Modern techniques of ice-load assessment and icing maps creation for the design of overhead transmission lines used in the Russian Federation

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In the Russian Federation regional maps are used to assess the climatic loads for the existing and newly designed transmission lines. The making of ice-load and combined wind-ice load regional maps is a complex work that is based on a vast set of data.

Currently is carried on an extensive work for the harmonisation of Russian standards with International recommendations in the field of design of overhead transmission lines. At the same time a huge work has been done with the introduction of modern computer and program technologies for data storing, processing and ice-map creation.

Climatic loads. Climatic loads are the main loads which determine the planning of transmission lines. Wind, ice and ice-wind loads are considered during designing of transmission lines (OHL).

In the Russian Federation, main loads affecting the normal functioning of OHL are *ice load* (loads from all types of icing, like precipitation icing and in-cloud icing, on the components of the line) and *combined ice-wind load* (wind load on the ice-covered components of the line). These loads are the main scope of this article. The value of the load depends on the design principle of the line, which means its voltage, design of towers, diameters of conductors and ground wires, their height above the ground.

Transmission line should be designed with sufficient reliability depending on the degree of importance of the line. A sufficient reliability of the OHL means an improved ability to maintain its power transmitting capacity during all operating period.

Assessing ice loads.

Basic parameters for assessing ice loads. Ice load on transmission line is calculated using a basic parameter, which is the ice formation on a wire of the *standard transmission line* with a uniform radial thickness (in mm) and density of 0.9 g/cm^3.

When referring to standard transmission line we mean line having conductor with a diameter of 10 mm that is suspended 10 m above the ground.

As basic parameters for assessing combined ice-wind load on OHL we consider the conventional diameter of cylindrical ice shape (in mm) on a wire of the standard transmission line, and the maximum wind speed observed during this icing event.

Basic ice data. In the Russian Federation hydrometeorological information, including information about atmospheric events and, in particular, atmospheric icing, are collected in the meteorological stations network that covers all the territory of the country.

Meteorological stations use special device that has been designed to perform ice observations (*icing device*). This icing device consists of four cables of 5 mm in diameter, fixed in pair towards meridional and latitudinal directions and suspended at the two different heights of 1,9 and 2,2 m for each pair. For every icing event are measured size of ice accretion, its weight and type (glaze ice, hard rime, etc.). During every icing event are also measured other meteorological parameters, such as air temperature, wind speed and direction. Wind speed and direction are measured on weather-vane or wind meter at 10 m height above the ground. Beginning and end times of icing events. Along with icing growth time, are also recorded.

Data concerning all observations done by meteorological stations are collected and stored by the National Meteorological Service (Rosgidromet).

Mass observations of icing events have been carried on by the meteorological stations network in the territory of the Russian Federation done mainly since 1951. Today's observations of icing events are performed by 1254 meteorological stations all over the territory of Russia. The period of instrumental observations reaches today 58 years, and for some stations even beyond.

Basic ice data processing. In order to process vast amounts of observations data, a method has been finalised to ensure that data are alike and therefore comparable to each other. Processed data under such method are defined as data brought to "conditions of open territory".

Sometimes icing devices on meteorological stations could be shaded by meteostation's fences, constructions, trees or bushes, which lead to reduced measurements during observations. To remove this shading effect and to bring data to the conditions of open territory we use a special coefficient, which depends on the height of the shading object and the distance from it.

During calculations we also take into account the angle between wind direction and the conductor installed on the icing device. Icing on conductor located perpendicular to the wind will be of bigger size then on conductor oriented at certain angle to wind direction. A special coefficient is introduced to convert data to the conditions of perpendicular wind; such coefficient depends on the angle between wind direction and conductor.

Data brought to the conditions of open territory are used to calculate the radial ice thickness and combined ice-wind load on the wire of standard transmission line.

Statistical arrays. Equivalent radial ice thickness and combined ice-wind load are calculated for every icing event during the cold season. Maximum values (equivalent radial ice thickness, combined ice-wind load and maximum wind speed for icing event) corresponding to every cold season (called yearly maximum) are used to create statistical arrays for every considered meteorological station.

For every statistical array we calculate the following statistical parameters: mean value, standard deviation and coefficient of variation.

To describe the distribution of statistical arrays it is used Gumbel distribution law:

$$F(x) = e^{-e^{-\alpha(x-\beta)}}$$

For those cases when statistical arrays cannot be described by a Gumbel law we use other statistical laws:

• Fisher-Tippet distribution law:

$$F(x) = e^{-\left(\frac{x}{\beta}\right)^{\gamma}}$$

• Distribution with cumulative distribution function:

$$F(x) = e^{-Ae^{-\left(\frac{x}{\beta}\right)^{\gamma}}}$$

In formulas above: x – variable, and α, β, γ, A – parameters of distribution function.

Values of climatic loads having certain exclusion limit are calculated by using one of those distribution laws.

In order to obtain reliable values of climatic loads the period of meteorological observations should be more than 30 years. If not than this data could be used as subsidiary data during the process of icing map creation.

Using past experience with existing OHL. For creating regional ice load maps we use past experience data of OHL located in the region. This means we utilize icing observations made on OHL conductors during line operation.

The major requirement to past experience data is the availability of reliable measurements of icing weight or its size and exact identification of its type or density. It is also essential that measurements refer to a particular geographic point (geographic coordinates and altitude). It is worthy to compare past experience data with observations of the nearest meteorological station.

Information on icing size and weight are collected for the entire operating period of the line.

Currently, we have two different ways of using past experience data:

- The first way employs information on size and weight of icing, collected for the entire operating period of the line. The data is ranked in ascending order and one of the statistical distribution is used to describe the distribution and to obtain the value of the ice load having a certain return period;
- The second way utilizes the maximum value of the ice load observed during the entire operating period. This maximum of the ice load is used to obtain the value having a certain return period by implementing empirical dependence.

Considering terrain influences. The regional and local topography (the relief) is one of the main factors affecting spatial distribution of climatic loads all along the territory. Depending on the morphometry of the relief (height above sea level and relative heights) it is defined the kind of large-scale relief type –

plain or height (hill). Considering main wind directions it is possible to distinguish different subtypes of large-scale relief: windward or leeward sides of heights, and valleys exposed or valleys closed for the main wind directions.

The map of types and subtypes of large-scale relief is then created.

Creation of regional icing maps. The use of regional icing maps of equivalent radial ice thickness and ice-wind load allow the assessment of ice- and ice-wind loads. Regional maps provide a visual representation of the distribution of climate parameters in a given territory.

For the making of regional icing maps are used maps of types and subtypes of large-scale relief, along with a graph of functional dependence of climatic characteristic from the height above sea level.

For types and subtypes of large-scale relief we build a graph of functional dependence of climatic characteristic (equivalent radial ice-thickness, ice-wind load, maximum wind speed for icing event) from the height above sea level. The dependence is $x=f(H)$ (where x – value of climatic characteristic, H - height above sea level) and is built considering local small-scale relief. In Russia for the break down of territory we use climatic characteristics having a return period of 25 years.

For the break down of the territory into icing regions we distinguish 8 regions with equivalent radial ice thickness from 10 to 40 mm and above. Gradation range of the region is 5 mm.

For the break down of the territory into ice-wind load regions we distinguish 9 regions with the value of ice-wind load from 3 to 28 N/m and above. For every ice-wind load region it is specified the wind speed having a return period of 25 years and a conventional equivalent radial ice-thickness.

For e.g. figures 1 and 2 show respectively regional icing maps of radial ice thickness and combined ice-wind load of Sochi District.

Modern techniques of ice-load assessment and icing maps creation.

The making of regional maps is a complex work that involves a series of factors: the reckoning of meteostations observation data and past experience data with existing transmission lines, the creation of statistical arrays and their statistical processing, the analysis of physical-geographical conditions and of local relief characteristics, the analysis of terrain conditions in which the meteorological station is located, the relevance of observed data and the analysis of synoptical processes. In order to perform efficiently the above-mentioned works, it is necessary to use modern computing techniques, having the target of ultimately automatize the reckoning process and the making of regional maps.

Today we have introduced semi-automatic processing for collection, storage and managing of observations data gathered from the meteorological station network. Furthermore, this system helps creating statistical arrays, assessment of statistical parameters and parameters of climatic characteristic having a given return period, and it provides processed data for the making of regional maps.

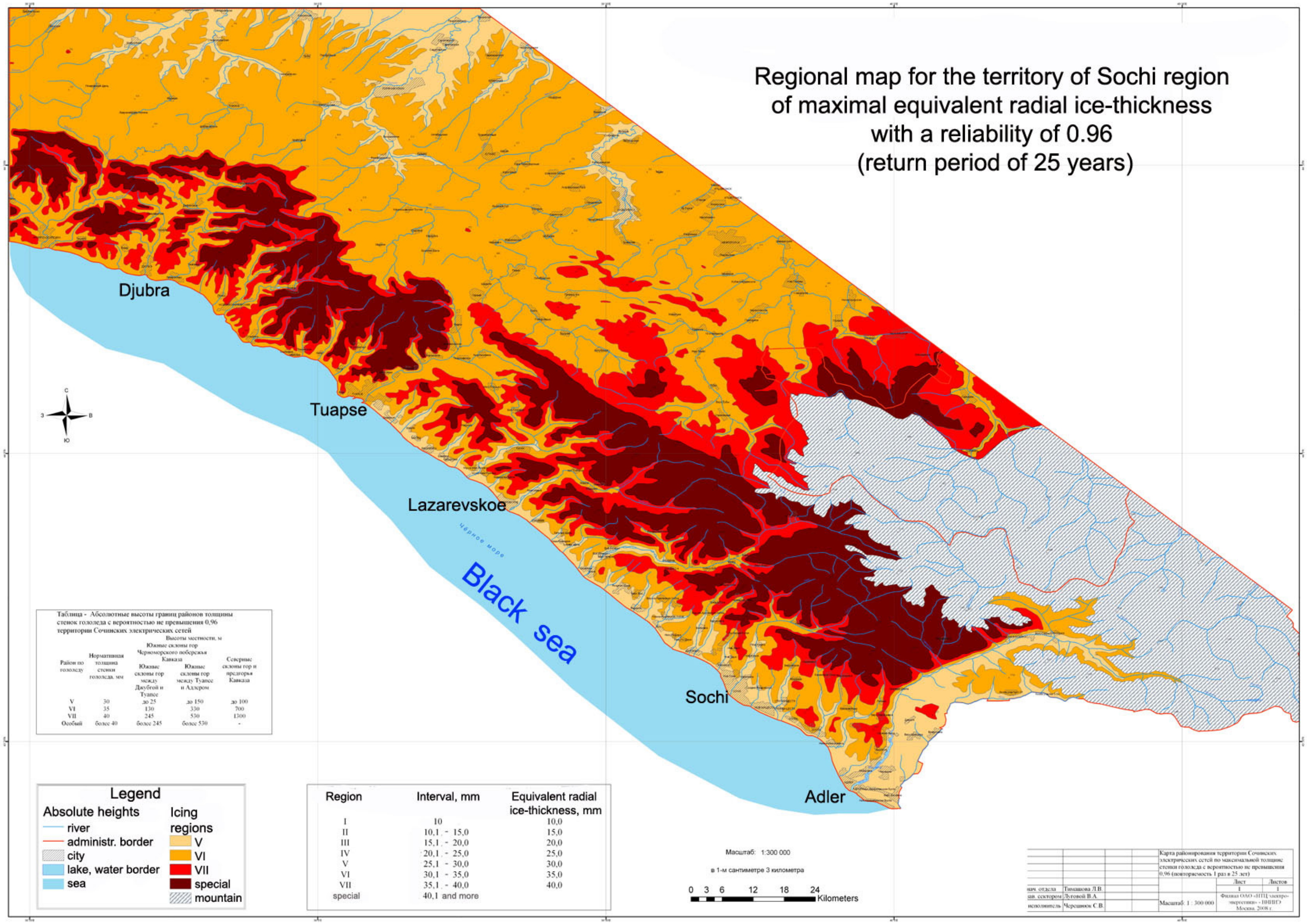

Figure 1: Example of a regional ice load map

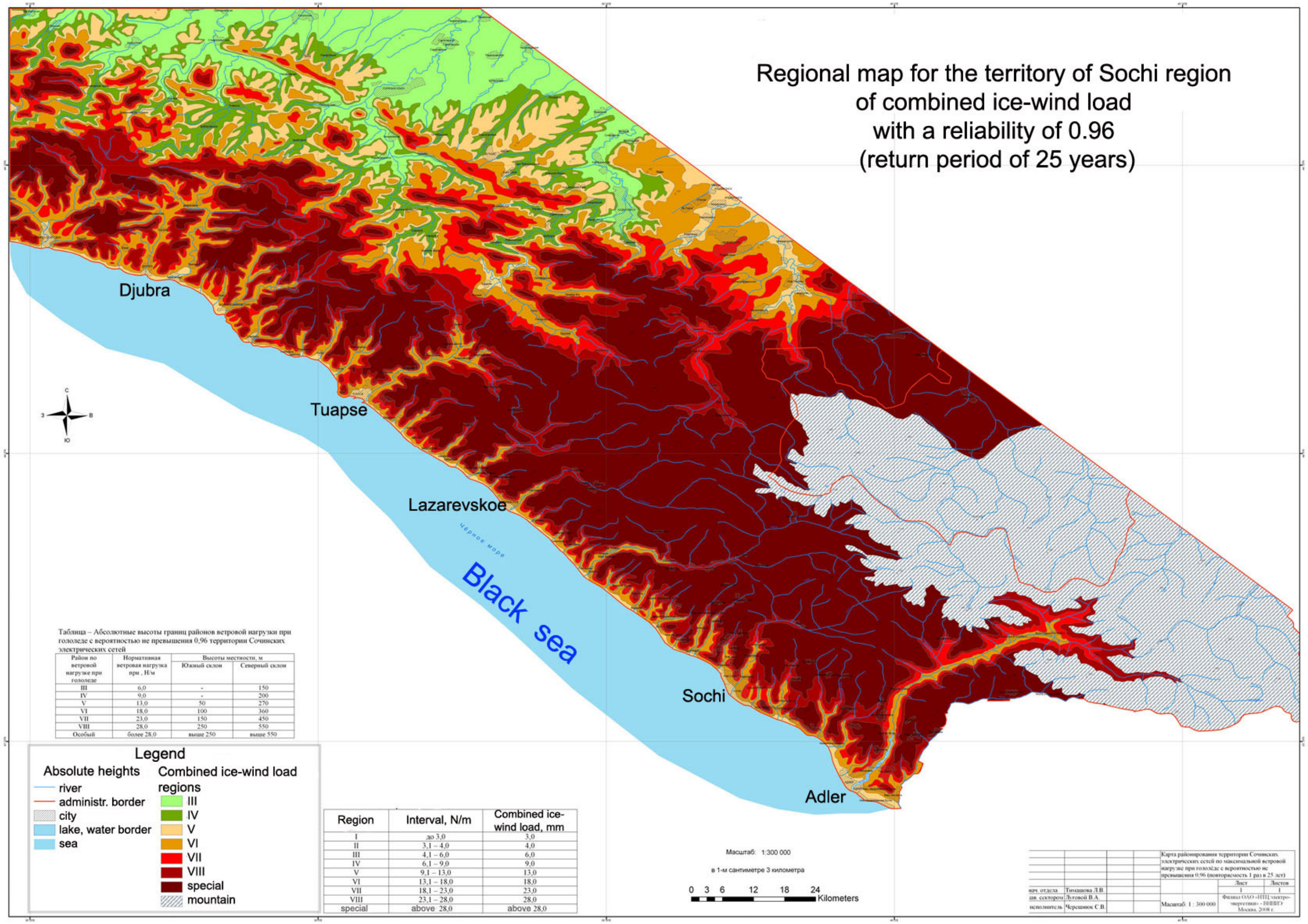

Figure 2: Example of a regional ice-wind load map

Information system for climate conditions and loads.

In order to obtain processed climatic data, we have created a specialised information system for climate conditions.

The information system consists of a database of climate conditions (DB) and of a specific program.

Thanks to long-term observations done in the meteo-station network in Russia, the DB contains the following information about icing events: date of observation, icing type, its size and weight, speed and direction of the wind at the beginning of the icing event, maximum wind speed during the icing event.

For every meteorological station the DB stores the following information: its name, administrative belonging, height above the sea level and technical characteristics such as height of weather-vane and height of wind meter.

On figure 3 it is represented the logical scheme of the database for climate conditions.

The program allows performing automatic data update in the DB in an electronic format, their handling, their processing in order to get uniform data, statistical arrays and statistical parameters. The program also allows describing the arrays with different statistical distributions, obtaining climatic characteristics having different return period.

Geographical Information System. In order to create regional maps of the territory of the Russian Federation we use a geo-information system. This Geographical Information System (GIS) is a system for the management of geographical information, their analysis and representation. Geographical information is given as a series of selected geographical data, which model the geographical environment with simple, summarised and structured data. GIS includes a set of modern and powerful instrumental means to work with geographical data.

The usage of GIS allows the making of regional maps with an elevate degree of detailed elaboration of the icing regions that takes into account local relief. Furthermore, the use of GIS improves significantly the effectiveness and quality of executed work.

We selected the GIS system of the company ESRI - ArcGIS 9.2. This system possesses a powerful set of instruments that allows processing all the range of cartographic work, the analysis of the data, mapping and final preparation of ready regional maps for printing.

From Figures 1 and 2 it is possible to see, that the use of GIS allows getting detailed information about climatic regions and their borders in relation to general geographic reference points like for e.g. cities, rivers, coastlines, local altitude marks, etc.

Climatic loads. Ice load and combined ice-wind load for the transmission line are used with different return period depending on line’s voltage. Recommended reliability levels for transmission lines are shown in table 1.

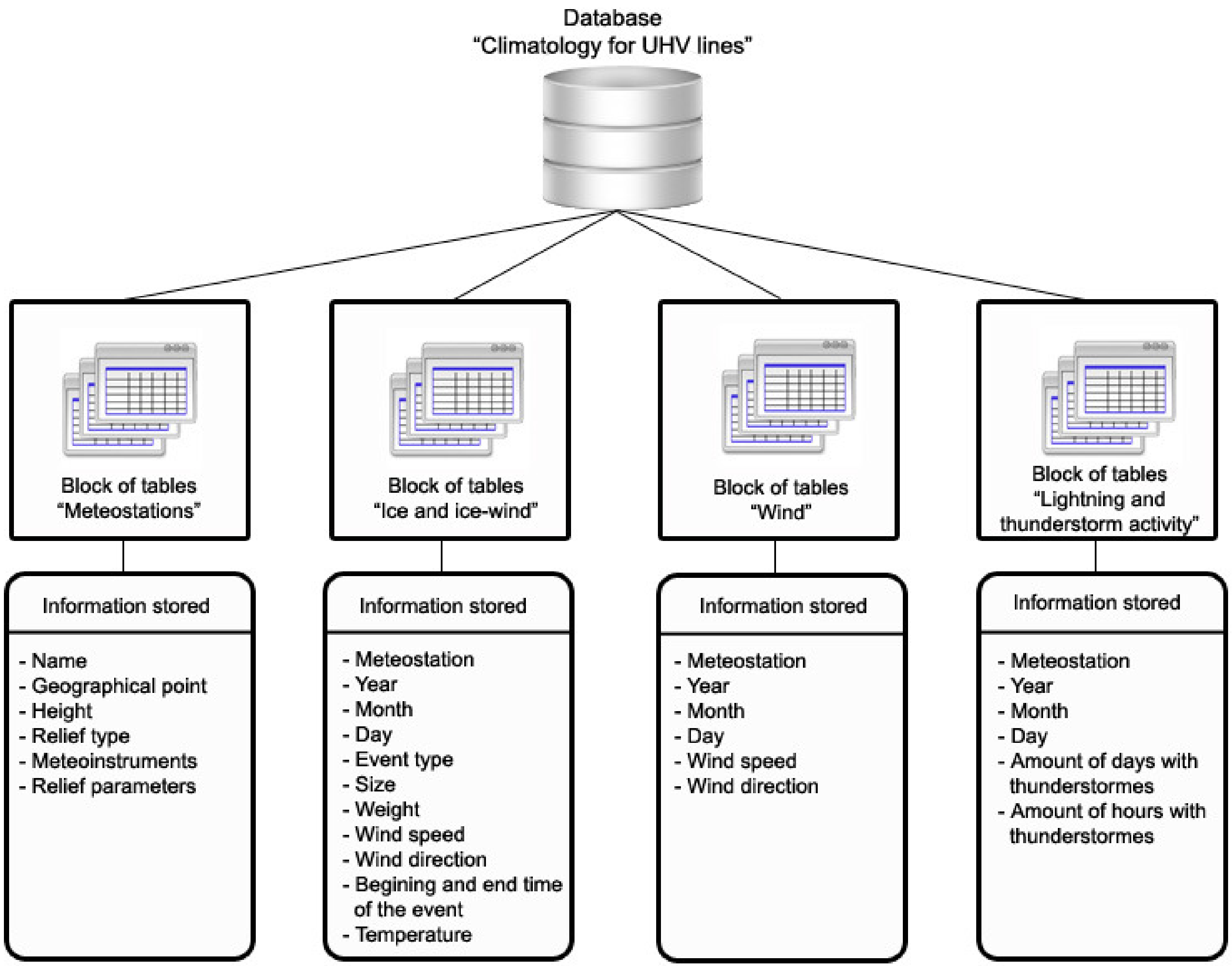

Figure 3: Logical scheme of the database for climate conditions

Table 1 - Recommended reliability levels for transmission lines

Transmission line voltage, kV	Line length, km	Recommended reliability level	Reliability, *P*	Return period, *T*, years
1	any	I	0,96	25
≤35	10-30	II	0,98	50
110	25-100	III	0,99	100
220	100-300			
330	100-300	IV	0,993	150
500	200-1000			
750	300-2000	V	0,998	500

Based on IEC and CIGRE recommendations was developed a method to obtain the climatic loads depending on a chosen reliability level.

For transmission lines having length more than 100 km, it has been developed a method that takes into account line length. With this method the transmission line is considered as an extensive object and the climatic load can change along its length and in time. The return period and the number of events exceeding the design load calculated for the entire line will differ from that one calculated in every given point of the transmission line. Reliabilities of calculated load for the entire line and for given point along the line will also differ one from another.

Such method uses the so called parameter "exceeding zone size". When referring to exceeding zone size we mean the extent (in km) of a statistical zone in which in every point the current load exceeds the design load. This size is calculated based on meteorological stations' observations and on past experience with existing transmission lines.

When we have the parameters of the size of the exceeding zone (θ) and the desired reliability of the entire line (P), we can calculate the reliability in every given point of the transmission line (φ):

$$\varphi = 1 - P^{\frac{\theta}{l+\theta}}$$

where l – line's length.

Conclusion. In order to increase the accuracy of climatic loads assessment it is worth to undertake the following:

- *Implementation of a supplementary observation program, in particular the installing of test sites with an automatic meteorological measurements in those places where frequent and significant ice- and combined ice-wind loads are observed;*
- *Development and implementation of medium scale numerical model of ice- and combined ice-wind loads on components of transmission line.*