altocumulus, Altostratus, Nimbostratus, Stratocumulus, Stratus, Cumulus, and Cumulonimbus.

Often clouds develop and move together with a weather front.

Except the three types of cirro-clouds all other clouds can generally cause precipitations. The presence of cumulus and cumulonimbus (thunderstorm cloud) leads only to showers (maybe heavy precipitation, but only for a short time), all other kind of clouds may lead to a longer time of precipitation. Cumulus and cumulonimbus only very rarely arise during the winter period, so they are not very relevant for the icing process on overheadline.

A stratus layer can be regarded as a layer of fog. It can be responsible for both mechanisms of getting ice on overheadline. Inside a stratus layer, icing is possible like in fog. Below a stratus layer, icing could be possible through falling of precipitation.

3.1.2. Precipitation

We can define precipitation as any aqueous deposit, in liquid or solid form, that develops in a saturated atmosphere (relative humidity equals 100 %) and falls to the ground generally from clouds. Most clouds, however, do not produce precipitation. In many clouds, water droplets and ice crystals are too small to overcome natural updrafts found in the atmosphere. As a result, the tiny water droplets and ice crystals remain suspended in the atmosphere as clouds.

Water droplets and ice crystals can only fall to the earth's surface, if they grow to a size that can overcome updrafts. Conditions for growth can develop in clouds via two different processes.

In clouds with temperatures above freezing, turbulent atmospheric mixing can cause droplets to grow through collision and coalescence. One initial condition, however, must be met for this process to begin: droplet size in the cloud must be variable. This

initial condition allows larger and heavier droplets to collide and coalesce with lighter smaller droplets during downdraft periods. If enough atmospheric mixing occurs the larger droplets can expand by up to 250 times and can become heavy enough to fall to the earth's surface.

The other mechanism of precipitation development involves clouds whose temperature is below freezing. In these clouds, large ice crystals grow due to the differences in vapor pressure between ice crystals and supercooled water droplets. Vapor pressure differences between ice and supercooled water causes a net migration of water vapor from water droplets to ice crystals. The ice crystal then absorbs the water vapor, depositing it on its surface. At the same time, the loss of vapor from the water droplets causes them to shrink in size. A necessary initial requirement for this process is the presence of both condensation nuclei and deposition nuclei. While deposition nuclei form ice crystals at temperatures just below zero degrees Celsius, condensation nuclei can remain liquid (supercooled) to temperatures as low as -40°C depending on size. Because of this phenomena, cold clouds can contain both ice crystals and supercooled water droplets. The relative proportion of these two types of particles determines whether snow crystals grow to a size to overcome atmospheric updrafts.

The following list describes the various types of precipitation that can form in the atmosphere:

Rain is any liquid deposit that falls from the atmosphere to the surface and has a diameter greater than 0.5 millimeters.

Freezing rain occurs when water droplets hit a cold surface and freeze. For this to occur, a surface temperature inversion is required. In such an inversion, the surface must have a temperature below freezing, while the temperature of the atmosphere where the precipitation forms is above freezing.

Snow can develop only from water vapor that deposits directly as a solid on a deposition nucleus at temperatures below freezing by passing the liquid state. A snowflake forms first as a very tiny crystal developing on a six-sided hexagonal deposition nucleus. The ice crystal then grows fastest at the six points as these areas are more directly exposed to the atmosphere's water vapor.

Snow pellets are white, spherical grains of ice 2 to 5 millimeters in diameter. They can be distinguished from packed snowflakes since snow pellets are firm enough to bounce when they hit the ground. Snow pellets develop as supercooled droplets freeze on ice crystals. They may fall for a brief period as the precipitation changes from ice pellets to snow.

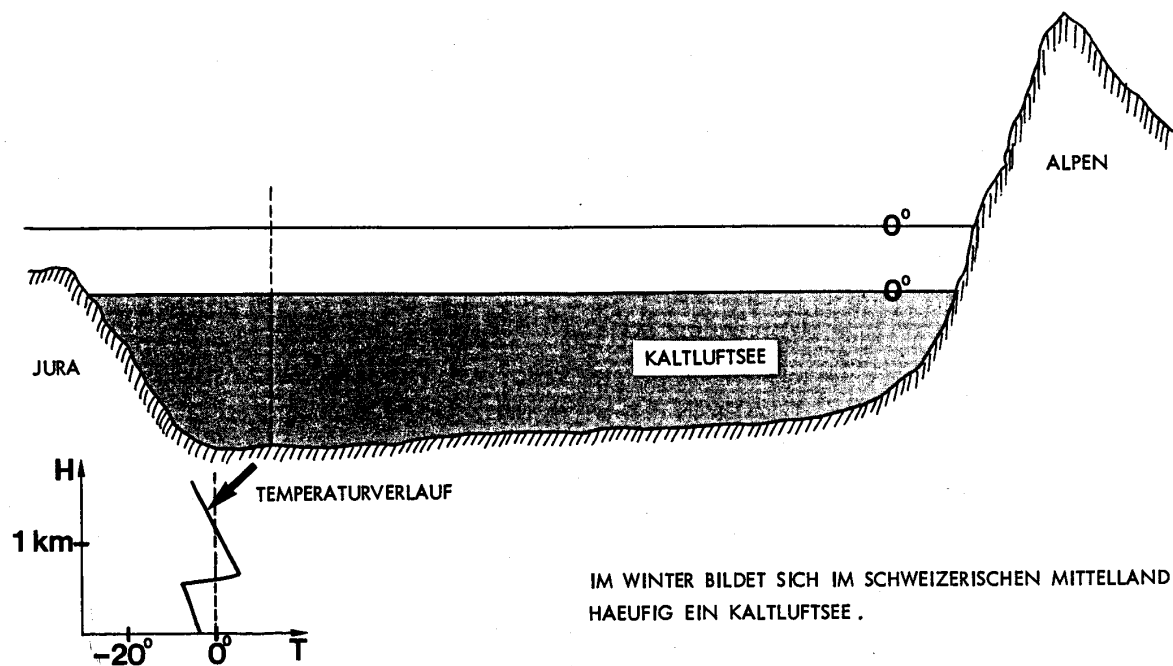
Ice pellets or **sleet** are transparent or translucent bits of frozen water with a diameter less than 5 millimeters. To form, these pellets require an environment where raindrops develop in an atmosphere where the temperature is above freezing and then fall into a lower layer of air with temperatures below freezing. In the lower layer of cold air the raindrops freeze into small ice pellets. Normally, to provide temperatures above freezing in the atmosphere above a colder atmospheric layer an upper air temperature inversion is required.

Hail is a destructive form of precipitation that is 5 to 190 millimeters in diameter. The large downdrafts in mature thunderstorm clouds provide the mechanism for hail formation. Hailstones normally have concentric shells of ice alternating between those with a milky appearance and those that are clear. The milky white shells, containing bubbles and partially melted snowflakes, correspond to a period of rapid freezing, while the clear shells develop as the liquid water freezes much more slowly.

Conclusions:

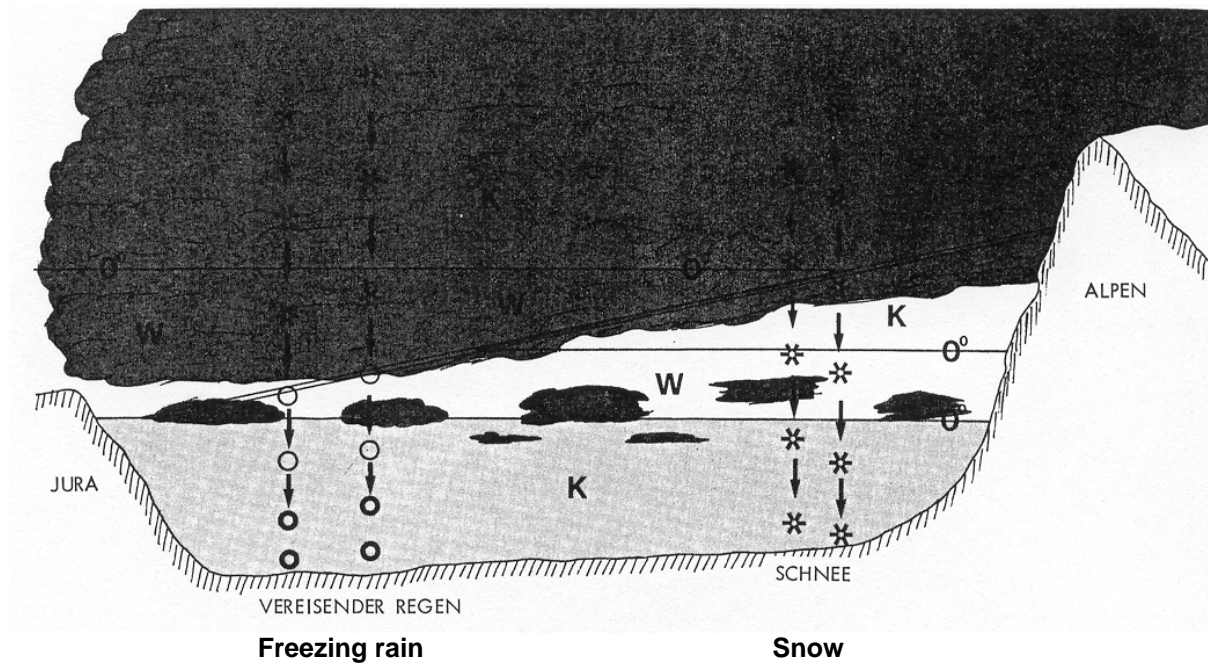
Especially rain and snow may lead to icing on the overheadline. Freezing rain is worst what can happen, but fortunately it is very rare. Hail cannot lead to ice on the overheadline, because these parts are unable to be deposited on the surface of the overheadline wire.

3.1.3. Freezing rain



IM WINTER BILDET SICH IM SCHWEIZERISCHEN MITTELLAND HAEUFIG EIN KALTLUFTSEE .

During winter time there often is a „cold air lake“ in the lowlands of Switzerland



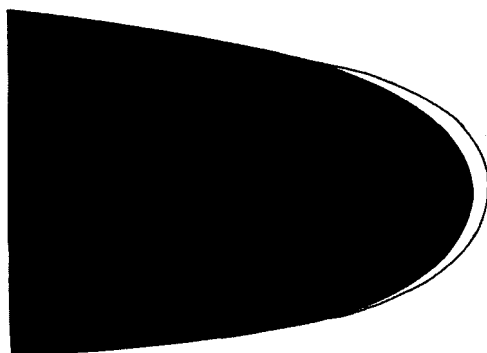
A weather front coming from west cannot kick out the cold air. Rain droplets, which are falling in the „lake of cold air“ will be cooled down and maybe freezing in the air or at the time they are reaching the ground.

4. Types of ice

According to the temperature range, the quality and structure of ice will be different.

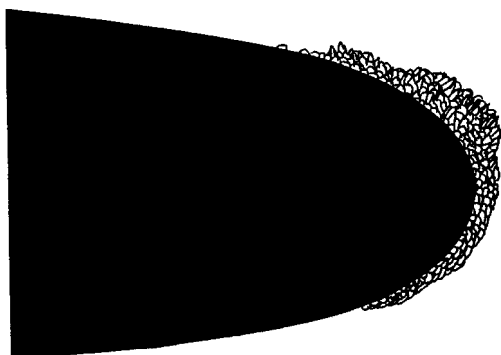
Clear ice

0°C until -6°C (big droplets)
transparent, well sticking, smoothly surface, thick ice layers are possible



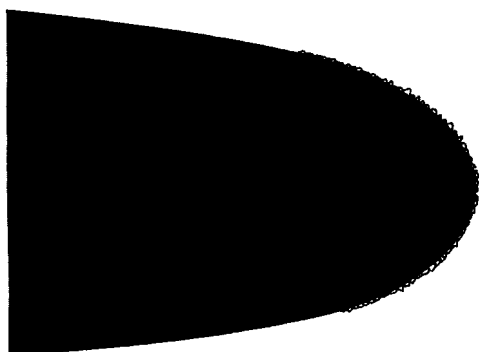
Rime ice

-6°C until -12°C (small droplets)
white, granular, rough surface, sticking worse than clear ice, strong
excrescences are possible, thick ice layers are possible



Hear frost

lower than -12°C (very small droplets)
white, sticking worse, rough surface, only thin ice layer



5. Summary

There are two meteorological phenomenas which can lead to ice on overheadline

- **Fog**
- **Precipitation**

Conditions for icing due to fog

1. Presence of a mass of air containing humidity
2. Condition for condensation $T \leq T_{\text{Dewpoint}}$
3. Condition for freezing $T \leq 0^{\circ}\text{C}$

Relevant parameters

The **highest probability** of icing on overheadline due to fog in a typical european continental country (with mountains and valleys, lowlands and hills like Switzerland), is influenced by the following parameters :

- Mechanism Radiation fog
- Time early morning hours (before sunrise)
- Location near at bottom of valleys, lowlands
- Temperature not too much below 0°C
- Wind no wind or only calm wind
- Sky clear, no cloud layers

Conditions for icing due to precipitation

1. Presence of a mass of air containing humidity
2. Condition for condensation \rightarrow clouds $T \leq T_{\text{Dewpoint}}$
3. Development of heavy enough droplets or flakes inside the clouds \rightarrow precipitation
4. Condition for freezing on the overheadline $T \leq 0^{\circ}\text{C}$

Relevant parameters

The **highest probability** of icing on overheadline due to precipitation, is influenced by the following parameters :

- Time possible at any time of the day
- Mechanism rain or wet snow
- Temperature the overheadline wire is below 0°C

(Freezing rain is worst of all icing scenarios, but fortunately it is very rare !)