Climate Change – What Do We Know, What Do We Not Know, and What May Be the Consequences For Electric Overhead Line Systems?

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Abstract — The validity of global climate being influenced by emissions of CO_2 and other greenhouse gases from human activities is now globally recognized. Although the global temperature is expected to rise, and consequently also precipitation amounts, many secondary effects are still uncertain, concerning for example flooding, storm frequencies, atmospheric icing and so on. However, many electrical utilities around the world are already considering preventive measures for their network, based on the philosophy that proactive measures in the long run are cheaper than taking extra costs for maintenance and repair after expected increases in damage and outage frequencies.

Keywords — Global warming, flooding, wind storms, atmospheric icing, forecasting of critical events.

I. INTRODUCTION

Since the industrial revolution started a century and half ago, and the required energy for the rapid developments of factories and new machines were produced by burning of coal, oil and gas, which consequently resulted in emissions of CO2 into the atmosphere. Figure 1 shows the time series of CO2 measurements from the most cited observatory on Mauna Loa on Hawaii from the start of these measurements in 1958. Due to the greenhouse effect of this and other gases the atmospheric temperature has increased in parallel with the CO2 curve during the same period as demonstrated in Figure 2.

Despite series of lively attacks from deniers of human influence on global climate in mass media within many countries, there has been a consensus within scientific communities since 1995 on this relation [1].

However, on the other hand many questions on secondary effects arising from this temperature increase, with respect to other weather elements like precipitation

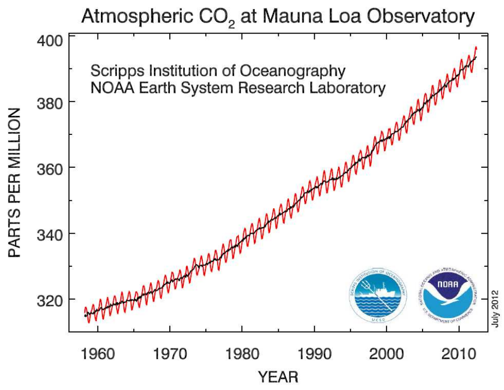

Figure 1. CO2 concentrations measured since 1958 on Mauna Loa Observatory, Hawaii (NOAA Earth System Research Laboratory). Red curve is winter-summer fluctuations.

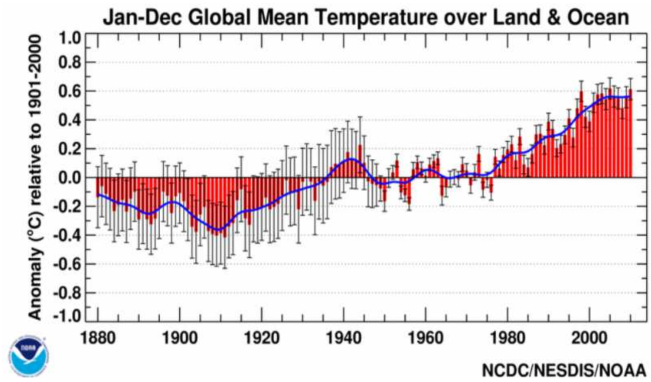

Figure 2. Annual global temperature anomalies (red columns, from 1901-2000 average. Grey columns: error bars.) 1880 – 2011 (NOAA National Data Climate Data Center).

intensities and distribution, flooding, droughts, wind storms, hurricanes, tornadoes, avalanches, permafrost, etc., still remain more or less unsolved. The only consequences of temperature rise which are quite likely are that the atmosphere will take more water vapor with increasing temperature and also that the sea level will

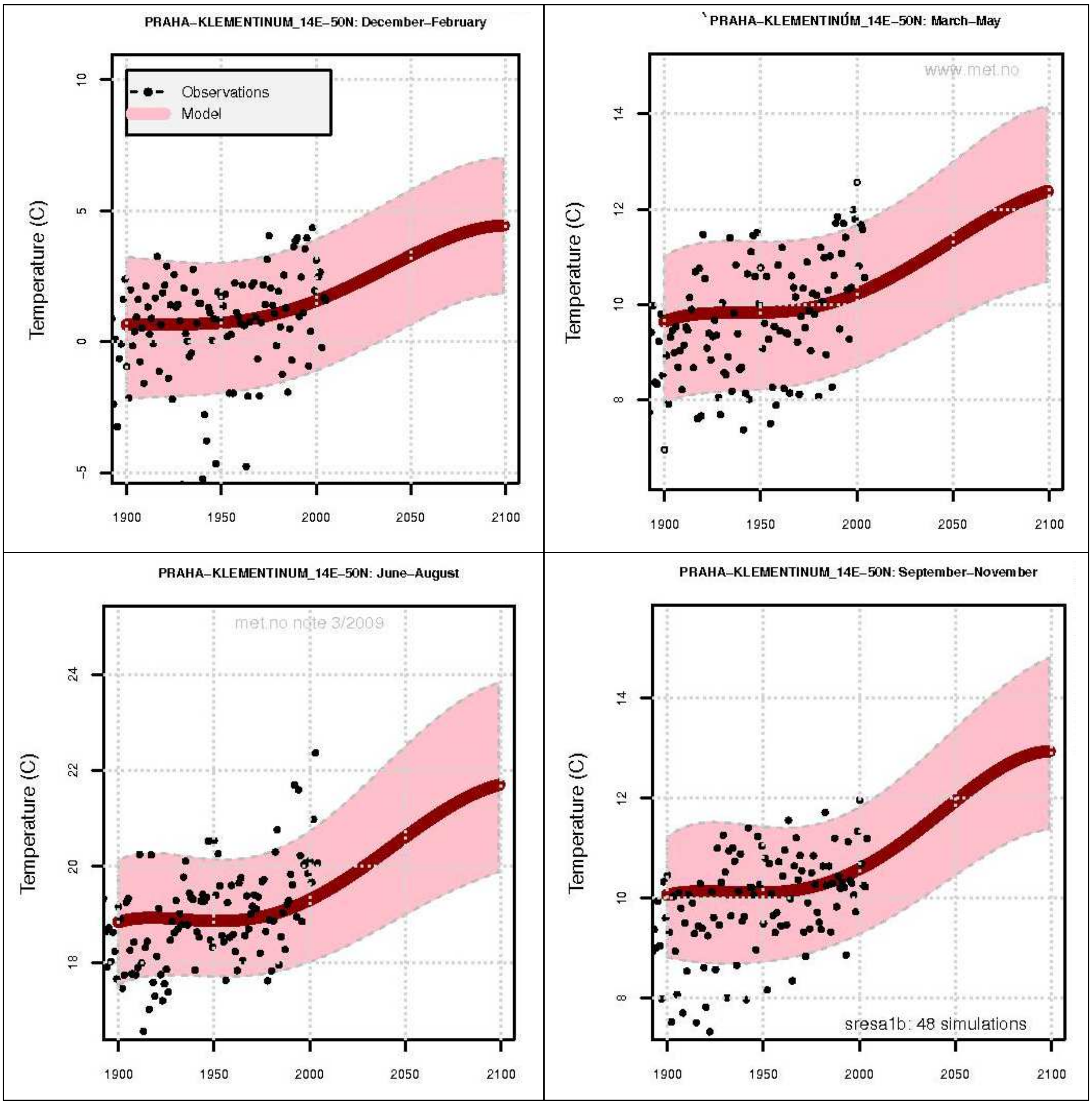

Figure 3. Historical and projected seasonal temperature scenarios for Praha – Klementinum over the period 1900 – 2100. Dots are measured values and thick read line model averages. Pink area represents the error bands of models. Note different scale in December-February diagram (upper left).

rise. Consequently, there are also very high probabilities for increased precipitation amounts and also precipitation intensity, summer and winter, in addition to higher variability in extremes, both with respect to flooding, drought and fire risk.

Although it is not yet possible to detail the developments in extreme weather, an increasing number of scientist reports indicate that severe weather events may increase in parallel with the atmospheric temperature rise. In order to summarize the state-of-art of the scientific knowledge in this field, the UN Intergovernmental Panel on Climate Change (IPCC) recently published a Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaption (SREX) [3]. The main purpose of this report is to raise the attention level among policymakers and stakeholders to potentially exposed areas of the world and to encourage adaption methods and mitigation procedures at an early stage, in order to minimize economic losses and human strains.

Based on such concerns numerous electrical utilities around the world are watching this situation closely for the safe operation of their electric grids, as will be exemplified in this paper.

II. Climate Projections for Czech Republic

The Ministry of the Environment of the Czech Republic has issued a Brochure on effects forming climate change on the Czech Republic [4] where also the power industry is discussed. However, this discussion relates mainly to the production of energy from renewable sources. Many temperature projections are certainly available for the Czech Republic. However, it appeared easier to go through the web site of the Norwegian Meteorological Institute (www.met.no) where temperature projections were presented through Google Earth for hundreds of locations around the world [5].

An example of historical and projected seasonal temperature is shown for Praha – Klementinum over a 200 year period in Figure 3. According to this figure the average temperature in Prague is expected to rise roughly about 3 °C for all seasons during our century.

It is unfortunately not yet possible to downscale projections of other weather phenomena to such a degree that they are of practical value for an objective discussion of potential effects on the electric grids. Due to these limitations the further discussion must therefore be generalized and based on experiences and knowledge about how harsh weather do influence the impacts and stability of our electric power overhead line grids.

Since the winter temperature will remain above the freezing point for a longer time further along the century, it means that there will be on the average less snow fall and hence shorter periods with snow on the ground as well.

However, it is frequently stated in climate projections that the variability is likely to increase too [3]. This means that, for instance, if the temperature generally increases, cold spells and seasons may very well be as we have always seen, although they may occur less frequently. This applies to any other weather event as well. The IPCC SREX [3] states that:

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events.

This is however a global statement, but it emphasizes the fact that it is strongly recommended to look at future climate with an open mind for potential extreme events of a different kind that could not be foreseen from historic experiences forming the area.

III. Some Considerations Concerning Electric Power Grids in the Czech Republic

A. General

Electric power overhead lines are on a global scale generally subject to impacts from weather related phenomena like:

- high wind speeds,
- ice loadings (wet snow, rime ice, freezing rain),
- lightning,
- pollution,
- avalanches,
- landslides,
- flooding
- forest and grass fires,
- tornadoes and tropical cyclones,
- sea level rise
- high temperature (thermal rating)
- snow depth (lattice towers),
- cloudiness (for helicopter based maintenance operations), and
- ground water level (foundations).

All these weather related elements may be influenced by changes in atmospheric temperature, as briefly outlined in the previous section. Weather elements like lightning, pollution, avalanches, landslides, snow depths on ground, flooding, etc., are subject to national and regional analyses on a broader scale. In this article only atmospheric icing (wet snow and rime ice) can then be discussed in general terms based on experiences and the knowledge about physical processes in the atmosphere. Further details about icing conditions in the Czech Republic are published in the COST Action 727 “Atmospheric icing on Structures”, State of the Art Report from 2007 [6]

Additionally, some information from other countries is given, based on the author’s current knowledge. For further reading about atmospheric icing the Cigré TB 291 is recommended [7].

B. Wet snow

As already stated, the average air temperatures during winter are likely to increase by around 3 °C, and accordingly there will be less snowfall on the average, and accordingly fewer events with wet snow in the lowlands of Czech Republic. This may indicate that there will be fewer events with electric disturbances in the grid during winter. However, when wet snow may occur, the disturbances may be just as large and widespread as before. For the design ice loadings it is not possible to conclude on any trend, neither in magnitude nor in frequency for such events.

In higher altitude areas where dry snow frequently occurs in past decades, the rising temperature may probably lead to more wet snow events, when the snow occurs at temperatures closer to 0 °C, and therefore wet snow accretions may become more likely in the future. If this assumption will be correct, then it is also likely that the design loads (with a certain recurrence period, e.g. 50 years) may increase as well for altitudes above, say, 500 m above sea-level

Measurements of wet snow are very scarce throughout Europe, except for Iceland [7]. However, it is nowadays getting possible to calculate wet snow from regular weather observations by the use of wet snow accretion models, as has recently been done for the UK [8].

C. Rime ice (in-cloud ice)

Following the increasing air temperatures, it is quite certain that clouds will contain more water per unit volume cloud air on a general basis. Following this, it is then very likely that rime icing will increase accordingly for electric overhead lines in mountains which are exposed to such icing. Hence, it is also then very likely that the design values (return period 50 years) will increase as well for electric overhead lines exposed to such icing, unless the temperature increases so much that the zero-isotherm will remain above the altitude of such lines for longer periods.

In the Czech Republic we find however the longest time series of ice load measurements in the world. Such homogeneous measurements were taken since 1940/41on Mt. Studnice, 800 m above sea-level. Figure 4 is taken from [6] and shows the large variability of ice loads which has to be expected for such meteorological phenomena. These measurements were initiated by Mr František Popolanský of EGU, Brno, and comprise a unique time series which has been widely shown and discussed on the international arena where atmospheric icing ever was an issue.

It is strongly recommended that these measurements are to be continued, since they may also be a very good indicator of climatic changes for the combination of temperature and cloud humidity.

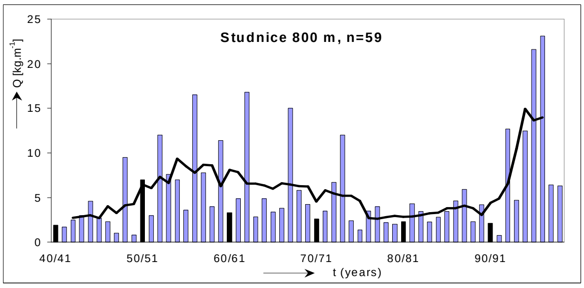

Figure 4. The longest continuous time series of ice load measurements in the world. Mt. Studnice, 800 m above sea-level, Czech Republic.

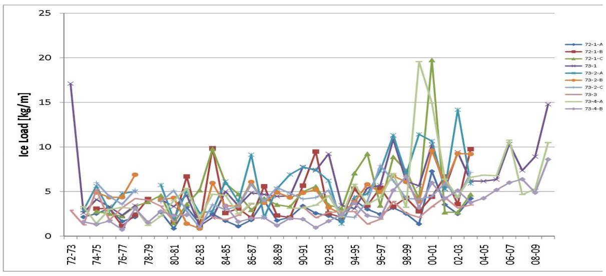

Figure 5. 39 years of ice loadings measured on 10 test spans in Iceland.

In Iceland they have measured wet snow and rime icing on automatic test spans since 1972, and have therefore a time series of nearly 40 years of data from numerous test spans spread over the country. Annual maxima for the 10 spans operated continuously since 1972 until 2010 are shown in Figure 5.

It can be seen from Figure 5 that there were some extreme events around the turn of the century, but also a slight increasing trend over the last decade or so. Whether this trend will continue is impossible to say, but the figure shows, similarly to the Czech measurements in Figure 4 that such data will be very important for the future.

To know more about rime ice loads it is necessary to monitor such icing on test sites. Atmospheric icing is generally not a topic for regular weather observations, therefore it must be monitored specifically by those for whom this is an economic issue. This applies even more for rime ice than for wet snow, since it is not possible to model rime icing as easily as for wet snow from other regular weather observations. To model rime ice it is basically necessary to scan through long time series of the physical atmosphere states in terms of gridded values of all meteorological parameter, as done by regular weather forecasting models.

However, modified versions of such weather forecasting models are now available for rime ice studies as shown in [8]. Such models can also be used for studies of historical events as well as for detailed forecasting of adverse weather in the operation phase of electric overhead lines.

IV. International concerns and actions

The information in this chapter was collected from Cigré colleagues in preparation of the Tutorial at the Cigré Study Committee B2 meeting in Reykjavik 2011 [9]. Individual informants are mentioned for each country below. The lists of items are not complete for most countries, but some highlighted topics of particular attention are listed for each country.

A. Australia (Henry Hawes, in collaboration with Energy Networks Association (ENA))

ENA – Key issues are mentioned as follows:

1. Climate change is emerging as a major issue for operation of networks in relation to temperature, heat wave, flooding, wind, and fire weather.
2. Changes in single events (cyclones and flooding) as well as shift in frequency and intensity of weather regimes.
3. Intensity increase of East coast cyclones.
4. Hail risks associated with severe thunderstorm activity in Eastern Australia.
5. More frequent and intense droughts and heat waves.
6. Bush fire risk (“Extreme fire weather” may increase with 100-300 days).

B. Canada (Dr. Janos Toth, BC Hydro, R&D)

Studies are performed in collaboration with Environment Canada, University of British Columbia, Pacific Climate Change Consortium, University of Alberta, and others. Areas for particular attention are identified as follows:

1. Temperature increase
    a. Beetle infestation
    b. Drier summers (fire risks, slope stability)
    c. Woodpeckers
    d. Changes to energy and peak load consumption patterns
2. Precipitation
    a. River erosion, flooding
    b. Mudslides
    c. Increased corrosion
    d. Higher frequency and severity of wind and ice storm, and hail storms
    e. Reduced opportunity for live-line work (due to more rainy days)
3. Wind
    a. Changes in wind speeds and prevailing wind direction will affect failure rates, recovery time and reliability
    b. Need to adjust vegetation control practices
    c. Wind withstand levels of hardware will need to be increased
4. Other effects
    a. Rising sea level
    b. Melting permafrost
    c. Maintenance and structural integrity of transmission lines could be affected
    d. Increased lightning activities
    e. Fog increase means more in-cloud icing and reduced line access
    f. Transmission line ratings could be affected
5. Adaption measures
    a. Driver for technology developments (robotics, remote sensing)
    b. Specialized weather prediction
    c. Modify maintenance and design
    d. Dynamic thermal rating
    e. Corrosion resistant material
    f. Review emergency response
    g. Probabilistic techniques to assess reliability

C. Norway (Svein M. Fikke, with input from the Norwegian Meteorological Institute (met.no) and the Norwegian Geotechnical Institute (NGI))

Norway is a coastal country, stretching from 58° to more than 71° N, with the warm North Atlantic Current along its coast. The climate varies from temperate in the south to arctic in the north. The climate predictions for Norway depend also on the routes of the extra tropical cyclones, how often they will go south of Norway (into the Skagerrak Sea) or northwards along the coast. However, the following scenarios are likely:

1. Atmospheric icing depends on wet snow and rime ice
   a. North Norway – More wet snow inland, little rime ice
   b. Along the coast (southwards from N. Norway) – Less frequent wet snow little rime ice
   c. Central mountain range – More frequent wet snow and higher extremes, less rime ice below 900 m above sea level , more rime ice above 900 m above sea level
   d. SE Norway – More frequent wet snow, rime ice only above 1 000 m above sea level
2. Avalanches
   a. Transition from dry to wet snow avalanches below 800 – 1 000 m above sea level
   b. Higher areas – More snow and dry avalanches give longer discharge ranges
   c. Known avalanches will increase in size
   d. More often wet snow avalanches and mud-slides due to more and intense rainfall
   e. “Safe” areas may become unsafe
3. Operation and maintenance
   a. Large parts of the transmission system pass through exposed mountain areas
   b. Helicopter is often the only tool to access such lines, especially in winter
   c. Higher frequency of low clouds and extreme weather will reduce weather windows for maintenance

Russia (Sergey Chereshnyuk. VNIEE)

Russian topics of concern are

1. Temperature increase of about 5 °C in Russian arctic regions already recorded
2. Serious damage to buildings due to melting permafrost
3. Permafrost area reduction of 15-30 % (by 2050)
4. Flooding and landslide
5. Wind loads will decrease in some regions and increase in others

D. United Kingdom (Dr Brian Wareing, Brian Wareing.Tech, in collaboration with UK Met Office)

Some examples of diagnostics are:

1. Evaluating the change in risk of high wind and wet snow accretion on overhead conductors
2. Estimating the change in rating associated with low wind and high temperature
3. Calculating the change in the seasonality of demand due to, for example, increased use of air conditioning

E. CIGRÉ

In the Technical Brochure 291 [3] Cigré WG B2.16 states the following concerning atmospheric icing in general terms:

1. Coastal areas: More seldom wet snow in lowlands, may be more in the mountains
2. Inland areas with cold climate: Wet snow may increase in frequency and intensity at all elevations
3. Mountain areas: Risk of rime ice may decrease in lower levels and increase in higher levels
4. Freezing rain: Not possible to evaluate yet.

V. CONCLUDING REMARKS

As mentioned in the Introduction, there are many questions and research issues which still remain unsolved. Also, among the more settled issues there are still a lot of smaller or bigger uncertainties which are subject to lively discussions in the scientific communities. In particular, major uncertainties remain as to the development of greenhouse gas emissions around the world.

It may seem frustrating that there is so little development in international agreements and binding actions to stabilize and reduce emissions on a global scale. However, on the other hand, there are more encouraging actions in the other end, with respect to topic like cleaner electricity production (especially solar and wind), use of electric cars, energy conservation, reduced energy demands in buildings (private, public and industrial), public transportation, recycling of materials and resources etc.

Similar movements are going on around the globe, and it may be so well that the "down-top" actions will in the end work better than "top-down" actions and regulations. In these matters neither USA nor China should be disregarded. Such activities are driven by public demands. People do not like to live any more in houses or flats with high energy demands for heating, for instance. And they don't want to drive cars in densely populated cities. Therefore it is always also important to be ahead of the development in order to ensure future markets and demands.

As a conclusion of this paper some key points may be noted:

- Evolution in the global climate must be accounted for.
- There are no significant indications in storm and tornado frequencies yet. Probably this applies to lightning as well.
- Consider cheap actions before you are forced to take on the expensive ones.
- Consider life time of ohls in relation to time scales for climate change.
- Notify and file events in your grid.

As electric grids may become more vulnerable to adverse weather, it should also be emphasized that the options of detailed and on-purpose weather forecasts are developing rapidly. The Cigré Session paper 2012 [8] demonstrates some applications for such models. However, it is more up to the utilities to ask for developments in such technologies to improve the reliability in the operation of their networks.

Finally, it is important to note that potential challenges for electric production and transportation systems are continuously dealt with by organizations and groups like Cigré and IEEE, in addition to the countries mentioned above. Cigré has established a new WG B2.54 "Management of Risk Associated with Severe Climatic Events and Climate Change on Overhead Lines". This was established in 2011 and will end in 2014. This WG is convened by Henry Hawes, Australia.

IEEE Power and Energy Society (IEEE – PES) has established the "IEEE Climate Change Technology Sub-Committee" (CCTSC) to deal with such issues. More information can be found on their web site: https://collaborase.com/ieee-cctsc "Climate Change Adaption Planning – an update for the Power Industry. Special Focus: Lessons learned from Extreme Weather & Natural Disasters" and "New Planning Practices Considering Renewable Resources Integration and Distributed Energy Resources". Papers from these sessions may be available from IEEE – PES.

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