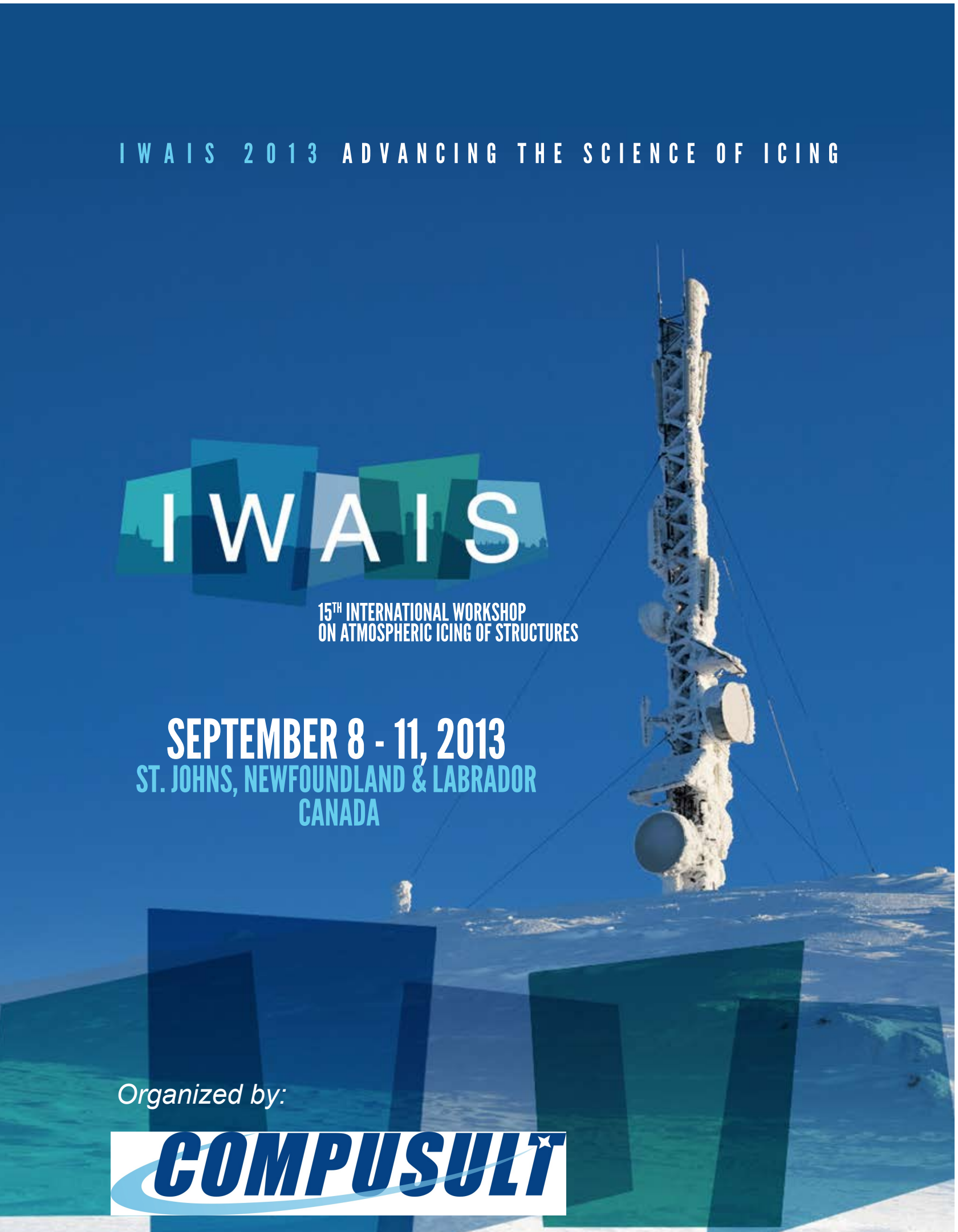
IWAIS 2013 ADVANCING THE SCIENCE OF ICING



IWAIS

15TH INTERNATIONAL WORKSHOP ON ATMOSPHERIC ICING OF STRUCTURES

SEPTEMBER 8 - 11, 2013

ST. JOHNS, NEWFOUNDLAND & LABRADOR CANADA

Organized by:

COMPUSULT

Welcome to St. John's and IWAIS 2013

Dear Colleagues and Friends,

I'm very pleased to welcome all of you to the 15th International Workshop on Atmospheric Icing of Structures (IWAIS 2013). This is the first time that the workshop has been held in Newfoundland and Labrador and we're very honoured that Compusult was selected by the International Advisory Committee (IAC) to host and organize this event in our province in Canada.

Atmospheric ice accumulation on structures is a serious and costly problem affecting a wide variety of human activities such as electric power transmission and distribution, transportation, wind energy, oil and gas production/exploration, telecommunications, Arctic and sub-Arctic operations, etc. The purpose of this workshop is to facilitate scientific and technical information exchanges among utilities and other industries operating in icing-prone environments, as well as meteorological services, technology companies, research centres, laboratories, and universities.

IWAIS 2013 includes over 50 oral and poster presentations, thus providing a unique opportunity to learn more about the latest research, development, and newly acquired knowledge in areas such as:

- Methods for protection against icing and reduction of risk and damage, such as anti-icing methods and hydrophobic coatings
- Theoretical studies and verification testing for in-cloud icing, wet snow accretion and freezing rain, accumulation and shedding mechanisms
- Mapping and assessing the climatic risks affecting various types of structures
- Techniques for icing forecasting and alerting systems
- Field observations and storm analyses for various types of atmospheric and spray icing
- Basic research and laboratory measurements associated with the physics and dynamics of ice accretion

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- Analyses of the mechanical effects of ice accumulation on structures
- The effects of storms and icing on telecommunications, electrical distribution, wind energy production
- Electrical properties of iced conductors and insulators, and flashover
- Catastrophic ice storms, analysis of meteorological situations and damage incurred, and the possibilities for forecasting such events

IWAIS 2013 has attracted presenters and attendees from many different organizations and over 14 countries. Once again, we're honoured that you've come to participate in this event in Newfoundland and Labrador. I hope everyone also takes time to enjoy our fun, friendly, scenic, and captivating province while you're here.

I would like to thank a number of individuals and organizations:

- The employees of Compusult who contributed to IWAIS 2013
- The members of the IWAIS International Advisory Committee (IAC) who supported us in hosting this event. I would especially like to thank Svein Fikke, Lasse Makkonen, and Asim Haldar for their advice and recommendations which greatly helped Compusult in organizing many aspects of this conference.
- All those who agreed to act as session chairpersons: Xingliang Jiang, Göran Ronsten, Svein Fikke, Lasse Makkonen, Masoud Farzaneh, and Jaroslav Šabata.
- The Newfoundland and Labrador Association of Technology Industries (NATI), who helped Compusult in many ways to make this event a success, including securing support from our sponsors, coordinating registration, assisting with logistics, and much more.
- Our sponsors, who we gratefully acknowledge on the following page.

I welcome you on behalf of Compusult and the Local Organizing Committee.

Paul Mitten, Vice-President, Compusult Limited

Many thanks to all our IWAIS 2013 Sponsors

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SCHEDULE - Sunday and Monday, September 8-9, 2013

Start Time	End Time	Description
16:00	19:00	**IWAIS 2013 Registration**
19:00	22:30	**IWAIS 2013 Icebreaker Party**
7:30	8:30	**Breakfast (60 minutes)**
8:30	8:40	**Welcome Address/Opening Business**
8:40	12:30	**SESSION 1 - ANTI-ICING / DE-ICING Oral Presentations Session Chairperson: Xingliang Jiang**
8:40	9:00	**Xingliang Jiang** - "Strategies and Status of Anti-icing and Disaster Reduction for Power Grid after the 2008 Ice Storm in China"
9:00	9:20	**Miroslav Radojcic** - "Comparative testing of different anti-ice coatings for overhead line conductors with special focus on ice accretion, RIV and visual impact"
9:20	9:40	**Reza Jafari** - "Design of superhydrophobic/icephobic composite coatings"
9:40	10:00	**Ladan Foroughi Mobarakeh** - "Effect of plasma deposition time on ice repellency of plasma polymerized HMDSO film"
10:00	10:20	**Haruka Endo** - "Behavior of a small water droplet on a superhydrophobic coating in a cold environment"
10:20	10:40	**Mitsugu Hasegawa** - "Numerical study of the freezing process of minute water droplet on superhydrophobic surface"
10:40	11:10	**Tea & Coffee Break (30 minutes)**
11:10	11:30	**Faranak Arianpour** - "Effect of immersion time on the hydrophobic and icephobic properties of self-assembled silane coatings on Al Substrates"
11:30	11:50	**Shahram Farhadi** - "Corrosion resistance, ice-releasing performance and stability of nanostructured superhydrophobic surfaces on Al substrates"
11:50	12:10	**Gelareh Momen** - "Delayed freezing time on various nanocomposite superhydrophobic surfaces"
12:10	12:30	**Siavash Asadollahi** - "Development of silicon-based superhydrophobic/icephobic surfaces by an atmospheric pressure plasma jet"
12:30	14:00	**Lunch Break (90 minutes)**
14:00	17:00	**SESSION 2 - ICING IN WIND ENERGY Oral Presentations Session Chairperson: Göran Ronsten**
14:00	14:20	**Michael Abbott** - "Design and Implementation of a Wind and Icing Monitoring System for 80m Wind Turbines in Northern Labrador"
14:20	14:40	**Antoine Lacroix** - "Assessment of Wind Energy Production Penalties Due to Cold Climate in Canada"
14:40	15:00	**Niels-Erik Clausen** - "Recommended practices for wind energy in cold climates – resource assessment and site classification"
15:00	15:20	**Qin Hu** - "Research Review of Wind Turbine Blade's Icing and Anti-icing/De-icing"
15:20	15:40	**Tea & Coffee Break (20 minutes)**
15:40	16:00	**Adriána Hudecz** - "Ice accretion on wind turbine blades"
16:00	16:20	**Matthew Wadham-Gagnon** - "Field Measurement of Wind Turbine Blade Icing"
16:20	16:40	**Ville Lehtomäki** - "Ice Induced Vibration on Wind Turbines"
16:40	17:00	**Neil Davis** - "Forecasting Production Losses by Applying the Makkonen Icing Model to Wind Turbine Blades"
19:00	22:00	**Banquet**

SCHEDULE - Tuesday, September 10, 2013

Start Time	End Time	Description
7:30	8:30	Breakfast (60 minutes)
9:00	10:40	**SESSION 3 - ICING MEASUREMENT & MODELLING** **Oral Presentations (Part 1)** **Session Chairperson: Svein Fikke**
9:00	9:20	**Árni Jón Elíasson** - "Wet-snow Accumulation – A Study of two severe Events in complex Terrain in Iceland"
9:20	9:40	**Hálfdán Ágústsson** - "Modeling wet-snow accretion Comparison of cylindrical model to field measurements"
9:40	10:00	**Bjørn Egil Kringlebotn Nygaard** - "A study on the sticking efficiency of wet snow using 50 years of observations"
10:00	10:20	**Matthew Wadham-Gagnon** - "Met mast configuration guidelines in Cold Climate"
10:20	10:40	**Lasse Makkonen** - "Icing of a 328m tall tower - a case study"
10:40	11:10	Tea & Coffee Break (30 minutes)
11:10	12:30	**SESSION 3 - ICING MEASUREMENT & MODELLING** **Oral Presentations (Part 2)** **Session Chairperson: Lasse Makkonen**
11:10	11:30	**Brian Wareing** - "A New Severe Weather test site for OHL conductors and fittings"
11:30	11:50	**Kathleen F. Jones** - "Winter measurements of sea spray at Mt. Desert Rock"
11:50	12:10	**Toshihiro Ozeki** - "Laboratory experiments of saline water spray icing – Features of hydrophilic and hydrophobic pliable sheets"
12:10	12:30	**Xinbo Huang** - "Ice Growth Prediction Model of Transmission Lines Based on Mamdani-type Fuzzy Neural Network"
12:30	14:00	Lunch Break (90 minutes)
14:00	16:00	**SESSION 4 - CONDUCTORS/INSULATORS/FLASHOVER** **Oral Presentations** **Session Chairperson: Masoud Farzaneh**
14:00	14:20	**Fanghui Yin** - "Influence of Electric Field on Conductor Icing"
14:20	14:40	**Zhijin Zhang** - "Study on the Influence of Mixed-phase ice on Corona Inception Voltage of Smooth Conductor"
14:40	15:00	**Borut Zemljarič** - "Post line insulator and classical insulator dynamics at snow shedding"
15:20	15:40	**Hiroya Homma** - "Evaluation on Flashover Voltage Property of Snow Accreted Insulators for 154kV Transmission Lines"
15:40	16:00	**Sonja Berlijn** - "Summarizing results and knowledge from laboratory ice and snow test on glass and composite insulators for overhead lines"
16:00	18:00	Tea & Coffee Break & Formal Poster Session (2 hours)
16:30	18:00	**International Advisory Committee (IAC) Meeting**
18:30	21:00	**Nalcor Energy Sponsored Dinner for IAC Members and Accompanying Persons**

SCHEDULE - Wednesday and Thursday, September 11-12, 2013

Start Time	End Time	Description
7:30	8:30	Breakfast
8:40	10:40	**SESSION 5 - ICING CLIMATE & ICING FORECASTING** **Oral Presentations** **Session Chairperson: Jaroslav Šabata**
8:40	9:00	**William Henson** - "Forecasting of Icing Events and Icing Accumulation on Transmission Lines at Hawke Hill, Newfoundland and Labrador"
9:00	9:20	**Svein M. Fikke** - "Application of numerical weather forecasting models on atmospheric icing in Long Range Mountains"
9:20	9:40	**Sergey Chereshnyuk** - "A new set of climatic loads maps for Russia"
9:40	10:00	**Svein M. Fikke** - "The Development of New Maps for Design Ice Loads for Great Britain"
10:00	10:20	**Sergey Chereshnyuk** - "Icing conditions forecast using weather forecast model COSMO-RU"
10:20	10:40	**Xunjian Xu** - "Short-term Winter Icing Climate Prediction of power line Based on the Polar Vortex Area and the Subtropical High"
10:40	11:10	Tea & Coffee Break (30 minutes)
11:10	12:30	**SESSION 6 - VARIOUS ICING TOPICS** **Oral Presentations** **Session Chairperson: Paul Mitten**
11:10	11:30	**Asim Haldar** - "Guide for the Preparation of an Emergency Restoration Plan"
11:30	11:50	**Hongxian Zhang** - "Research and engineering application of power grid large-scale ice-disaster prevention and cure technology"
11:50	12:10	**Holger H. Koss** - "Influence of Icing on Bridge Cable Aerodynamics"
12:10	12:30	**Chun Zhao** - "A Portable DC De-icer for Rural Power Network Transmission Line"
12:30	14:00	Lunch Break (90 minutes)
14:00	14:20	**Muhammad Virk** - "Atmospheric Icing on Structures: COLDTECH-RT3 Perspective"
14:40	15:00	**H. Banitalebi Dehkordi** - "Wind tunnel glaze ice simulation on a vertical angle member for different aerodynamic angles"
15:00	15:30	**PRESENTATIONS BY SPONSORS & EXHIBITORS**
15:30	16:00	Tea & Coffee Break (30 minutes)
16:00	16:15	**CLOSING ADDRESS**
Depart at 8:30	**Return by 15:30**	**Optional Site Visit to Hawke Hill and Fermeuse Wind Power Project** **(NOTE: This requires separate registration and cost. Also, safety boots are required to visit Hawke Hill.)**

Lecture Abstracts

The following pages present the abstracts for IWAIS 2013 lectures.

The presentations have been organized into the following sessions and categories:

- SESSION 1: ANTI-ICING / DE-ICING
- SESSION 2: ICING MEASUREMENT AND MODELLING
- SESSION 3: ICING IN WIND ENERGY
- SESSION 4: CONDUCTORS / INSULATORS / FLASHOVER
- SESSION 5: ICING CLIMATE AND ICING FORECASTING
- SESSION 6: VARIOUS ICING TOPICS

Session 1: Anti-Icing and De-Icing

Strategies and Status of Anti-icing and Disaster Reduction for Power Grid after the 2008' Ice Storm in China

JIANG Xing-liang[1], DONG Bing-bing[1], DONG Li-na[2], LU Jia-zheng[3], ZHANG Ji-wu[4]

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***Abstract*:** The ice storm of 2008 caused serious damage to power systems in Southern China, with more than 100 billion yuan ($ 16 billion) in direct economic losses. In order to prevent the large-scale ice disaster in grid, the Chinese government, the State Grid and China Southern Power Grid attach great importance to prevent the ice disaster in grid. The accident of the ice disaster has been reduced significantly by strengthening management, conducting scientific research, and applying new technologies and new methods. After five years of efforts, the ice map has been developed, and some de-icing methods have also been studied in China, such as coating, laser, robot, and AC/DC ice-melting. The experience of engineering applications and practices shows that the coating can not meet the requirements in a large area. Laser, robotic, and microwave technology are not yet mature and can not be used in engineering. AC ice-melting method consumes a large amount of reactive power. DC ice-melting is a good method with low power requirement, high efficiency, and convenience. Therefore, the fixed and mobile DC ice-melting devices are developed. The large fixed ice-melting device can meet the requirements in a range of 100 km radius, with a maximum capacity of 1200 MW. The small mobile ice-melting devices can only be used for local line, with a power of 100 kW to 500 kW and weight of 100~300 kg. So far, fixed DC ice-melting devices have been installed in more than 200 substations in State Grid and China Southern Power Grid in China. The DC ice-melting mobile devices have been applied in all the power companies with serious icing. Also, the ice-melting has been solved for the overhead ground and optic cable. These methods and technologies play an important role in Chinese grid in recent years and reduce the number of ice disaster accident effectively.

***Keywords*:** ice disaster; power systems; anti-icing; de-icing; AC/DC ice-melting.

Comparative Testing of Different Anti-ice Coatings for Overhead Line Conductors with Special Focus on Ice Accretion, Riv And Visual Impact

Miroslav Radojcic, Kjell Halsan, Igor Gutman*, Andreas Dernfalk*, Lillemor Carlshem**, Lars Wallin**
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Abstract: A number of important tests for the first (screening type) evaluation of new types of super-hydrophobic coatings applicable for both conductors and insulators were identified and included: ice tests in laboratory and outdoors; audible noise test; ageing test; visual impact test. Based on the obtained results the authors believe that there are positive indications for the super-hydrophobic coating. Further work would be of interest, in order to explore nano-coating regarding ice formation and adhesion properties, and also to explore ageing performance of such coating in field conditions.

Design of superhydrophobic/icephobic composite coatings

Reza Jafari and Masoud Farzaneh
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Abstract: An easy and inexpensive method was used to elaborate superhydrophobic surfaces. A superhydrophobic surface was prepared by spray coating a mixture of calcium carbonate ($CaCO_3$) particles, stearic acid and polymer latex suspensions on an aluminum substrate. The Taguchi method was used to optimize the fabrication process parameters: the percentage of stearic acid, the $CaCO_3$ particles to copolymer weight ratio, and the spray distance from the substrate. It was found that the percentage of stearic acid plays the most significant role in affecting the coating's wettability. The optimal condition proposed by this method has been verified through additional experiments which showed an increase in static contact angle up to 158º. Study of its wettability at low temperature showed that the superhydrophobic surface becomes rather hydrophobic at supercooled temperatures. However, these results also showed a delayed freezing time of water droplets on its surface.

Keywords: component; Superhydrophobic surface, aluminium alloy, anti-icing coating, nanocomposite

Behavior of a Small Water Droplet on a Superhydrophobic Coating in a Cold Environment

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Abstract: Icing causes various problems. To counter these problems, deicing methods are required. In recent times, a combination of an electrothermal heater and superhydrophobic paint has been suggested as an innovative deicing method. There are some deicing methods using only an electrothermal heater. However, such methods may cause secondary icing owing to water formed by melting ice. To counter this, a surface coated with superhydrophobic paint can quickly remove such water.

Therefore, this study examines the behavior of a water droplet on a superhydrophobic coated surface for the development of the above-described method. Two experiments are conducted in this study: in one, a droplet drips onto the inclined plate and falls naturally by gravity, and in the other, a droplet is fixed and the plate under the droplet is moved for a fixed point observation. The droplet is approximately 2 mm in diameter, and the ambient temperature is maintained at -15°C; the droplet is dripped onto the surface with several initial temperatures. These experiments showed that the distance by which a droplet moves varies with the droplet's initial temperature; specifically, the distance decreases with increasing of the initial temperature. This indicates that heating control is required to prevent an increase in the water temperature in the method employing a combination of an electrothermal heater and a superhydrophobic coating.

Effect of plasma deposition time on ice repellency of plasma polymerized HMDSO film

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Abstract: Plasma polymerization is a suitable technique for thin film deposition with widespread applications in domains as biomedical, biofouling, anti-corrosion and anti-icing. In this study, low pressure plasma polymerization of Hexamethyldisiloxane (PP-HMDSO) was carried out to impart a superhydrophobic coating with icephobic properties on anodized aluminium surfaces. Before low surface energy coating, an aluminium surface was anodized to make it rough. The superhydrophobic and icephobic properties of the developed coating were studied by considering the effects of deposition time (t = 15 to 25 min) of the plasma polymerization process. The results showed that increasing the treatment time leads to an increase of the contact angle from 158º to 164º while the sliding angle decreases from 8º to 3º. It was also observed that the ice adhesion strength of coatings decreased to 100 kPa for t = 15 min and to 83 kPa for t = 25 min compared to ice adhesion strength of an untreated aluminium surface (350 kPa). The durability of the PP-

HMDSO coatings showed that after 15 consecutive icing/de-icing cycles the shear stress for t = 15 min increased to 250 kPa whereas it was 130 kPa for t = 25 min. The surfaces can keep their icephobic properties after 15 consecutive icing/de-icing cycles.

Keywords: Superhydrophobicity, plasma polymerization, Hexamethyldisiloxane, Icephobicity, Contact angle.

Numerical study of the freezing process of minute water droplet on superhydrophobic surface

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***Abstract*:** A new anti-icing / de-icing method using the combination of heating and superhydrophobic surface has been developed to prevent ice accretion on structures in cold climate. Liquid water effectively can be removed from the surface in this method. The motion of a droplet of molten water can affect the cooling behavior while the droplet is moving on cooled surface. The numerical analysis of two-dimensional heat transfer for hypothetical liquid cylinder was performed to consider how rolling motion affects the cooling behavior of the droplet. The numerical model calculates temperature distribution on the cross section of the cylinder rolling on the surface. The experiments were also carried out to measure the surface temperature of a water droplet rolling on cooled plate. The droplet was deposited on cooled plate and then forcedly rolled. The model results showed the motion of rotation cause the effect of heat advection to the cooling behavior. The location near three-phase point at one side then can become the coldest any time during temperature transition in the case of motion of rotation. The qualitative comparison of experimental and numerical results showed that the motion of the real moving droplet also affects the cooling behavior.

Effect of immersion time on the hydrophobic and icephobic properties of self-assembled silane coatings on Al substrates

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Abstract: The effect of immersion time on hydrophobic and icephobic properties of self-assembled monolayers (*SAM*s) thin films of OD (octadecyltrichlorosilane) on flat aluminum alloy (AA6061) substrate was investigated. By rising the immersion time from 15 minutes to 12 hours, the hydrophobic properties of the coating were improved. More precisely, in their corresponding baths, hydrophobic properties improved as contact angle (CA) increased from about 108^{o} to 160^{o} while contact angle hysteresis (CAH) decreased as much as 7^{o}, corresponding to superhydrophobic

characteristics (switching wetting regime from Wenzel to Cassie-Baxter regime). Icing tests showed delayed ice formation and lower adhesion strength on samples with large and small wetting hysteresis.

Corrosion Resistance, Ice-Releasing Performance and Stability of Nanostructured AA2024-T3 Superhydrophobic Surfaces

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Abstract: Ice and wet-snow adhesion and its accumulation on exposed structures and equipment is well known to cause serious problems in cold climate regions such as Canada, the U.S, China, Russia etc. To counter this problem, various anti-icing and de-icing techniques have been introduced and developed over years. Among these, superhydrophobic coatings have been recently proposed as a passive technique to reduce or prevent ice build-ups on outdoor structures. In this study, hydrophobic and ice-repellent properties as well as anti-corrosive performance of hierarchical micro-/nano-rough superhydrophobic coatings prepared on Al alloy 2024-T3 substrates were studied. The samples were prepared by etching the Al substrate in HCl followed by further hydrophobization of the rough nanostructured surface with octadecyltrimethoxysilane $C_{18}H_{37}Si(OCH_3)_3$, known as wet-chemistry technique. The stability of the prepared coated samples was evaluated over time and in different conditions, in terms of their ice-repellent behaviour and anti-corrosive performance. Artificially created glaze ice was deposited on the nanostructured coated surfaces by spraying supercooled water micro-droplets with an average size of ~65 µm in a wind tunnel at subzero temperature (-10 ^{o}C) and a wind speed of 11 m/s to simulate most severe natural atmospheric icing. Ice adhesion strength was evaluated by spinning the samples in a centrifuge machine at constantly increasing speed until the accumulated ice detached from the samples. The samples were tested over repeated icing/de-icing cycles in order to assess the durability of their ice-repellent properties. The results showed that both water-repellent and ice-repellent properties of the surfaces degraded over time and after successive icing/de-icing cycles. Potentiodynamic polarization tests and salt spray exposure studies revealed that the corrosion resistance of the modified substrates improved compared to the unmodified ones. While extensive corrosion appeared on unmodified flat Al samples after only 8 cycles of salt spray exposure, early stage corrosion was observed for rough modified samples only after 18 cycles of exposure.

Keywords: Self-assembling; Low surface energy coating; Nanostructured AA2024-T3; Sperhydrophobicity; Ice adhesion strength; Potentiodynamic polarization; Salt-Spray test and durability; Wetting hysteresis.

Delayed freezing time on ZnO based nanocomposite superhydrophobic surface

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Abstract: Superhydrophobic silicone rubber nanocomposite coatings based on the addition of ZnO nanoparticles have been developed and their wettability behaviour was analysed in the temperature range from 20 to −15 °C. At 20 °C, high static contact angle > 155º and low contact angle hysteresis of about 5º was obtained for the as-prepared superhydrophobic surfaces from which water drops easily roll off. Such surfaces at supercooled temperature showed important delayed freezing time of water droplets onto the silicone rubber hydrophobic surface and aluminum bar. Drop crystallization on superhydrophobic surfaces was observed after 4-5 min, which is significantly longer than on an aluminium surface (~40s) or on an RTV-coated surface (~100 s). Lower wettability was observed when the surface temperature went down from 20 to -15 °C. Indeed, when nanocomposites surfaces were exposed to temperatures lower than 0 °C, condensed water penetrated into the porosities of the coating and water vapour condensation lead to a transition to the Cassie-Wenzel regime resulting in lower contact angles. The surface energy of aluminum bar, and the hydrophobic and superhydrophobic surfaces was investigated by estimating the free energy of the total surface using the Owens–Wendt equation. The free energy of the total surface for the superhydrophobic nanocomposites showed an important reduction as compared to aluminum.

Keywords: Superhydrophobicity, Surface energy, Nanocomposite , Freezing time , Contact angle.

Development of Silicon-based Superhydrophobic/icephobic Surfaces Using an Atmospheric Pressure Plasma Jet

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Abstract: During the past few decades, superhydrophobic coatings have gained a lot of interest due to their several applications, most notably self-cleaning icephobic surfaces. On the other hand, plasma based surface treatment techniques have proven to be an economical, quick and environmental method for development of various organic and inorganic coatings. In this study the plasma process parameters are optimized in an atmospheric pressure plasma jet system with an organosilicon based monomer (HMDSO) to deposit superhydrophobic coatings on aluminum substrates with contact angles as high as 160°. A wind tunnel which operates in sub-zero temperatures is then used to simulate the severe winter conditions that such coatings are usually exposed to. Ice adhesion strength is measured by a centrifugal method. Furthermore, contact angle

goniometry and FT-IR confirm the presence of low surface energy chemical functions on the coating and a micro roughened structure which leads to a high contact angle and low contact angle hysteresis. The results show that an atmospheric pressure plasma jet technique may be an industrial, economic and environmental-friendly method to prevent or reduce the ice accumulation on aluminum substrates.

Session 2: Icing in Wind Energy

Design and Implementation of a Wind and Icing Monitoring System for 80m Wind Turbines in Northern Labrador.

Michael Abbott, William Henson
AMEC, Environment & Infrastructure AMEC, Environment & Infrastructure
St. John's, NL, Canada; Ottawa, ON, Canada
Eric Gionet, David Bryan
AMEC, Environment & Infrastructure AMEC, Environment & Infrastructure
Halifax, NS, Canada; St. John's, NL, Canada

***Abstract*:** The coastal region of Labrador is populated with many isolated communities that face challenges in providing electrical power generation. Vale NL Ltd. is investigating the use of wind turbines to provide electrical power for its mining facility at Voisey's Bay. Vale has commissioned AMEC to perform a wind resource assessment and evaluation of icing potential at a candidate site near Voisey's Bay.

The candidate site is located in a harsh, marine environment, in close proximity to the Labrador Sea, that experiences extreme cold temperatures, high winds and significant icing events. Compounding the challenge is the remote nature of the candidate site; it can only be accessed by helicopter, making inspection and maintenance visits difficult and infrequent.

Because of these challenges, AMEC undertook a system design that recognized the harshness of the environment and the potential for failures. The monitoring tower was commissioned in December 2012 and the data recording and analysis program will proceed for at least 12 months. A suite of monitoring sensors was deployed at the site to provide real-time data recording of the critical meteorological parameters (primarily wind speed, wind direction, temperature, etc.) and icing accumulation. The system design incorporated several levels of redundancy at the sensor level, data storage level and power levels to mitigate the impacts of an individual failure. An overview will be presented of the system design to suit the project requirements and challenges, as well as a preliminary, qualitative assessment of the performance of the monitoring system.

Assessment of Wind Energy Production Penalties Due to Cold Climate in Canada

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***Abstract*:** Canada's total installed wind energy capacity has grown by more than 900 percent over the last decade, resulting in an installed capacity of 6,500 MW as of January 2013. With this significant growth in wind power development, operational impacts due to Canada's cold climate are becoming evident.

A study was undertaken to evaluate the impact of cold climate conditions on wind energy production. Actual production data from 24 wind farms located across Canada were compared with reference data generated using wind data from Environment Canada's weather stations, a measure-correlate-predict algorithm (MCP), and wind energy production simulation software. The study also looked at the predicted losses in the projects' preliminary feasibility studies. The initial results indicate that cold climate losses in the order of $100 million occur annually. The presentation will break down cold climate losses into national and regional production loss percentages.

Wind farm sites located in regions where colder temperatures occur over greater parts of the year represent a significant wind energy production potential for Canada. As fewer temperate sites become available, large wind energy projects in colder climates will increasingly be developed. Better understanding of the losses associated with cold climate operation, coupled with research into areas such as icing characterization, icing maps, along with ice detection and protection, will improve the performance of existing wind farms and most certainly enhance the productivity of future wind farms.

Keywords: wind energy; turbine; icing; losses; cold climates; rime

Recommended Practices for Wind Energy in Cold Climates: Resource Assessment and Site Classification

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Abstract: Deployment of wind energy in cold climate (CC) areas is growing rapidly. The main issues of wind energy in CC arise from icing of wind turbine rotor blades which reduces energy yield, mechanical life time of turbines and increases safety risks due to ice throw. Another aspect of CC is low temperatures, which also can reduce a turbine's mechanical lifetime. Wind resources in CC areas are typically good and large-scale exploitation of cold climate sites has started, but despite of new technical solutions for wind turbines for CC the question "how does CC affect wind resources and resource assessment" still remains largely unanswered.

Cold Climates is defined by IEA RD&D Wind's Task 19 – Wind Energy in Cold Climates, research collaboration under the (IEA Task 19), as regions where significant icing events or periods with temperatures below the operational limits of standard wind turbines occur. These factors along with large amounts of snow may impact project implementation, economics and safety. IEA Task 19 has produced the report "Recommended practices for wind energy projects in cold climates" in which special requirements for CC wind energy projects are proposed in order to reduce uncertainties and lower the risks of a project.

The severity of the CC issues at the site under interest is to be determined in the resource assessment phase. In the "Recommended practices for wind energy projects in cold climates"

report IEA Wind's Task 19 introduced for the first time a site classification, which allows planners to classify a project site according to the site-specific icing frequency. Based on this site ice classification, the order of magnitude of production losses due to icing can be estimated and classified already in the planning phase. This is the first step towards a standardisation of wind energy sites with regard to icing and forms the basis for a future wind turbine classification related to icing. The Recommended Practices report also describes how to properly plan for and install measurement equipment for resource assessment in CC, how to interpret the measurement results, and mitigate the risk associated with measrements in icing conditions and low temperatures.

Two sites were studied to provide examples of site classification: One in Québec, Canada and one in Switzerland.

These examples highlight the importance of using multiple ice assessment methods as well as the value of having long term data in order to reduce uncertainties related to icing during the project development stage of a CC site.

The Research Review of Wind Turbine Blade's Icing and Anti-icing/De-icing

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***Abstract*:** In recent years, the wind power installed capacity of China has ranked first in the world, and is showing a trend of rapid development. Wind turbine blade's icing has serious harms. It will affect the safety of equipment and operation, and reduce power generation. However, because the wind power industry started very late in China, the research about wind turbine blade's icing and anti-icing/de-icing has not attracted people's attention and there is few related research in China. In this paper, the physical model of wind turbine blade's icing as well as the simulation method, the anti-icing/de-icing thermodynamic model of blades, and some technical methods about wind blade's anti-icing/de-icing are reviewed. It's regarded that most of the present wind turbine blade's icing model are established on basis of aircraft icing model. As wind turbine blade is very different from aircraft in working environment and working mode, it is necessary to establish the wind turbine blade's icing model with considering the actual operation of wind turbine blades, and to verify the icing model of wind turbine blades in natural icing stations. In addition, some studies about choice of heating power of wind turbine blade's anti-icing/de-icing has been conducted by some institutions and manufacturers, but much of them are based on empirical formula rather than physical models. This paper puts forward that it is necessary to carry out researches on some fundamental problems such as wind turbine blade's icing mechanism, icing model, anti-icing/de-icing model and methods as soon as possible, and only by this way can we take preventive measures to protect the healthy development of China's wind power industry.

***Keywords*:** wind turbine blade, icing, anti-icing, de-icing, review

Ice Accretion on Wind Turbine Blades

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Abstract: In this paper, both experimental and numerical simulations of the effects of ice accretion on a NACA 64-618 airfoil section with 7^{o} angle of attack are presented. The wind tunnel tests wereconducted in a closed-circuit climatic wind tunnel at Force Technology in Denmark. The changes of aerodynamic forces were monitored as ice was building up on the airfoil for glaze, rime and mixed ice. In the first part of the numerical analysis, the resulted ice profiles of the wind tunnel tests were compared to profiles estimated by using the 2D ice accretion code TURBICE. In the second part, Ansys Fluent was used to estimate the aerodynamic coefficients of the iced profiles. It was found that both reduction of lift coefficient and increase of drag coefficient is a nearly linear process. Mixed ice formation causes the largest flow disturbance and thus the most lift degradation. Whereas, the suction side of the rime iced ice profile follows the streamlines quite well, disturbing the flow the least. The TURBICE analysis agrees fairly with the profiles produced during the wind tunnel testing.

Field Measurement of Wind Turbine Icing

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Abstract: In 2011, the TechnoCentre Éolien (TCE) and Repower initiated an ice measurement campaign conducted at TCE's Site Nordique Expérimental Éolien CORUS (SNEEC) in Rivière-au-Renard, Qc, Canada. The outcome of this ongoing campaign has and will continue to serve the following objectives:

1) study ice loads on wind turbine blades;
2) improve ice detection methods based on computer vision;
3) have a better understanding of ice throw;
4) correlate icing to weather forecasts;
5) assess ice protection systems like passive anti icing and de-icing;
6) create a database with visual observations and meteorological data.

But one of the most significant outcomes to date of the measurement campaign resulted from a dimensional analysis of the different observations (ice on blades, ice on nacelle weather mast and ice throw) which has led to a classification of ice profiles for different icing events with a distinction between rime and glaze.

With this methodology and results presented in this paper, the severity of ice on nacelle weather mast during an icing event can be correlated to productions losses. Furthermore, the distribution of icing severities over the course of a year combined with correlations to production losses could eventually lead to improved resource assessment and site classification.

Ice Induced Vibration on Wind Turbines

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Abstract: Technological advancements are making cold climate sites, which generally have excellent wind resources, more and more attractive for wind farm deployment. Most turbine manufacturers have designed turbines capable of operating in low temperatures. Much effort has and still is being put in to reducing uncertainties associated with and developing technologies to reduce the production losses caused by ice accretion on blades. However there is still very limited understanding of the longer term effects of dynamic loads caused by ice on the design life of a wind turbine.

In order to investigate these dynamic effects, two measurement campaigns were conducted on two different sites; one in Canada and one in Finland. Load measurements were collected between 2007-2010 on a 2MW turbine in Southern Finland and between 2011-2013 load and acceleration measurements on two 2MW turbines in Eastern Canada.

The results of the case study in Finland indicate that ice accretion affects the dynamics of the turbine. An imbalance in strain measured between two different blades during icing events suggests aerodynamic imbalance due to ice on blades simultaneously increasing tower base fatigue loads.

The study in Canada revealed that ice accretion on the rotor blades can induce higher tower oscillations and increase tower base fatigue loads.

Finally, the two cases support each other well. It can be concluded that icing can cause imbalances to the rotor that results in additional oscillations which should be considered during fatigue life design of wind turbines.

Forecasting Production Losses by Applying the Makkonen Icing Model to Wind Turbine Blades

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Abstract: In the work presented here, the iceBlade model is used to simulate ice growth on both an ISO standard cylinder and on a cylinder representing the blade airfoil, using inputs from an atmospheric model. The airfoil like approach has shown to better correlate with the periods of reduced production, which are believed to be due to icing. These results when coupled to a statistical model show improvements in production loss estimation compared to the standard Makkonen model approach, however the use of only results from the meteorological model are shown to perform similarly to models using the icing forecasts. The ability to accurately model wind turbine production losses due to icing can greatly improve the siting and power forecasting of wind energy projects in cold climates. Unlike wind speed, measuring icing directly is a challenging task, and current measurement techniques do not correlate well with periods of decreased production. Therefore, numerical modeling is required to gain a better understanding of the impact blade icing has on wind power production. The aviation industry has developed many advanced models for ice growth on airfoils, but these tend to be computationally expensive. For siting and power forecasting cheaper models such as iceBlade are required to ensure reasonable simulation times.

Keywords: icing, Weather Forecasting and Research, wind energy

Session 3: Icing Measurement & Modelling

Wet-snow accumulation
A study of two severe events in complex terrain in Iceland

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Abstract: On 10 September 2012 and 30 December 2012, two severe northeasterly wet-snow storms caused extreme ice load on many transmission and distribution lines in North Iceland. The wet-snow accretion was combined with strong winds, resulting in broken wooden poles and H-frame towers. The September event was exceptional because of extreme snowfall so early in the autumn. The snowfall was associated with average wind speeds in excess of 20 m/s, causing widespread accumulation of wet snow within a certain altitude interval in North Iceland. In the latter event, heavy snowfall and gale-force winds, as well as extreme wet-snow loading, were more localized, occurring mostly in the lee of the complex orography of Northwest Iceland. The wet snow data are based on: 1) detailed in-situ inspection of accumulated wet snow on conductors of transmission and distribution lines in the affected areas. 2) accurate measurements of accumulation with load cells installed in suspension towers of operating overhead transmission lines and special test span in the areas where the most extreme accumulation occurred. The collected load data are unique in the sense that they describe in detail both the exact timing and magnitude of the wet snow accumulation. Meteorological observations of wind, temperature and precipitation are moreover available from synoptic and automatic weather stations in the areas. The atmospheric flow during the events is analyzed, based on weather observations and simulations at high resolution with an atmospheric model. The simulated data are subsequently used as input for a cylindrical wet-snow accretion model. The measured and simulated wet-snow loading are analyzed and put in relation with the weather during the event, highlighting several key aspects of the flow and icing process that needs further attention.

Modeling wet-snow accretion
Comparison of cylindrical model to field measurements

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***Abstract*:** Field measurements of wet-snow accretion have been made for numerous events in Iceland. The measurements are made with load cells in special test spans and, in some cases, in operating transmission lines. They can accurately identify the rate and size of accumulation and normally include measurements of air temperature as well. The largest events include wet snow

accumulation above 15 kg/m within 10 hours, and they are associated with very large amounts of precipitation and/or gale force winds. Six cases are selected and used to evaluate how well two existing cylindrical accretion models of wet snow can predict the accretion of wet-snow icing. The weather parameters that were not directly measured in-situ and are needed for the accretion models, i.e., wind speed, precipitation rate and snowflake liquid water fraction, are derived by using A-WRF simulations that were specially made for the cases at high resolution, and by studying observations of weather from a dense network of weather stations. The performance of the cylindrical accretion models is analyzed with special attention to the influence of sticking efficiency on the amount and timing of wet-snow accretion. The strong and weak points of the models are discussed.

A study on the sticking efficiency of wet snow using 50 years of observations

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***Abstract*:** Methods to model wet snow accretion on structures are developed and improved, based on unique records of wet snow icing events as well as large datasets of observed and simulated weather. Hundreds of observed wet snow icing events are logged in detail in a database, most of which include an estimate of the mean and maximum diameter of observed wet snow icing on overhead power conductors. Observations of weather are furthermore available from a dense network of weather stations. Common for wet snow accretion models is the vast uncertainty related to the bouncing of the snow flakes after collision (sticking efficiency), and its relation to the meteorological parameters. In the current study a standard cylindrical accretion model is updated with a snow flake liquid fraction based criterion to identify wet snow, together with an updated value for the terminal fall speed of wet snow flakes. By comparing extreme value distributions from modeled and measured wet snow loads, it is found that the widely used parameterization of the sticking efficiency strongly underestimate the accretion rate. A calibrated parameterization of the sticking efficiency is therefore suggested based on the long term statistics of observed and modeled wet snow loads. The results form a basis for mapping the climatology of wet snow icing as well as for preparing operational forecasts of wet snow icing and severe weather for overhead power transmission lines.

Keywords: wet snow; wrf model; sticking efficiency; power lines; liquid water fraction.

Met mast configuration guidelines in Cold Climate

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Abstract: Many options are given for wind farm developers to assess appropriately cold climate sites: Lidar (wind profiler), Sodar, tilt up tower (temporary met mast) and permanent met masts. For all options, wind farm developers need to optimize the data availability of each technology to reduce uncertainties during measurement campaigns.

In this paper, we explain met mast problematic management based to maintenance statistics and field experience over three test sites. In the same way, this paper will introduce additional recommendations for met masts configuration consistent to IEA Task 19.

To increase the data availability, many considerations need to be taking into account: booms configuration, choice of sensors, heat sensors recommendations, power supplies, communications features, and tower design.

Keywords: Cold climate, resource assessment, wind, sensors, met mast, icing, low temperatures, anemometer.

Icing of a 326 m tall tower - a case study

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Abstract: We present detailed field observations of an icing event on a 326 m tall guyed television tower. Ice samples were collected and photos taken from various heights on the tower which was equipped with anti-iced anemometers and thermometers at five levels. Modeling of the accumulation of ice on the tower was made by the Weather Research and Forecasting model combined with a numerical icing model. The simulated time series of temperature, wind velocity, cloud and drizzle liquid water contents and median volume droplet sizes were used to drive the icing model. The measured vertical distribution of the ice load was compared with that modeled by the WRF simulations. The cloud microphysics scheme and WRF provide remarkably accurate predictions of the meteorological conditions and result in very useful estimates of the ice loads at different levels on the tower. We also used a simple icing model, based on the observed weather data, to estimate the ice load. The results from both models support the approximate height distribution of ice mass proposed in the ISO 12494 code for atmospheric icing.

Keywords: Ice load; Icing; Tower; Height dependence

A New Severe Weather Test Site for OHL Conductors and Fittings

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Abstract: The UK suffers from severe wind, wet snow and differing icing conditions which can affect overhead electricity supplies and result in supply disruption. For the last 24 years, EA Technology has operated several severe weather test sites. These sites are aimed at providing the worst weather conditions for the testing of OHL conductors and fittings. The only remaining functional site is at Deadwater Fell which is located on an isolated hill top at an height of 590m near to the Scottish/English border has just been rebuilt and had a major refurbishment. The site is fully equipped with meteorological instruments to measure wind speed and direction, humidity, precipitation and temperature. It is used commercially by National Grid, Nexans, CTC, EGU, Nokia Cables, Alliance, etc to test their conductors and fittings and has been used to develop a new weather maps for the UK. All conductors have load cells and vibration monitors and a series of time lapse colour video cameras are used to monitor sag, galloping and accretion type. The newly rebuilt site has two steel supports that can take up to 10 conductors on a 190m span and a further steel support that can take further conductors on a 100m span. The site is currently testing Rubus AAAC and HD copper conductors along with porcelain/composite insulators and wedge clamps. In a normal winter the site suffers over 20 icing incidents with regular wind speeds to storm force. It is now the only severe weather test site for OHL conductors in Europe.

Keywords: Severe weather; test site; test spans; wet snow; rime ice; ice load tests.

Winter Measurements of Sea Spray at Mt. Desert Rock

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Abstract: As part of a project to investigate the severity of sea spray icing on fixed offshore structures, we spent a month in the winter of 2012-2013 on an island in the Gulf of Maine measuring sea spray. Mt. Desert Rock is about 500 m long and 200 m wide at low tide, loses about half that area at high tide, and is underwater in severe storms. College of the Atlantic's Edward

McC. Blair Marine Research Station occupies the lighthouse and associated structures on the island and serves as a base for marine mammal research. We collected sea spray on microscope slides from the lighthouse catwalk at 20 m above sea level, to sample the spray generated over the ocean rather than the local splash drops from waves breaking on the rocky shore. We had hoped to also characterize the sea spray using a rotating multicylinder, long used to characterize super cooled clouds at the Mt. Washington Observatory, but it was not quite windy enough. In this paper we present and discuss our drop slide measurements and compare the resulting liquid water contents to simulated spray profiles. Finally, we discuss the advantages and challenges of using multicylinder observations to characterize sea spray.

Laboratory Experiments of Saline Water Spray Icing –Features of Hydrophilic and Hydrophobic Pliable Sheets–

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***Abstract*:** Ice accretion caused by seawater spray is a major problem faced not only by fishing vessels and trawlers, but also by offshore structures. Marine disasters caused by such accretion occur frequently in cold regions. Yet, even in this age of high technology, deicing continues to be a manual operation that usually involves the use of a hammer.

We conducted a cold experiment on an ice model basin to investigate the wet growth from spray icing. Experiments using the two textiles—a high hydrophobic sheet and a high hydrophilic sheet—were conducted to reveal the sea spray icing characteristics of hydrophobic and hydrophilic surfaces. A PVC coating sheet was selected to compare the ice accretion effect. The air temperature in the cold room was maintained at approximately –10 °C and –14 °C. Small water particles were supplied by nozzles and sprayed on the cylindrical test specimen. The wind speed was 3–5 m/s and 5–7 m/s. The salinity of the supplied water was 26–29 wt‰. The liquid water flow, initial growth, and growing pattern of ice were observed during the experiments.

Wet growth from spray icing occurred on the windward side of both test materials. The initial icing depended considerably on whether the surface of the sheet model was hydrophobic or hydrophilic. The initial growth on the hydrophobic surface was characterized by the formation of hemispheric water droplets and a vein of ice on the textile surface. Irregular projections were observed on the spray ice surface. Spray water formed fluid flowing film on the highly hydrophilic surface. Exfoliated pieces of the membranous ice were often observed during the initial growth. Deicing of both the pliable sheets was easy owing to the low adhesion strength of saline ice and the aforementioned exfoliation.

Ice Growth Prediction Model of Transmission Lines Based on Mamdani-type Fuzzy Neural Network

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Abstract: As the global extreme climate phenomena occur frequently, ice disasters on power grid become more and more serious all over the world, they exert a more tremendous influence and cause greater harm than ever before. The transmission lines icing that affected by terrain and micro-meteorological condition often causes serious accidents, such as hardware and insulator damaged, break line, inter-phase short-circuiting and collapsed towers, which is easy to evoke a serious threat to power system security and cause huge economic loss. On the basis of the analysis of field measured data, the relation between micro-meteorological condition (*environmental temperature, humidity, wind speed*) , *conductor temperature* and transmission lines icing is researched, and a prediction model of ice growth of transmission lines based on Mamdani-type fuzzy neural network （FNN）theory is put forward in this paper, which overcomes the lack of adaptive ability under fuzzy system and the incompetence of fully express the human reasoning capabilities under neural network. The programing result shows that this model has an error less than 10% between the predicted value and the actual value on the *ice thickness*, and the method for establishing ice growth prediction model based on Mamdani-type FNN theory is feasible and practical. Therefore, this model has provided theoretical basis for the prediction of the *ice thickness*. Knowing well of the ice condition in transmission lines in real time plays a meaningful and significant role in ensuring the safety and stabilization of power systems.

Keywords: Fuzzy neural network (FNN), icing, ice thickness, model validation, prediction model, transmission line

Session 4: Conductors/Insulators/Flashover

Influence of Electric Field on Conductor Icing

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Abstract: The influence of electric field on the appearance, amount and density of ice accretion and spacing between icicles on aluminum conductors were investigated in the laboratory. It was found that the mass and density first rise as the electric field increased and then decreased with higher electric field strength. When the electric field is lower and no corona phenomenon occurs, the freezing water conductivity has little influence on the mass and density of the ice accretion. It was also found that the spacing of icicles is independent of conductor diameter and liquid water content. As the water droplet will be elongated by the electric field, the spacing is decreased as the electric field increases.

Keywords: Composite insulator; Icing flashover; icing energized

Study on the Influence of Mixed-phase Ice on Corona Inception Voltage of Smooth Conductor

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Abstract: Mixed-phase ice disaster which has happened frequently in China's winter affects the safe operation of transmission line seriously. Iced surface on conductor become so rough that the growth of the dentritic crystal and icicle make the electrical field distorted seriously and then it will decrease the conductor corona onset voltage. Although the international and domestic academics has done much research on the corona problems of different conductors, there had been no in-depth analysis of the regularity of conductor corona onset voltage caused by mixed-phase ice. Therefore a series of test of AC corona of mixed-phase iced smooth conductors were implemented in the artificial climate chamber combined with the icing morphology to establish conductor's electrical field model to research its corona characteristics, and the UV imaging technology and I-U curve

fitting measurement are employed to analyze the inception voltage. The results show that mixed-phase ice can cause the inception voltage value to fall significantly. As the icing time increase, corona onset voltage will decrease continually, but it will gradually become saturated. The conclusion of this paper may be a reference for the design and onset voltage calculation of the overhead transmission line in areas suffered mixed-phase ice.

Keywords: smooth conductor; mixed-phase ice; inception voltage; ultraviolet imagery

The Braced Post Assembly and the I Insulator String Dynamics Comparison at the Snow Shedding

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Abstract: Narrowing the overhead line tower can be achieved by using post line insulators. A post line insulator with its base rigidly attached to the supporting structure must withstand unbalanced loads and the bending stress inside the insulator's fiberglass core. Because the insulator mechanical limits, at higher conductor cross section it is necessary to using rotating post line insulators base on tower. Two problems arise from the insulator rotating base at the compact line. First problem is distance between the conductors in mid span. Most of compact line solutions use the same insulators length, so the conductors lie in vertical disposition. In that case the distances should be big enough to prevent short circuit at snow shedding. The second problem is to satisfy the safety distance to the ground obstacles. By rotating post line insulator base, the conductor behavior is different as in the case using classical vertical I suspension insulator string, especially in areas where additional loads caused by snow can be expected. So our goal is to get additional knowledge about sag behavior when we using the rotating braced post assembly.

The dynamical numerical model based on lumped conductor mass was developed to predict conductor and insulator movements during snow accretion or shading. The model is compared with model based on Adina program. At next step, comparison in conductor movement and forces between classical string and rotating post line insulator has been made. Based on comparison the basic recommendations using rotating post line in snowy area were developed.

Keywords: overhead lines, cable, dynamics, shedding

Evaluation of Flashover Voltage of Snow Accreted Insulators for 154 kV Transmission Lines

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Abstract: In December 2005, Japan experienced a major outage in Niigata Kaetsu area due to a large amount of wet snow mixed with sea-salt accreted on several transmission insulators. To clarify the causes of the snow damage and increase reliability of the networks, a 154 kV class full-scale snow test procedure to be used for evaluation of different insulator designs was developed and artificial flashover voltage tests of snow accreted insulators were carried out. The test procedure consisted of four steps, 1) generation of artificial snow with defined conductivity, 2) accretion of packed snow on the insulator sample, 3) increase of liquid water content of the accreted snow, 4) voltage application. As illustrated by the test results, the target values for wet and packed snow with defined conductivity were reproduced and the effectiveness of the test procedure for the evaluation of flashover properties of 154 kV class insulators was verified. High voltage flashover tests showed that the flashover voltage of both long-rod and cap & pin insulators were decreased with the increase of snow conductivity. Also, cap & pin insulators showed significantly higher flashover voltage than long-rod insulators. Thus, substitution of cap & pin insulators for longrod insulators seemed to be reasonable as a countermeasure against snow induced flashovers.

Keywords: component; insulator, wet snow, packed snow, seasalt, flashover

Summarizing knowledge from laboratory ice and snow tests on glass and composite insulators for overhead lines

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Abstract: This paper summarizes practical experience with ice testing performed at STRI on behalf of Statnett and SvK. for more than decade. Also the results obtained by snow test method developed by CRIEPI (Japan) in collaboration with STRI are discussed. Practical, representative and repeatable test methods were applied for different glass, porcelain, and RTV-coated and composite insulators. The intention was to provide flashover performance curves directly applicable for the Line Performance Estimator software program. This program is used by Statnett on a regular basis for the insulation coordination of the upgrading of 1500 km overhead lines from 300 kV to 420 kV. Examples of how the laboratory-obtained data was used in practice are given in the paper.

Keywords: Insulator; ice test; snow test; statistical dimensioning.

Session 5: Icing Climate and Icing Forecasting

Forecasting of Icing Events and Icing Accumulation on a Test Transmission Line at Hawke Hill, Newfoundland and Labrador

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***Abstract*:** The island of Newfoundland, given its relatively high latitude and marine location, is noted as a location that receives frequent freezing rain events [1]. The frequent icing conditions and the remote nature of much of Newfoundland present challenges for electrical transmission lines and other infrastructure. To mitigate the risk of damage due to ice loading, it is desirable to model the meteorological conditions under which icing may occur, predict the amount of ice accumulation and estimate the ice load on transmission line cables.

In order to address this issue, Newfoundland and Labrador Hydro (NLH) set up a test site at Hawke Hill, Newfoundland in the early 1990's. A suite of instruments were deployed with the aim of observing meteorological conditions with a focus on icing events. Hawke Hill also resides within radar coverage of the Environment Canada's Holyrood radar. AMEC used the observation data and a combination of Numerical Weather Prediction models, icing models and probabilistic models to provide a forecasting system for the Hawke Hill site. AMEC was then asked to perform a blind forecast for two periods in the winter of 2012-2013 during which icing was known to have occurred. An overview of these events and the results of the forecast, as well as some of the challenges that were faced, will be presented.

Application of Numerical Weather Forecasting Models on Atmospheric Icing in LRM

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***Abstract*:** The electric power to be produced at the Lower Churchill Project in Labrador will be transmitted over to Newfoundland by a HVDC link. This link has to pass over the Long Range Mountains (LRM) and through areas where extreme weather may cause unknown, but probably severe loadings on such electric overhead lines. These weather impacts must be taken into account both for safe design and for reliable operation of this electric connection which has an extremely high socio-economic importance and value for Nalcor Energy and its customers. The local weather and icing patterns are studied by using a modern numerical weather forecasting model where local topography and physical icing models are included. In combination with Google Earth it is possible to look at icing conditions in detail along the planned HVDC line route.

A new set of climatic loads maps for Russia

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***Abstract*:** In Russia regional maps are used to assess the climatic loads for the existing and newly designed transmission lines. For each of the 79 federal subjects of the Russian Federation it was developed a set of 4 climatic regional maps (wind load map, ice load map, combined ice-wind load map, lightning activity map). For the maps developing we have used observation data of nearly 2000 meteorological stations all over the country, most of them have a period of observations more than 50 years. For the climatic characteristics (wind load, ice load, combined ice-wind load) according to national standards we have used a return period of 25 years with possibility to recalculate loads to return periods up to one in 500 year. All maps were created in electronic format, using ArcGIS system, having scale 1 : 500 000. The work was done in years 2010-2013 and it is for the first time that a complete set of climatic loads maps was developed for all regions of the country as a requirement from the Federal Grid Company

The Development of New Maps for Design Ice Loads for Great Britain

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***Abstract*:** A new high resolution map of extreme snow and ice loads has been produced. Wet snow accumulations on overhead power lines are estimated using observations from a network of surface synoptic weather stations, while areas of severe in-cloud icing (rime icing) are identified from high resolution numerical weather prediction model simulations. Ice loads at 50 year return period were estimated using the "Peaks-Over-Threshold" (POT) method and interpolated to a high resolution map using regression kriging. The results indicate a significant variation both with altitude and latitude, with the highest loads expected in the wettest parts of the Scottish Highlands. In-cloud icing occurs mainly above 300-400 meters and is the dominant icing type above 500-700 meters depending on location. The final icing map demonstrates how state of the art atmospheric icing models can be successfully utilized to estimate the icing climate even when only very limited measurements of actual icing are available.

Keywords: Icing map; accretion model; wet snow; WRF model, extreme values; regression kriging

Icing conditions forecast using weather forecast model COSMO-RU

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***Abstract* :** In 2009 the Russian Federation had joined the international consortium COSMO (the COnsortium for Small-scale MOdelling). The main goal of this consortium is to develop and maintain nonhydrostatic mesoscale weather forecast model COSMO used to produce high resolution forecasts for certain territory. From April 2011 weather forecast model COSMO-Ru

(COSMO for Russia) is used as main in everyday work in Hydrometeorological Research Centre of Russian Federation and other forecast / prognostic institutions in Russia. At the moment forecasts for the European part of the territory of Russia are made on a grid with horizontal resolution 7 km. Forecasts are made for the period up to 3,25 days (78 hours). For some regions in Central and South part of Russia the forecasts are made on a grid with horizontal resolution 2.2 km for 24 and 42 hours. In this article it is performed an attempt to forecast icing conditions with high resolution to predict possible icing of OHL wires and towers.

Short-term Winter Icing Climate Prediction Based on the Polar Vortex Area and the Subtropical High

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Abstract: After adding up the historical meteorological data of 97 sites in Hunan province of China during the past 60 years, we count the average number of days that icing occurred each winter, so that we can then define the degree of icing in Hunan province base on it. After calculating correlation coefficient of 74 atmospheric circulation Indices in the past 60 years and the average number of days that icing occurred each winter, we found that the correlation between days of winter icing and some of 74 circulation Indices in spring, summer or autumn in the very same year is significant, such as the index of Asian polar vortex area in winter and the index of subtropical high strength over Western Pacific in winter. And by calculating, we found the index of Asian polar vortex area in winter has a significant correlation with the 74 circulation Indices of spring; summer, autumn in the very same year. Then, by regression analysis, we can predict the value of it. And by the same method, we can also predict the index of subtropical high strength over Western Pacific in winter. After all, we qualitatively predict the degree of icing through the index of Asian polar vortex area in winter and the index of subtropical high strength index over Western Pacific in winter. Then, we quantitatively predict the number of average icing days through all of 74 atmospheric circulation indices. By the very same method from 2008, we successfully predicted the degree of winter icing in every November to Feb of 2008-2009, 2009-2010、2010-2011, 2011-2012, 2012-2013, and the result exactly consistent with actual fact.

Keywords: Icing Climate Prediction; Polar Vortex Area; Subtropical High; 74 Circulation Indices

Session 6: Various Icing Topics

Guide for the Preparation of an Emergency Restoration Plan

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Abstract: The "Guide for the Preparation of an Emergency Restoration Plan" provides a recommended procedure or road map for safe, efficient and orderly restoration of transmission lines after a major failure. It is designed to help the CEATI Wind & Ice Storm Mitigation Interest Group (WISMIG) members prepare their own Emergency Restoration Plans (ERPs) in relation to existing ERPs of their companies and government agencies.

Keywords: Emergency Restoration, Overhead Lines, Towers, Line Failures, Icing

Research and engineering application of power grid large-scale ice-disaster prevention and cure technology

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Abstract: Ice disaster of power grid has happened in more than 100 countries all around the world. Ice disaster is one of the biggest natural disaster to make threat on the safe operation of power grid, which may cause the tripping of transmission lines, towers broken down, even lead to severe paralysis of large area power grid. The research team has carried out a series of research works on the icing of power grid ever since 1998, including icing forecast, ice monitoring, insulator flashover and DC ice-melting technology. Through revealing the "Sun-Surface-Atmosphere Coupled" icing formation rules for power grid, we developed the first grid icing forecast system in the word, which has high prediction accuracy in short-term, medium-term and long-term power grid icing forecast. Besides, it invents the anti-fogging image monitoring method for conductor icing, proposes the icing thickness intelligent identification technology for the wire, and developed power grid icing monitoring and decision system. The regularity of iced insulators flashover is also revealed, and the the anti-icing composite insulator has been invented, which makes the line icing flashover rate decrease by 90%. Through overcoming the core technology of "impedance flow" rectifier transformer, series of DC de-icing technology and equipments have been developed, which have less harmonic, and can well satisfied the requirements of the standard with the reliability as high as 100%. Those proposed technology has been widely used in the 132 corporation in 8 provinces in southern China on 1023 transmission lines, and has fight against

several frozen rain and snow disasters in 2009-2013 by accurate prediction, reliable monitoring, and ice melting with high efficiency. It has constructed the scientific and complete supporting system for ice disaster prevention of the power grid, which can provide the economic and efficiency solution for ice disaster control management.

Keywords: Icing Disaster; Icing Prevention; Icing Forecast; Icing Monitoring; Anti-Icing; DC Ice-melting; Supporting System

Influence of Icing on Bridge Cable Aerodynamics

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Abstract: In recent years the relevance of ice accretion for wind-induced vibration of structural bridge cables has been recognised and became a subject of research in bridge engineering. Full-scale monitoring and observation indicate that light precipitation at moderate low temperatures between zero and -5°C may lead to large amplitude vibrations of bridge cables under wind action. For the prediction of aerodynamic instability quasi-steady models have been developed estimating the cable response magnitude based on structural properties and aerodynamic force coefficients for drag, lift and torsion. The determination of these force coefficients require a proper simulation of the ice layer occurring under the specific climatic conditions, favouring real ice accretion over simplified artificial reproduction. The work presented in this paper was performed to study the influence of ice accretion on the aerodynamic forces of different bridge cables types. The experiments were conducted in a wind tunnel facility capable amongst others to simulate in-cloud icing conditions.

A Portable DC De-icer for Rural Power Network Transmission Line

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***Abstract*:** The rural power network transmission lines built in the mountain areas are very easy to suffer the accidents of tower collapse and line breakage under the atrocious icing weather. The widely used manual de-icing methods are hardworking and low efficient. The successfully used DC de-icing methods in the main frame grids cannot be applied to the rural power network directly. A portable DC de-icer is proposed in this paper to solve the problems of the rural power network transmission lines de-icing. A petrolic generator with adjustable output voltage provides the 200 Hz three-phase power supply. An uncontrollable three-phase bridge rectifier converts AC to DC. Fast clamps are developed to make the de-icing manipulation more convenient and more efficient. Onsite application of the portable DC de-icer for the rural power network transmission line was performed on the 10kV Yangta Line in Hunan Province of China. Under the environmental temperature of -7 °C, it took less than one hour to successfully remove the thickest covered ice of 16 mm from two sections of the line with the current of 300 A and 360 A from the portable DC de-icer. The application shows that the portable DC de-icer can operate reliably and can nicely meet the demand of rural power network de-icing.

Keywords: rural power network; portable; DC de-icer; medium frequency technology

Atmospheric Icing on Structures: COLDTECH-RT3 Perspective

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Abstract: When planning technological activities in polar and sub-polar regions, atmospheric icing on structures is very likely to occur and need to be considered. The COLDECH-RT3 project vision is to establish a competence platform for development of new and improved infrastructure, safe and environmentally friendly industrial operation in the arctic regions under icing conditions. This paper gives an overview about the ongoing research activities related to COLDTECH-RT3, at Narvik University College by its atmospheric icing research team. The work was initiated later in 2010. The activities described in this paper are mainly focused on three areas, field measurements of atmospheric icing, design and development of icing sensor & numerical modeling of atmospheric icing. The overall objective of COLDTECH-RT3 project is to facilitate the development of sustainable infrastructure and operations in the high north under icing conditions.

Keywords: Atmospheric icing, COLDTECH, Field measurements, Sensor design, CFD

Wind tunnel glaze ice simulation on a vertical angle member for different aerodynamic angles

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***Abstract*:** Atmospheric icing is one of the major problems in cold climate regions, which can impose serious damage to the structures, notably power network transmission lines. This paper investigates the glaze ice accretion on power transmission network pylons. In order to simulate the natural winter condition, an icing wind tunnel is utilized. Initially an aluminum angle member was mounted vertically in the test section of the wind tunnel. The angle member was then rotated in three dimensions to evaluate the effect of different angles (angle of attack, yaw angle, and rolling angle) on ice morphology and ice accretion mass per unit length. The tests were performed with liquid water content (LWC) of 0.9gr/kg^3 and the duration of each test was 30 min.

Ice profiles and morphologies were affected by gravity effects, which where produced by various aerodynamic angles, and the drag effects. The formation of glaze ice initiates with the formation of ice dendrites on the surface. Due to the effect of gravity forces and relatively warm temperatures, these ice dendrites will then grow into a glaze ice structure. A new parameter was defined as ice mass per unit length, which quantifies the effects of gravity and drag mechanisms on ice accretion. It was shown that ice mass per unit length was a function of different aerodynamic angles.

***Keywords*:** Atmospheric icing, Aerodynamic angles, Angle member, Angle of attack

Poster Abstracts

The following pages present the abstracts for IWAIS 2013 posters.

They have been organized into the following categories:

- 1: ANTI-ICING / DE-ICING
- 2: ICING MEASUREMENT AND MODELLING
- 3: CONDUCTORS / INSULATORS / FLASHOVER
- 4: ICING CLIMATE AND ICING FORECASTING
- 5: VARIOUS ICING TOPICS

1: Anti-icing and De-icing

A novel approach to fabricate anti-corrosive coatings with hydrophobic properties on an aluminium alloy surface

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Abstract: In cold climate regions, many structures such as transmission lines, telecommunication networks, bridges, etc. are exposed to ice and snow accretions. These accumulations are at the source of several types of damage and malfunctions. A way to reduce or prevent ice accumulation on exposed surfaces is to develop and apply icephobic coatings. At the same time, corrosion protection of metallic substrates such as Al and its alloys is another critical issue when these surfaces are exposed to moisture, water or other types of aggressive molecules. The main purpose of this paper is to systematically study certain organic coatings terminated with surface alkyl groups, which are expected to reduce the adhesion of ice to Al surfaces. More specifically, thin films of 1,2-bis-trioxymethyl-silyl-ethane [C14H34O6Si2] and octadecyltrimethoxysilane C18H37Si(OCH3)3 were prepared using wet-chemistry techniques on polished aluminium alloy (AA2024-T3). The first layer was used as an under-layer expecting to improve the anti-corrosive performance for the top-layer providing surface water and ice repellency. The stability of the prepared coatings was evaluated following exposition to water, basic and acidic media, showing gradual loss of hydrophobic properties over time and in different media. The ice accumulated on sample surfaces was prepared in a wind tunnel at subzero temperature by spraying supercooled water droplets simulating the deposit of reproducible glaze-type ice. While uncoated mirror-polished and as-received Al samples showed average ice detachment shear stress values of ~270±20 kPa and ~370±30 kPa, respectively, the coated samples showed reduced values of ~182±15 kPa. This reduction is attributed to the presence of a low surface-energy top layer. The ice-releasing performance of the sample gradually decreased after repeated icing/de-icing cycles. SEM observations revealed traces of corrosion products after wetting durability and icing/de-icing tests suggesting an interaction of water with the coatings during tests, gradually altering them. Potentiodynamic polarizations and salt spray exposure studies revealed that the corrosion resistance of modified aluminium alloys improved remarkably compared to unmodified samples. While extensive corrosion appeared on unmodified Al samples after only 8 cycles of salt spray exposure, only tiny traces of corrosion wer observed on the modified samples even after 81 cycles of exposure.

Keywords: Anti-corrosive performance; Low surface energy coating; Self-assembling process; Hydrophobicity; Ice adhesion strength; Durability; Potentiodynamic polarization; Salt-spray test

Study on the Critical Anti-icing Current of Conductors and Its Impacting Factors

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Abstract: Conductor icing is one of the major factors which affects the safe operation of the transmission line, and the anti-icing method based on the Joule heating effect is feasible and effective. This paper tries to analyze the heat transfer process of conductor's surface in critical icing condition and the effect of geometric shapes and water film covering conductors on heat transfer process. Based on Joule heating effect and the improvement of heat calculation, the formula to solve the critical anti-icing current considering the skin effect of conductors is proposed and also tested in an artificial climate chamber. The results showed that the relative error is within 10%. In addition, this paper also analyzes the effect of factors on critical anti-icing current and the results indicated that critical anti-icing current of the conductor has a relationship with the diameter and geometric profile of the conductor, ambient temperature and wind velocity. The critical anti-icing current (Ic) will increase sharply with the increasing of wind velocity and decreasing of ambient temperature.

2: Icing Measurement and Modelling

Wet-snow accretion on Overhead Lines
The RSE response to harmful winter blackouts in Italy

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Abstract: The heavy wet-snow storms are responsible for several and harmful winter blackouts on Italian electrical networks of high and medium voltage due to the formations of ice and snow on overhead conductors. It is estimated that every year, in Italy, the cost of damages from these particular snowstorms is greater than 200ML€.

In order to study the phenomenon, a research activity was started some years ago by RSE which led to the setting-up of an alert system for wet-snow accretion on overhead lines. The purpose of the system, named WOLF (Wet-snow Overload aLert and Forecasting), is to provide the wet-snow load forecast on overhead lines during wet-snow events and, sufficiently in advance, to alert the Italian TSO and DSO to take appropriate solutions to ensure the quality and continuity in the service of transmission and supply of energy.

The system is based on the outputs of a NWP model RAMS (Regional Atmospheric Modeling System), and the forecast is valid for the next 72 hours. The outputs of the NWP model feed an ice accretion model (Makkonen -ISO 12494-2000) for the evaluation of the wet-snow sleeve. WOLF implements the Cigrè thermal model for the estimation of the anti-icing current required to produce a "Joule effect" able to maintain the wire free from the ice in the expected weather conditions. All the outputs of the models are reported in an interactive Web-GIS tool developed by RSE to meet the demands of multiple users.

A meteorological station with an integrated monitoring system of the wet-snow sleeve, called WILD (Wet-snow Ice Laboratory Detection), was installed in the West Alps, an area where these phenomena occur with some frequency. The measures gathered allowed to analyze the weather conditions most critical for the wet-snow accretion and, at the same time, to carry out the "tuning" of the parameters in the models of growth.

The wet-snow models properly validated, led by NWP model, can contribute to the knowledge of the distribution of the phenomena of wet-snow on the Italian territory, also useful in the design and planning of new power lines.

Research on Transmission Line Ice Automatic Identification System Based on Video Monitoring

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Abstract: Along with the implementation of the power transmission from west to east in China and the rapid development of uhv transmission project, the scale of power grid is continuously expanding, more and more transmission lines cross canyons, rivers and other regions where are so easy to cause icing. The icing disasters of transmission line such as conductor overload, conductor galloping, break line, pole collapse, insulator flashover and communication interruption have posed a serious threat to the security and stability of power system. Therefore, how to grasp transmission line ice situation with real-time visualize technology has become an urgent problem to be solved. In order to overcome this main hurdle, a system has been designed and developed in this paper, which has a camera installed at the tower to capture the conductor and insulator images of the transmission lines at intervals during daytime and nightime. The captured images are tranfered to the background monitoring center, then the embeded icing identification algorithm can be used to anlayze whether it is iced or not, if there is ice covered on it, the equivalent ice thickness of the conductor or the insulator can be calculated out, the alarm module would work while the ice thickness was over a given value. The ice automatic identification algorithms are mainly studied in this paper, including image preprocessing, image segmentation, edge detection, the camera calibration and other algorithms, meanwhile, test results shows that on-site acquired image of transmission lines verifies the algorithm can automatically identifies the icing status, and the conductor icing thickness error between the algorithm results and field manual measurements is less than 2 mm, and for the insulator, the error is less than 3mm.The system developed in this paper has been successfully put into use in multiple transmission lines, it is in good running condition and can realize the real-time monitoring on ice thickness and timely alarm of transmission line exceptional icing state.

Keywords: Video mornitoring, transmission lines, icing identification, ice thickness calculation

Research on Stranded Conductor Corona Onset Characteristic after Energizing Rime Icing

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Abstract: Rime makes conductor surface extremely rough and it will distort the electric field seriously. Numerous studies about icing conductors had been done but the fact that conductors operating under voltage was always ignored and Aluminum pipes were applied to study the actual

conductors. Moreover, no lights had been thrown into decrease regularities of corona onset voltage(COV) after energized icing. Therefore, a series of AC corona tests of charged rime icing had been done in the Multi-functional Climate Chamber. UV imaging technology and I-U curve fitting were applied to measure the COV and the finite element model was established to research field strength after icing. Results show that rime can bring COV down significantly. Ice-tree of rime in various shapes lead to different COV values. Increasing in icing time will raise COV values while the rising speed slowed down gradually. Conductivity has no impact on rime form or COV. The sharper ice-trees are, the more seriously electric field distorted and the lower COV values. This paper can provide information about design of transmission lines in regard to corona losses after icing.

Keywords: stranded conductor, energized icing, rime, corona onset voltage, conductivity, UV imaging

3: Conductors / Insulators / Flashover

DC Icing Flashover Characteristics on Composite Insulators with Parallel Air Gap for Ground Wire

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Abstract: Icing disaster of transmission line and its prevention has become an important and hot problem. Insulators with a parallel air gap are generally installed for overhead-ground-wire insulation, and the de-icing voltage is related with the insulator's flashover voltage and the air gap's DC flashover voltage, and thus the parallel air gap distance affects the de-icing length of the overhead ground wire. Quantitative contrast experiments to study the relationship between icing flashover performance of composite insulators used for overhead-ground-wire and its parallel air gap as well as ice thickness were carried out. The test results show that, flashover path is related with the length of insulator's parallel air gap, and the flashover voltage increases with parallel air gap distance increasing. When the parallel air gap is short and all the flashovers occur between the air gap, we can use the ice thickness and flashover performance of non-iced insulator used for overhead-ground-wire to estimate the icing flashover voltage effectively.

Keywords: DC, composite insulator used for overhead-ground-wire insulation, parallel air gap, icing, flashover performance

Comparison on AC Icing Flashover Performance of Porcelain, Glass, and Composite Insulators

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Abstract: The electrical performance of insulators under the comprehensive conditions of low air pressure, pollution and icing, is an important basis for the selection of external insulation of transmission lines and substations in icing regions. However, little research has been dedicated to the comparison on ac icing flashover performance of composite, porcelain and glass insulators in this environment. Based on the investigations carried out in the artificial climate chamber on three types of iced insulators, the ac flashover performances of insulators were researched in this paper. In addition, the paper analyzed and compared the effects of various factors, including ice thickness,

pollution and air pressure on the flashover performance of three types of iced insulators. The experimental results show that the flashover voltage of three types of insulators decreased with the increase of ice thickness, pollution, and the altitude. The characteristic exponent characterizing the influence of the ice thickness, pollution and atmospheric pressure on the flashover voltage were related with the insulator types. The effect of ice thickness and atmospheric pressure on icing flashover voltage was more apparent for composite insulator than porcelain and glass insulator, and the characteristic exponent characterizing the influence of ice thickness and atmospheric pressure on the flashover voltage was obviously big for composite insulators. The characteristic exponent characterizing the influence of pollution on the flashover voltage was small for composite insulators. Under the same condition, the flashover voltage gradients of ice-covered composite insulators are slightly greater than porcelain and glass insulators.

Keywords: Insulators, icing flashover performance, ice thickness, low air pressure, pollution

4: Icing Climate and Icing Forecasting

The Spatial Distribution of Icing in Germany Estimated by the Analysis of Weather Station Data and of Direct Measurements of Icing

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Abstract: The spatial distribution of atmospheric icing in Germany was analyzed using weather station data of 74 meteorological stations evenly distributed over the territory of Germany for the period 1980-1999 as well as direct measurements of icing at up to 35 stations in the east part of Germany for the period 1980-1989.

The study was elaborated using the hourly ground SYNOP messages from weather stations as primary data in order to accomplish an accurate description of all icing phenomena from a homogeneous data set. All hourly ground SYNOP messages which report icing were analyzed. The frequencies of occurrence of icing were computed as the ratio of the number of SYNOP messages reporting icing phenomena to the total number of SYNOP messages.

Results of icing frequencies from weather station data were compared to the frequencies of occurrence of icing that were measured directly. The comparison shows, that low frequencies of icing are generally overestimated by the analysis of weather station data, whereas high frequencies of icing are mostly underestimated.

The spatial analysis of icing in Germany showed that freezing rain and in-cloud icing events occur more often in mountainous regions in altitudes between about 500 m and 1500 m above sea level than in lowland regions. The frequency of freezing rain decreases remarkable in high altitude areas, mainly at exposed locations, whereas the frequency of rime icing increases in those regions. Wet snow events are in general more frequent in lowland regions in (North-) West of Germany than in mountainous areas. The highest numbers of wet snow events were observed at stations that are situated in sheltered positions (e.g. valleys) in altitudes greater than 700 m a.s.l.

The frequency of occurrence of icing was examined for its dependence on the height above sea level. The results show that the frequency of icing occurrence increases with altitude in general. Furthermore, the (local) exposure of a location plays an important role in the icing process. Therefore, exposed (sheltered) locations may show much higher (lower) icing frequencies.

Finally, an icing map of Germany has been developed applying the knowledge on the dependence of icing on the height above sea level.

5: Various Icing Topics

Comparison of AC Ice-melting Characteristics of Conductors with or without the Freezing Rain Falling

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Abstract: The icing disaster of transmission line is becoming one of the most serious harm to power systems. So far, few researches have considered how the icing state of the conductor surface will influence ice-melting. In this paper, the glaze ice accretion on conductors was imitated in the artificial climate chamber, and tests about the ice-melting process with freezing rain falling were conducted. By means of thermodynamic theories and dynamic simulation of ice-melting process, the heat balance equation of the conductor ice-melting process has been established. . It shows that test results and simulation results are basically the same, the conclusions are listed as follows:（1）The joule heat generated by conductor conduct radiation heat through the leeward side of ice surface when freezing rain falling in environment.（2）The maximum temperature on conductor surface appears in the lower surface every moment during the ice-melting.（3）The highest temperature appears at the time when ice is shedding in the process of ice-melting.

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Compusult Limited is a Canadian-owned and diversified Information Technology company that's been in operation for over 28 years. We also specialize in ice accretion studies, probabilistic ice and wind loading assessments on land-based and marine structures, ice accretion modelling and measurement, and physical environmental data acquisition, monitoring, and management.

We have previously completed ice accretion related projects and studies for clients such as Environment Canada, National Research Council Canada, Newfoundland and Labrador Hydro, Newfoundland Power, Black & Veitch Architects/Engineers. We have also worked with leading ice accretion experts from the Technical Research Centre of Finland (VTT), University of Alberta (Canada), among others.

Compusult also has extensive experience developing, implementing, and enhancing time-dependent and simple numerical models and alert systems for atmospheric icing and associated wind loading on structures, including those for freezing precipitation (including icicle growth), wet snow and in-cloud (rime) ice accretion.

Compusult is the technical host and organizer of the International Workshop on Atmospheric Icing of Structures (IWAIS) 2013, in St. John's, NL, Canada, September 8-11, 2013.

For information on IWAIS 2013, please visit the conference website at: **iwais.compusult.net.**

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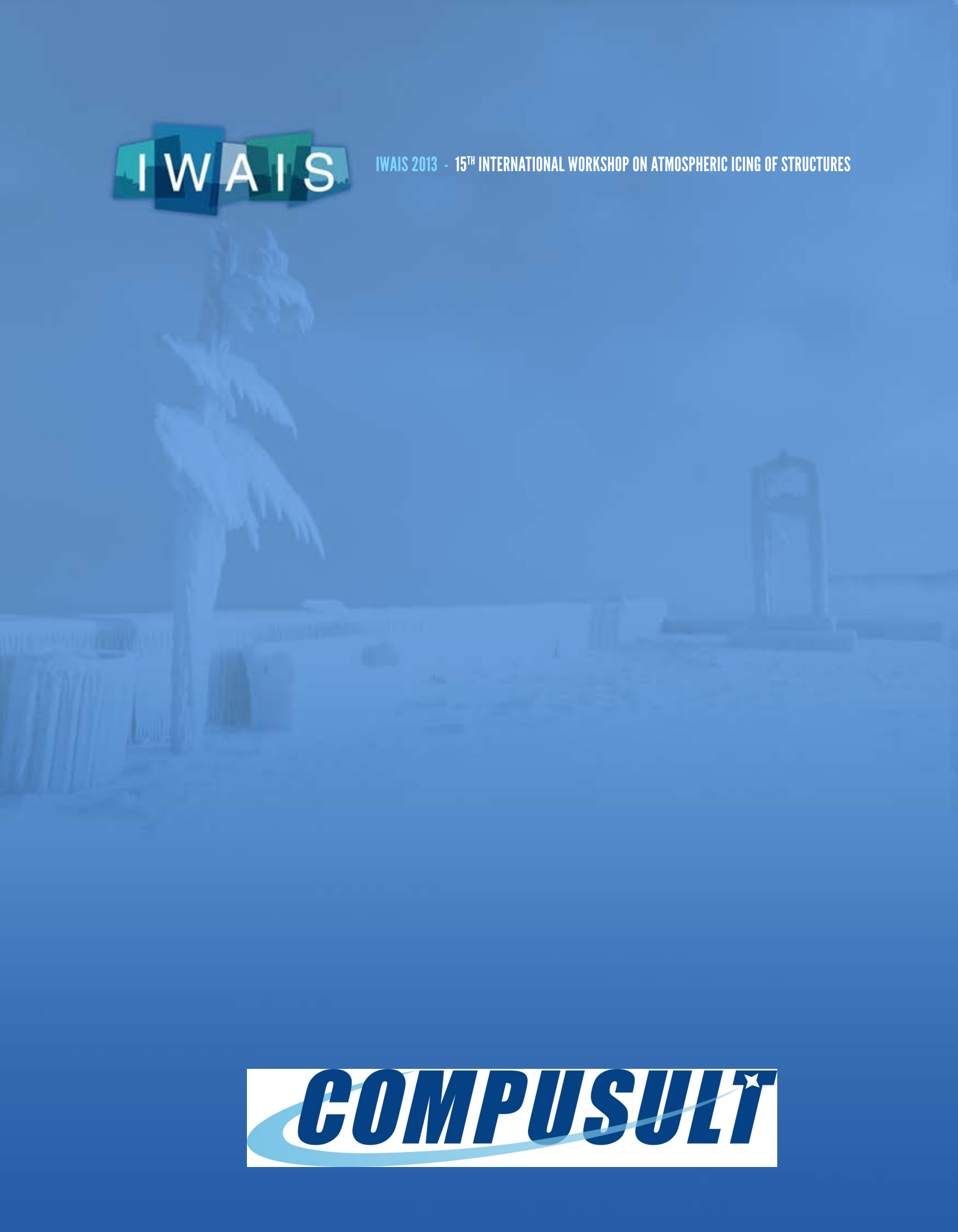
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