# Experiences From Real-Time LAPS-LOWICE Runs Over Sweden: 2011-2012 Icing Season

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Photo by J. Hirvonen

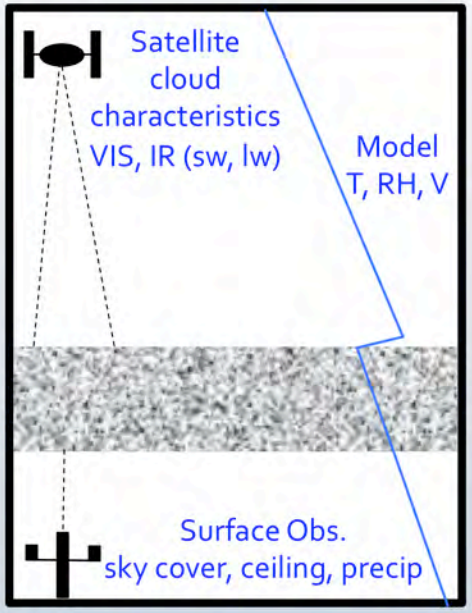
# Introduction

- Swedish Energy Agency program
  - Cooperation with O2
- Collect high-quality observations
  - Instrumented masts & turbines
  - Meteorological parameters
  - Icing parameters: load
  - Webcam images
    - Ice growth/decay
    - Clouds
  - Power production (select sites)


- Compare to real-time runs several icing prediction systems

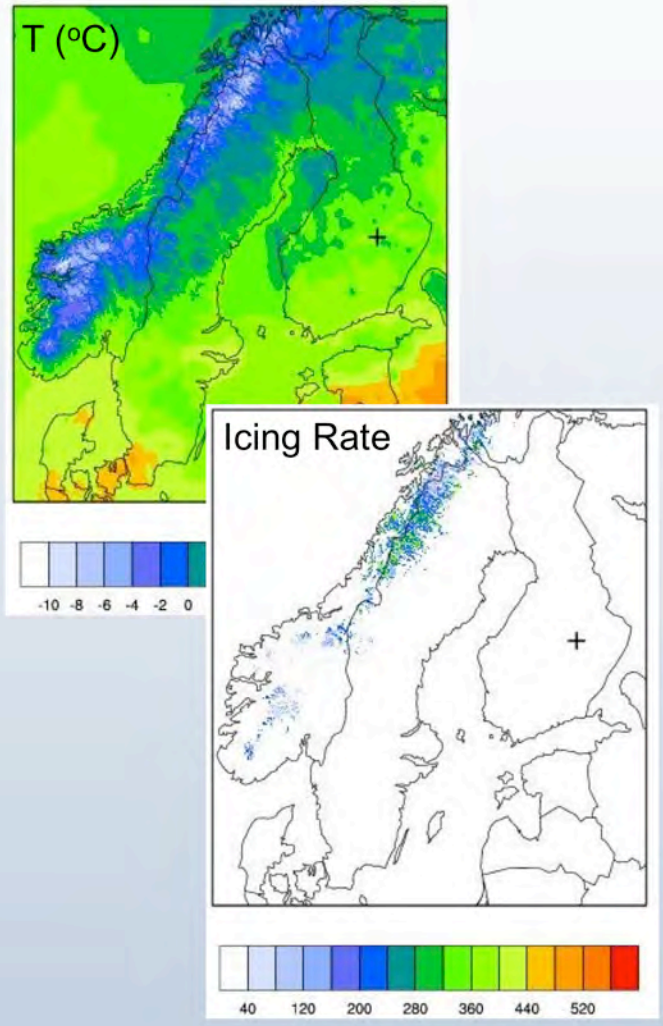
# LEA/FMI: LAPS-LOWICE

- Partnership
  - Finnish Meteorological Institute (FMI) provides weather data
  - Leading Edge Atmospherics (LEA) provides icing "model"
- FMI-LAPS (Local Analysis and Prediction System)
  - Assembles data from key icing sources
    - Observations: satellite, radar, surface…
    - Numerical weather model
    - Merge onto a common grid
    - Meteorologically consistent 3-D analysis
      - Clouds, precipitation, temperature, winds, etc.
      - Essential fields for icing
  - LAPS-Scandinavia
    - Hourly output
    - Grid: 3-km horizontal, 10-mb vertical spacing (~80 m)



# LEA/FMI: LAPS-LOWICE

- Using LAPS input, LOWICE:
  - Assesses icing situation at turbine
    - Meteorology that drives it
      - Temperature, LWC, wind speed
    - Builds and depletes the ice
    - Estimates power loss

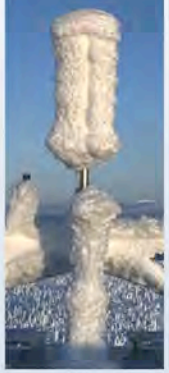


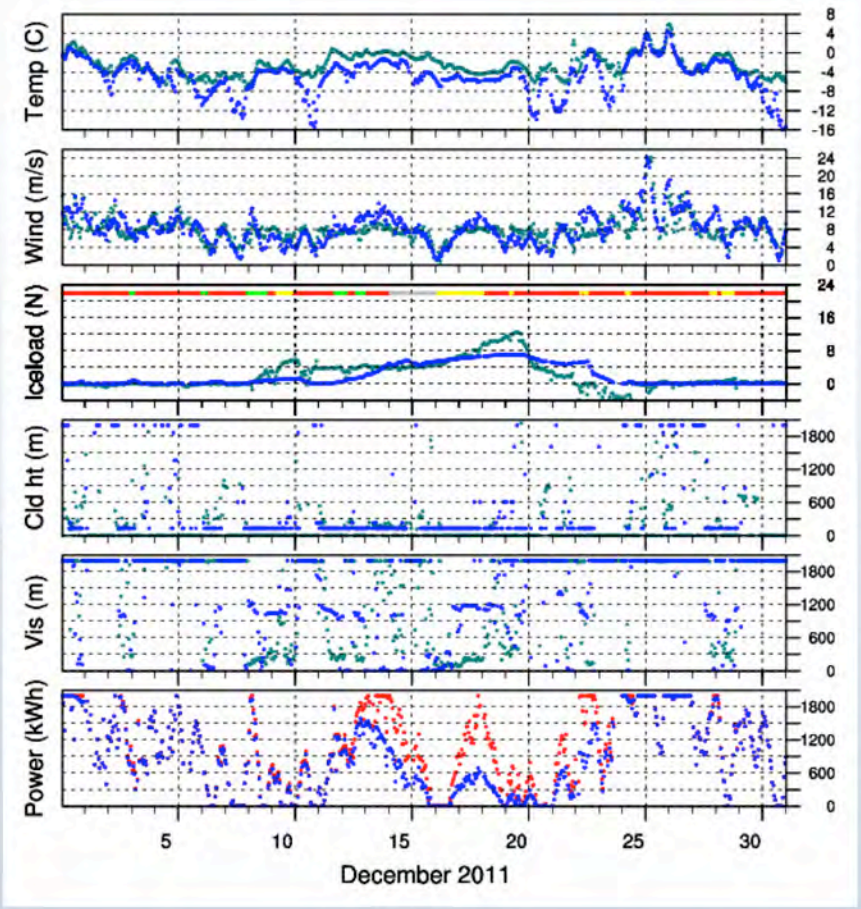
# 2011-2012

- Compare our real-time system with high-quality observations
  - O2, CombiTech, InSitu
- Challenging environment
  - Operate, measure, forecast
  - Press on, learn, get better

# Big Picture Results

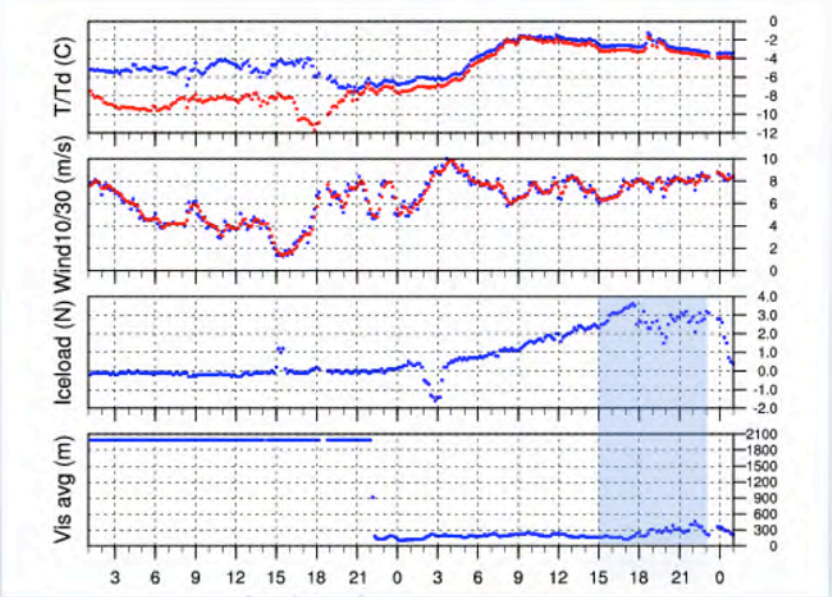
- Meteorological values
  - Temperature, winds
  - Cloudy or not?
- Icing parameters
  - Growth, decay
  - Cylinder
  - Reference point
- Generally do quite well
  - Statistics, time-series plots
  - Tracking, variability
  - Errors, biases





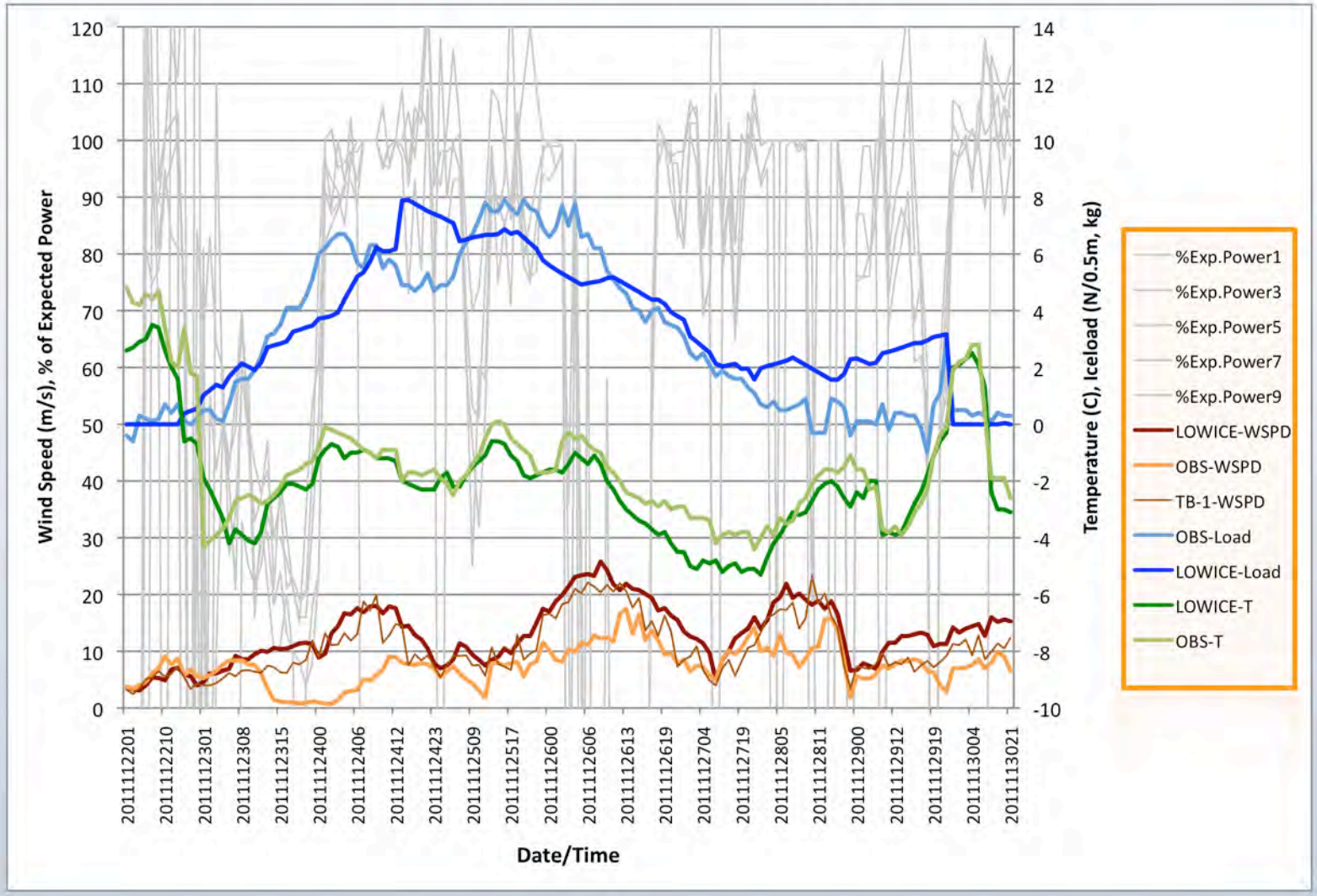
# A Closer Look

- Monitor the data every day
  - LOWICE output
  - Measurements, time-history
  - Webcams, loops
  - See the details
    - Small changes – big effects
  - Understand
    - Data, statistics
    - Our successes, failures
- Examine a series of events:
  - 1 site, 8 days
  - Weather
  - Icing
  - **POWER**

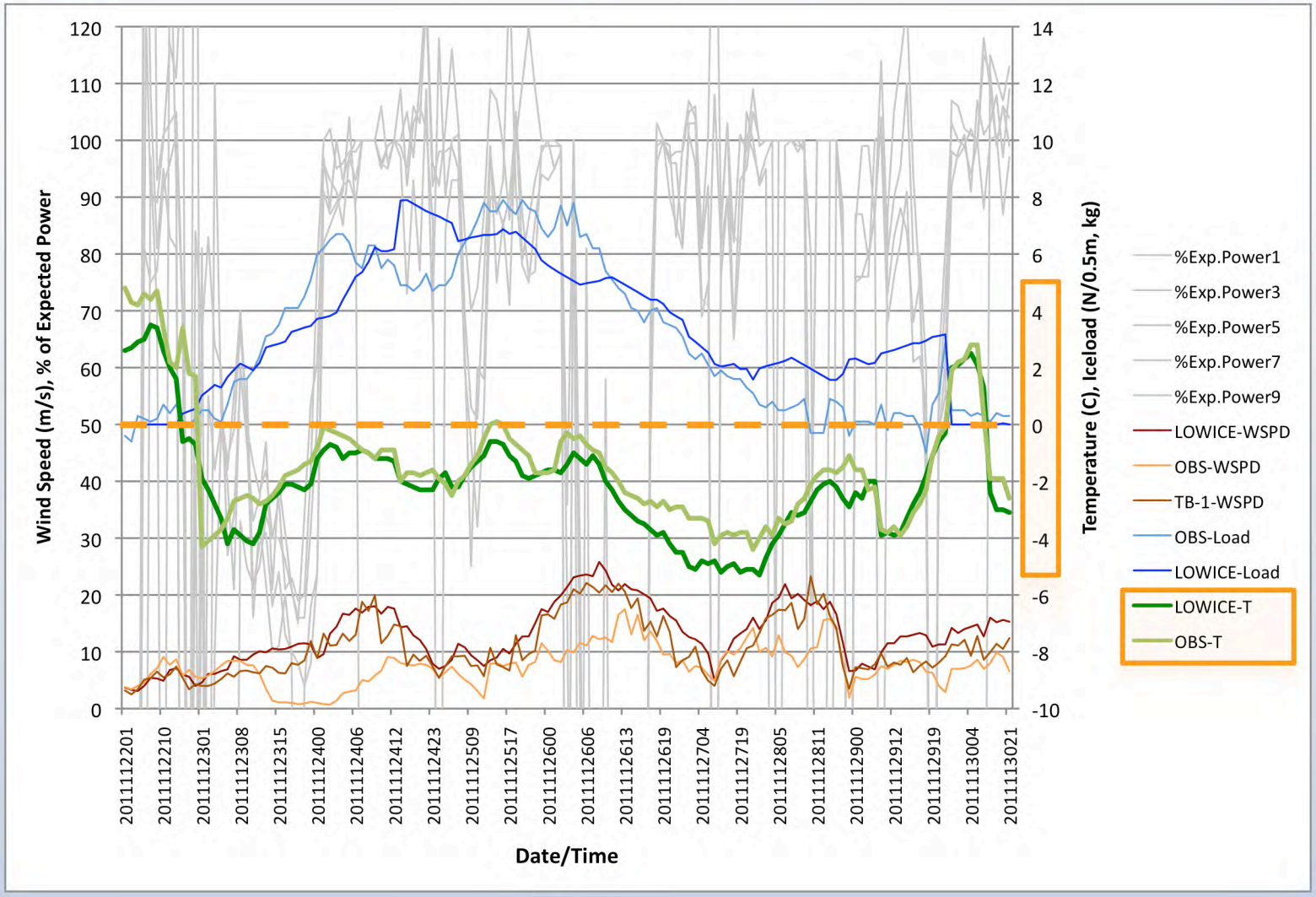



# Time History

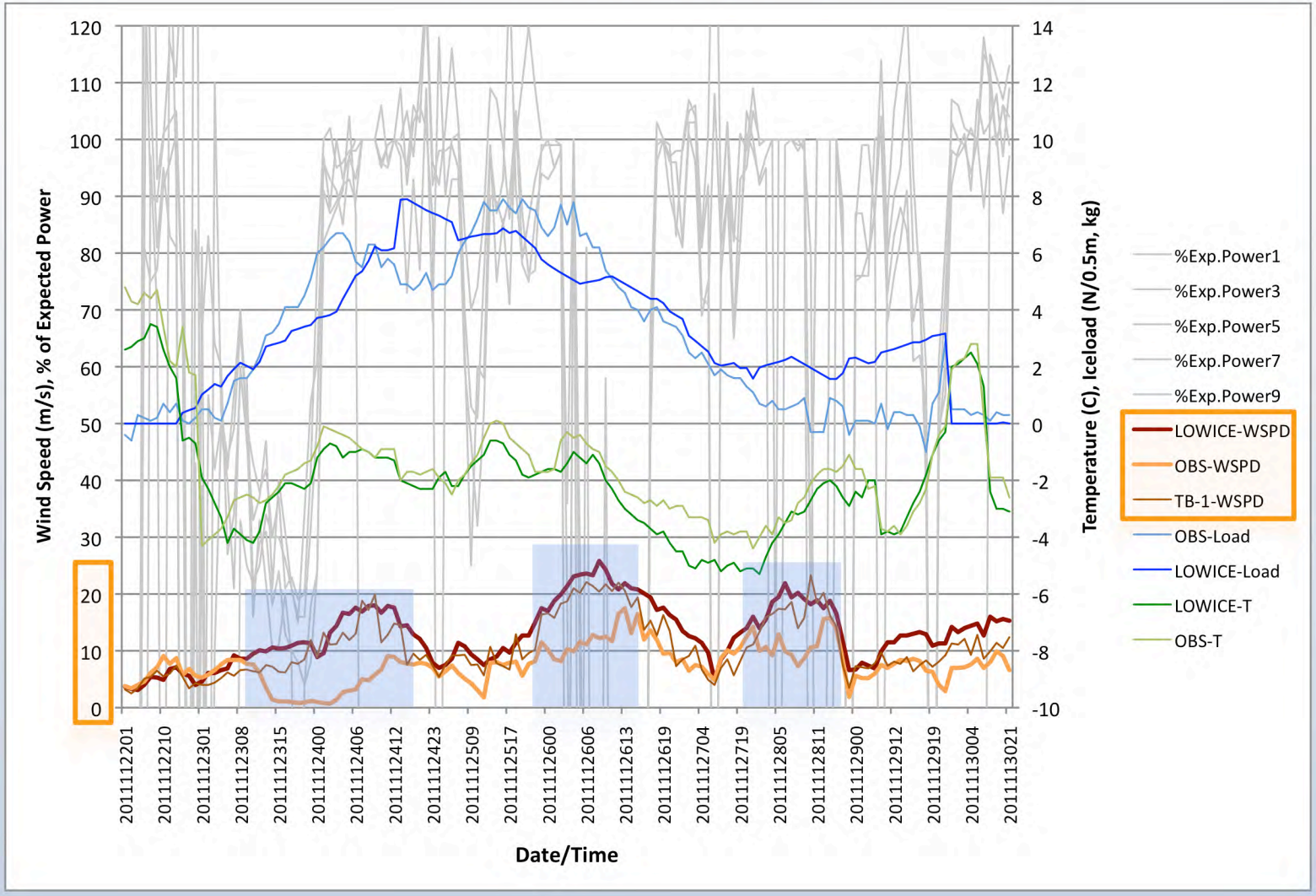
## Observations & LOWICE 23-30 Nov 2011



# Temperature

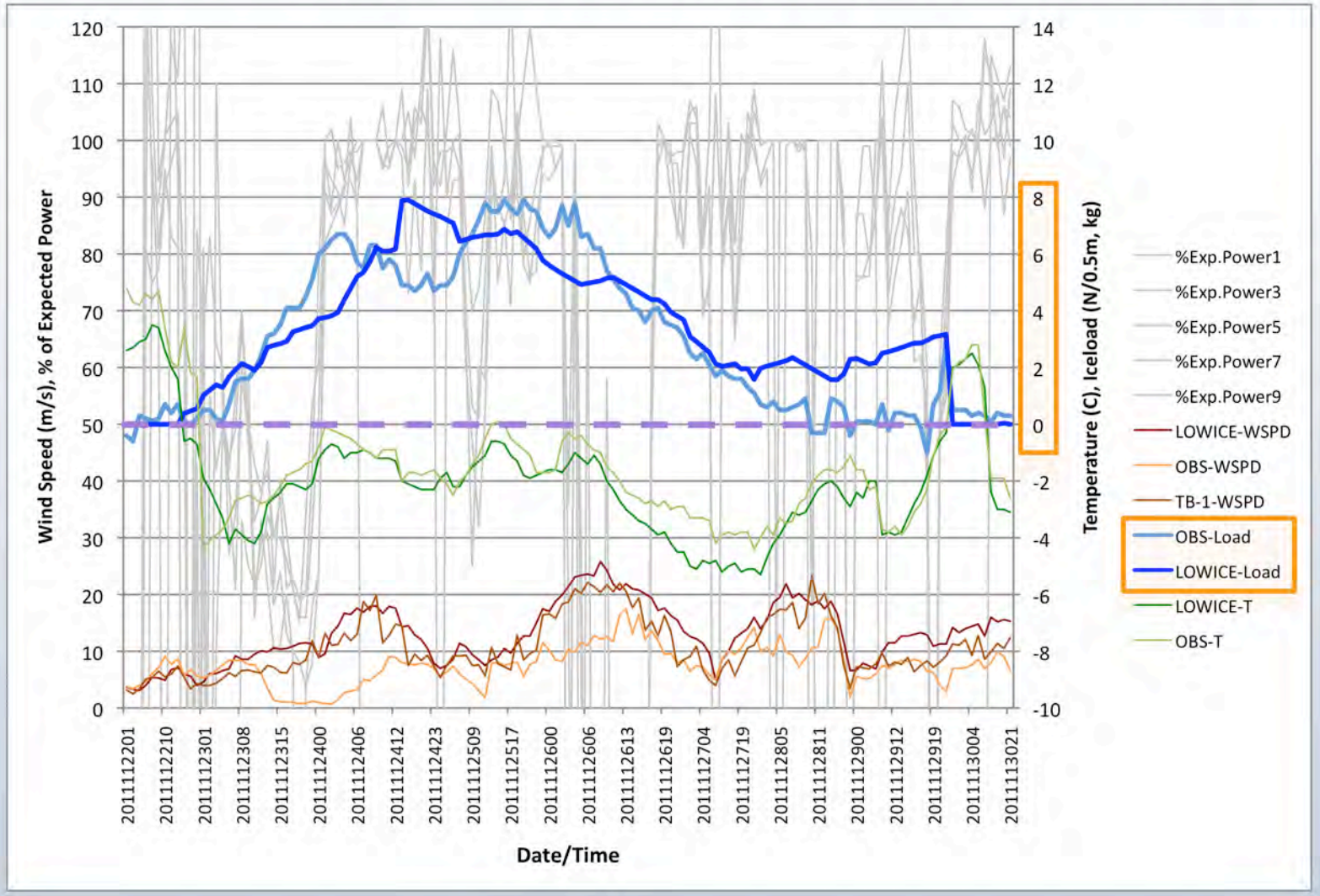


# Wind Speed


Wind Speed (m/s), % of Expected Power
Temperature (C), Iceload (N/0.5m, kg)
Date/Time
120
110
100
90
80
70
60
50
40
30
20
10
0
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
2011112201
2011112210
2011112301
2011112308
2011112315
2011112400
2011112406
2011112412
2011112423
2011112509
2011112517
2011112600
2011112606
2011112613
2011112619
2011112704
2011112719
2011112805
2011112811
2011112900
2011112912
2011112919
2011113004
2011113021
%Exp.Power1
%Exp.Power3
%Exp.Power5
%Exp.Power7
%Exp.Power9
LOWICE-WSPD
OBS-WSPD
TB-1-WSPD
OBS-Load
LOWICE-Load
LOWICE-T
OBS-T

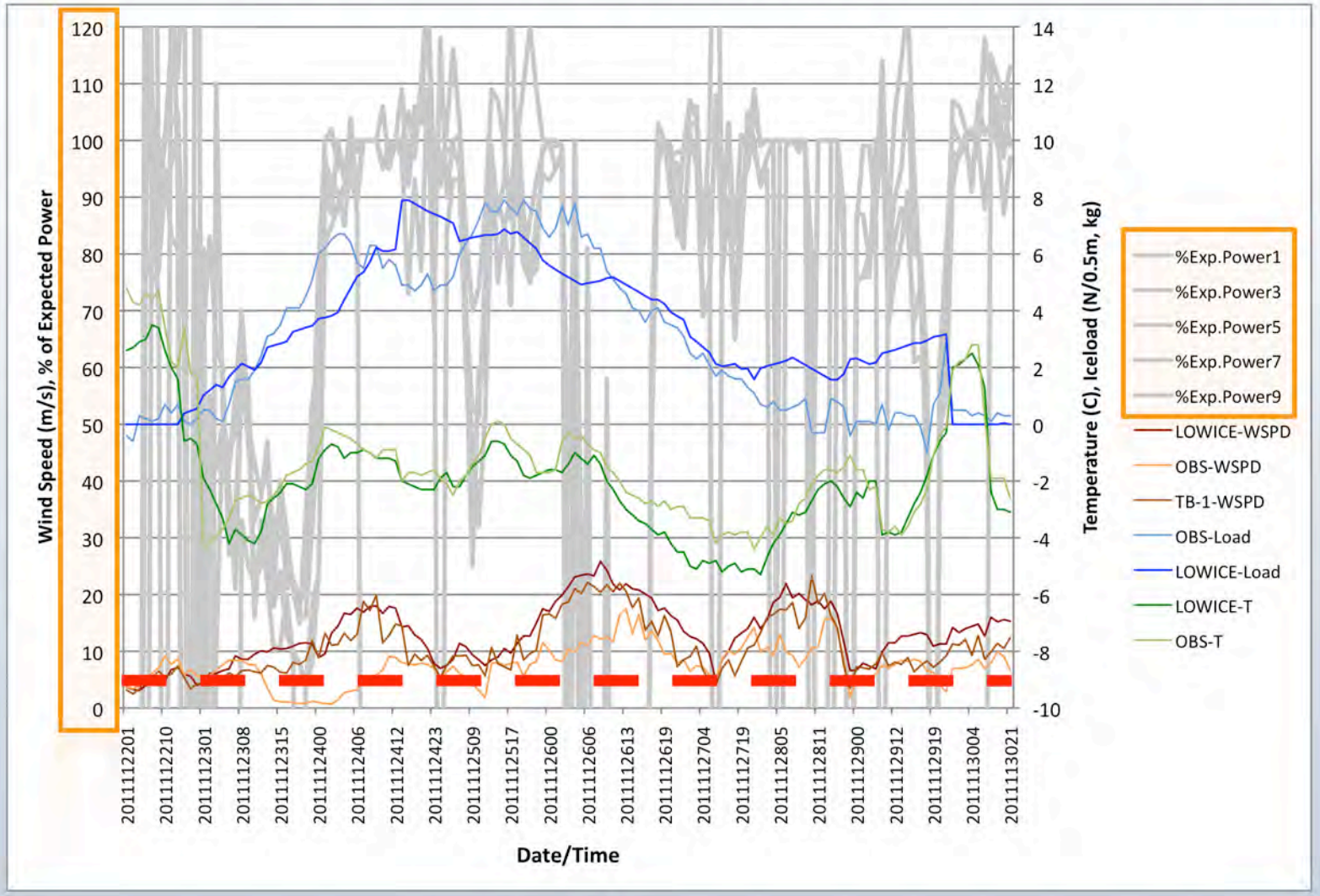
# Ice Load:

## Starts Clean – Gradual Erratic Growth – Gradual Loss, Rapid Loss



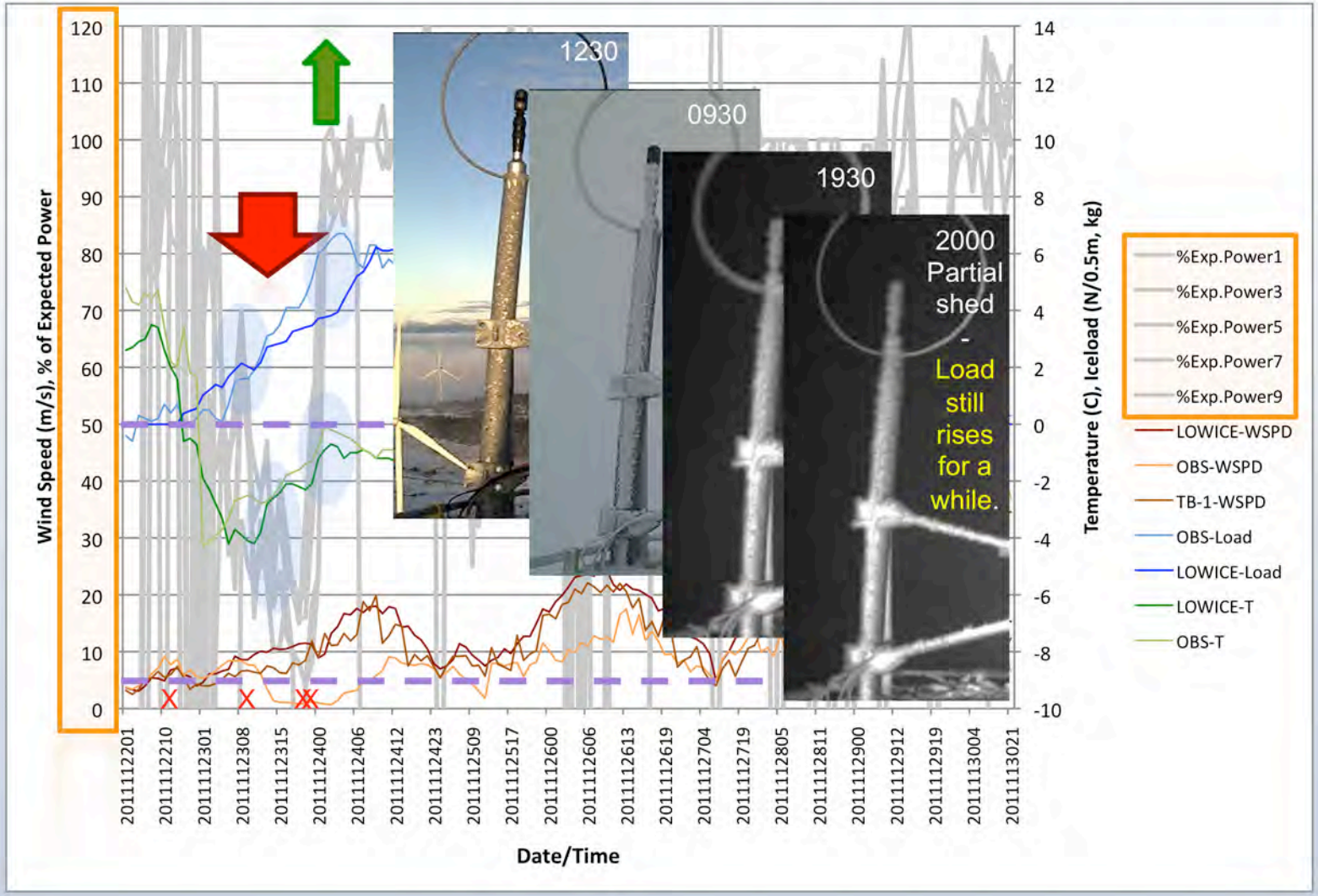
# Power

## Measured Power / [90% x Expected Power (OBS-WSPD)]



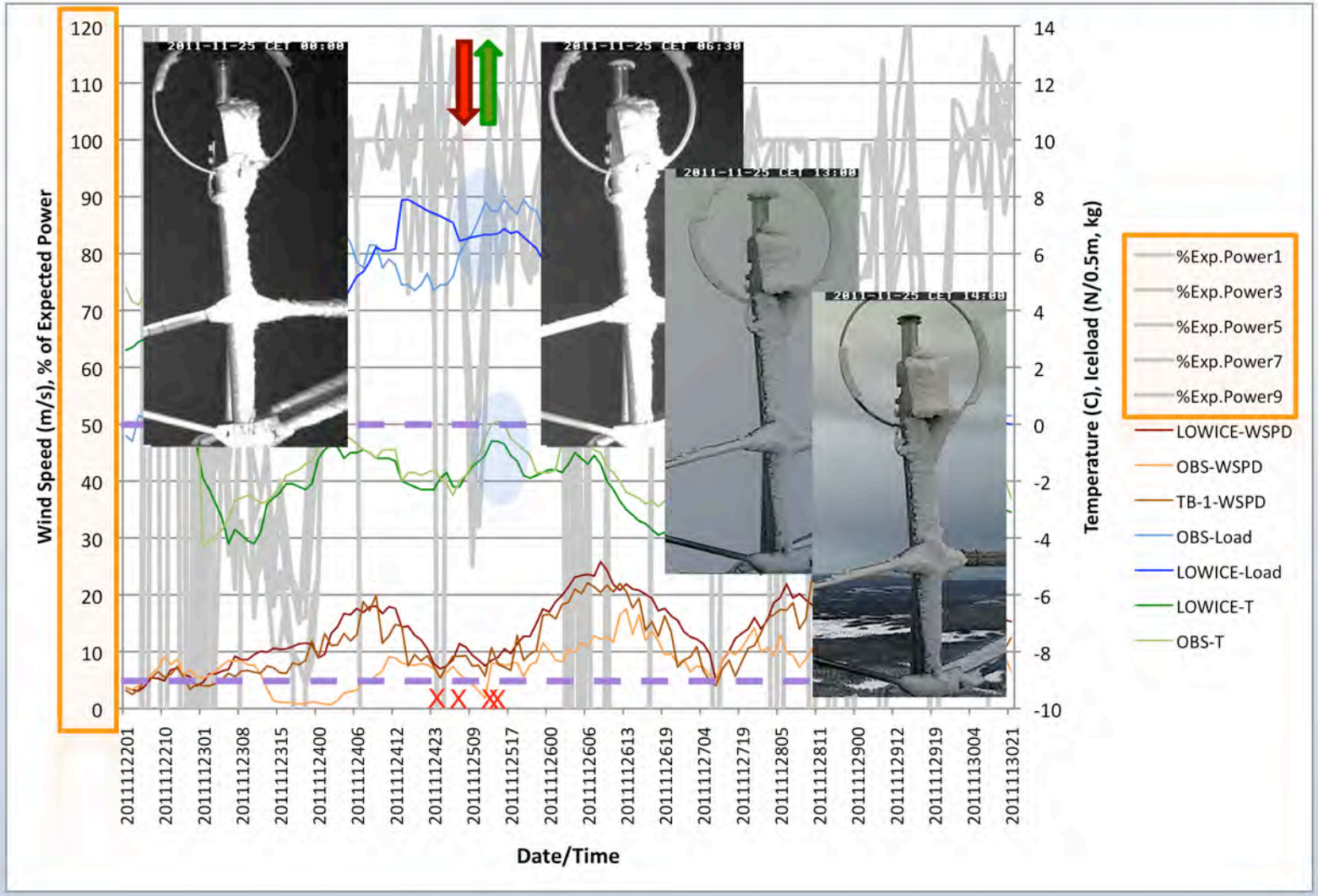
# Power – Event A

## Prolonged Active Icing, Rapid Loss, Erratic, Shed, Rapid Recovery



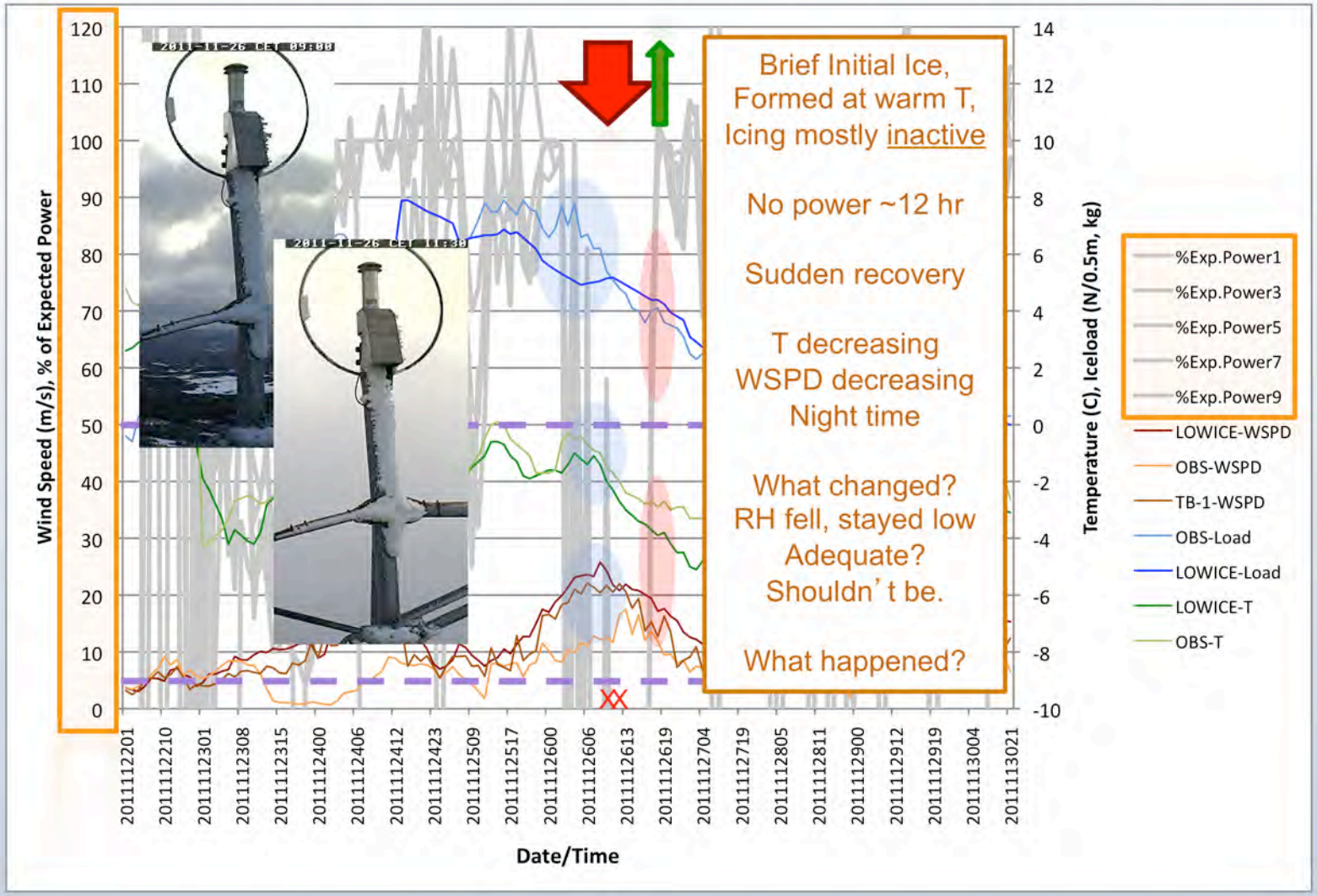
# Power – Event B

## Rapid Loss, Icing Stops, T Rises Toward o°C, Shed, Rapid Recovery



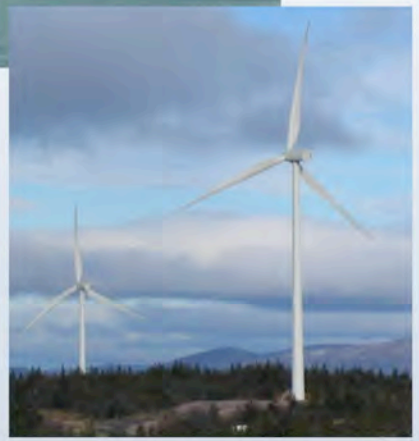
# Power – Event C (something different)

## Rapid & Lasting Loss – Eventual Rapid Recovery At All Turbines



# Observations

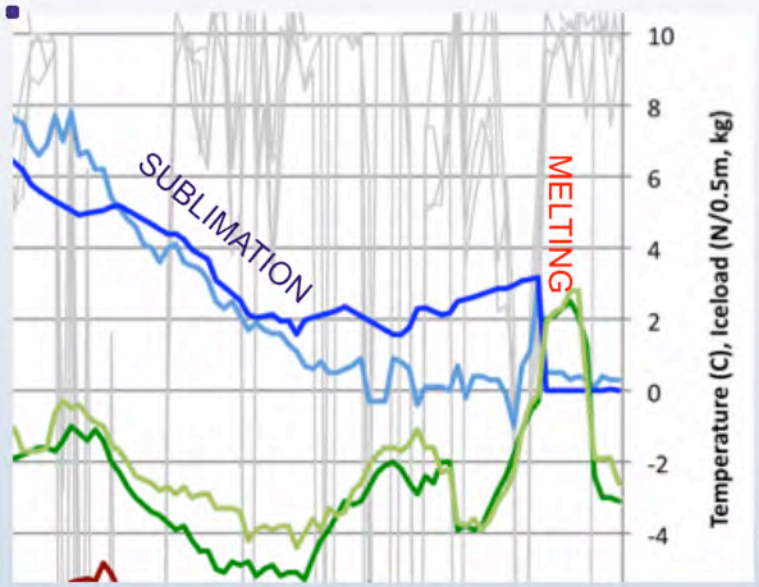
## FROM THIS CASE



- Losses develop EARLY in event
  - Power changes can be rapid.
  - Continue while icing is ACTIVE
- Recovery can be rapid
  - When icing is INACTIVE
  - When T approaches, surpasses 0°C (of course)
  - Partial recovery during brief inactivity (-3°C to -4°C)
- Some similarities to icing on helicopters
  - Growth regimes, power loss, recovery rate
- BEWARE – THIS IS ONLY ONE CASE!
  - Rather warm event, small ice loads
  - See some similar features - other cases and at other sites
    - Many differences, too – e.g. Events A, B versus C
    - Different environments, different mechanisms (formation and removal)
    - Needs further study before we can generalize, even for warm icing

# Improve Our Methods

- Current methods to deplete ice and recover power
  - Power loss = F (wind speed, ice load)
  - Ice load depleted by
    - Melting
      - Rapid loss of ice when T > 0°C
        - Rapid recovery of power
      - Highly sensitive (T near 0°C)
    - Sublimation
      - Erosion from dry air, wind
      - Gradual loss of ice
        - Recovery of power
  - Shedding NOT accounted for
    - Seemed too random
    - Really the case?

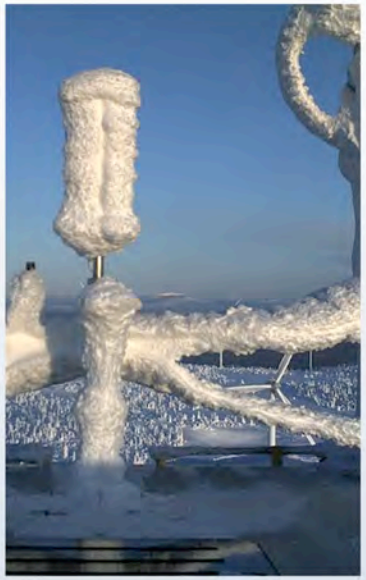


# Natural Recovery - Turbines

- Once active icing ends:
  - Rather than wait for ice to melt or sublimate off cylinder
    - Allow power to recover? How quickly?
  - How to account for temperature?
    - Example case was warm
    - How much will things change at colder temperatures?
      - More slowly? MUCH more? Not at all?
      - Rely on sublimation?
  - Account for wind speed?
    - Higher speed, more force for shedding, faster ice erosion
    - Faster recovery seems logical
  - Account for relative humidity?
    - Sublimation

# More Work To Be Done

- Predict amount of ice on a cylinder pretty well
- Struggle to relate it to power loss on a turbine
  - Correlation of load to loss is weak
  - Event ends
    - Load persists on cylinder
    - Indicated power loss persists
    - Turbine: real power may recover
- Can we to do better?



# More Work To Be Done

- Chasing the standard of a cylinder
  - Valuable measurement
  - The standard to compare with
- Need to mimic power patterns from turbines
  - Examine a wide variety of events
  - Icing types, temperatures, wind speeds, sequences
- Developing methods for LOWICE
  - Loss factor = F (dLoad/dt, icing type, inactivity time, T, WSPD, RH…)
- There is a great deal to learn
  - Requires detailed analysis, time
  - Program provides us with excellent data and opportunities to do so

# QUESTIONS?

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