Innovations in FLOWICE Real-Time Forecasts of Wind Power and Icing Effects

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Introduction

- Project: Swedish Energy Agency & OX2
- Period: 2009-2015
- Purpose: We were involved in modeling of wind turbine icing/power production
- Wind farms across Sweden, several in high terrain
- Our systems:
  - LOWICE: Hourly analysis
  - FLOWICE: Daily forecast out to 48 hours
    - **Focus of presentation is on FLOWICE**
    - But description of LOWICE is needed

LOWICE and FLOWICE

- Two systems, both run in real time:

  Analysis (LOWICE) and Forecast (FLOWICE)

- Use of models (both systems) and METARs (LOWICE only)

  To Determine:
  - Presence of clouds, precipitation (& type)
  - Cloud characteristics, layering, etc.
    - Cloud height relative to hub height
    - Cloud phase (snow, water, supercooled water)
    - Temperature, Liquid Water Content, Drop Size
  - Presence/absence of icing

  To Estimate:
  - Ice growth: Icing rate
  - Ice loss: melting, sublimation, shedding
  - The effects on power

LOWICE: LAPS + Observations

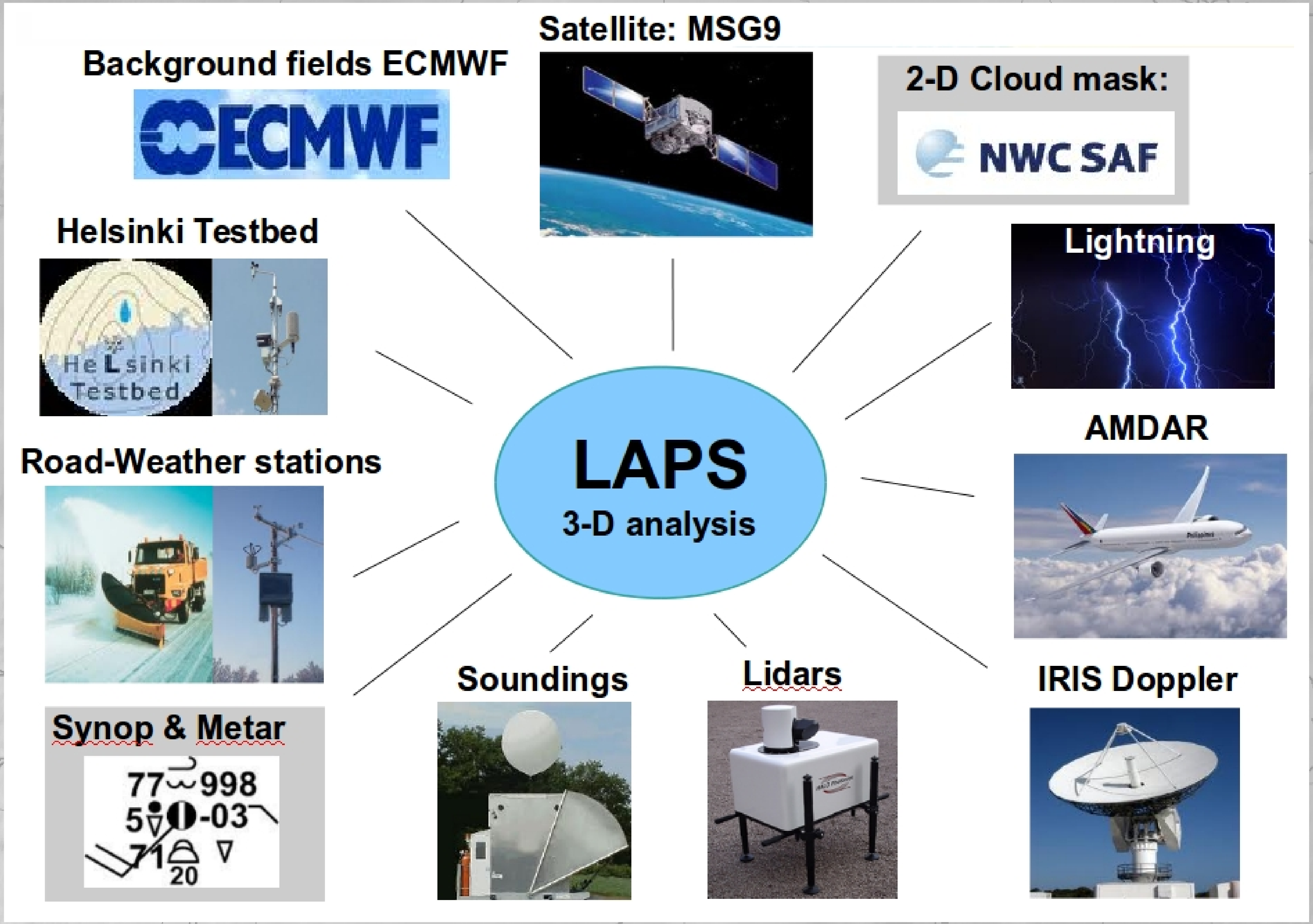
- **LAPS** (Local Analysis and Prediction System):
  - Ingest observations, blend with model fields
  - 3D Analysis of the atmosphere
  - Captures fine-scale features (important for icing)
  - Assimilates a wide range of obs. (next slide)

- <u>LOWICE ingest LAPS + adds extra info from METARs</u>

- LAPS operational Scandinavia:
  - Grid spacing of 3 km
  - Vertical: 44 levels (tightest at low lev.)

- Comparison with wind farm data:
  - T, U: Generally close, slight biases

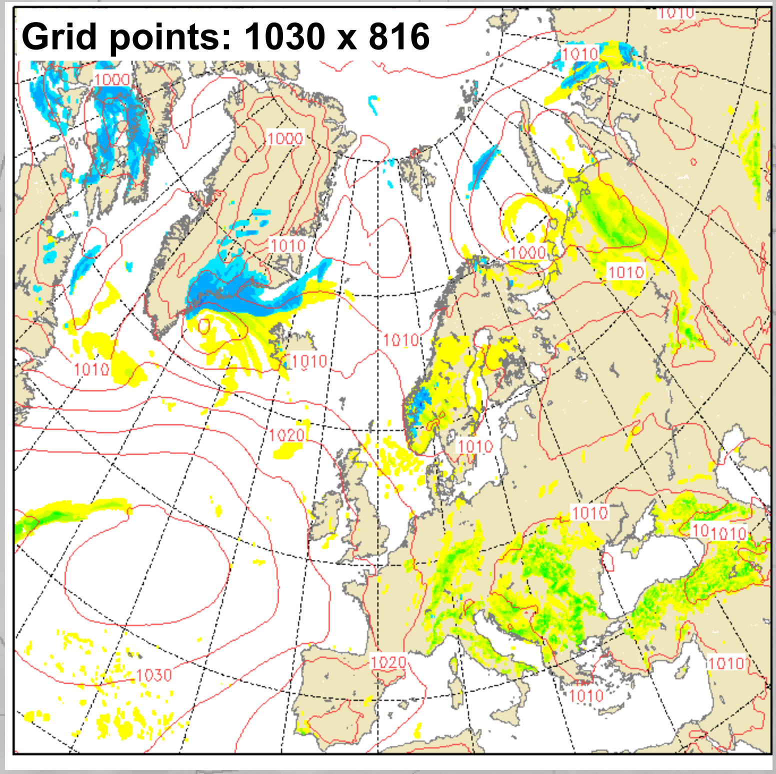
FMI-LAPS Observational Ingest



FLOWICE: Based on HIRLAM

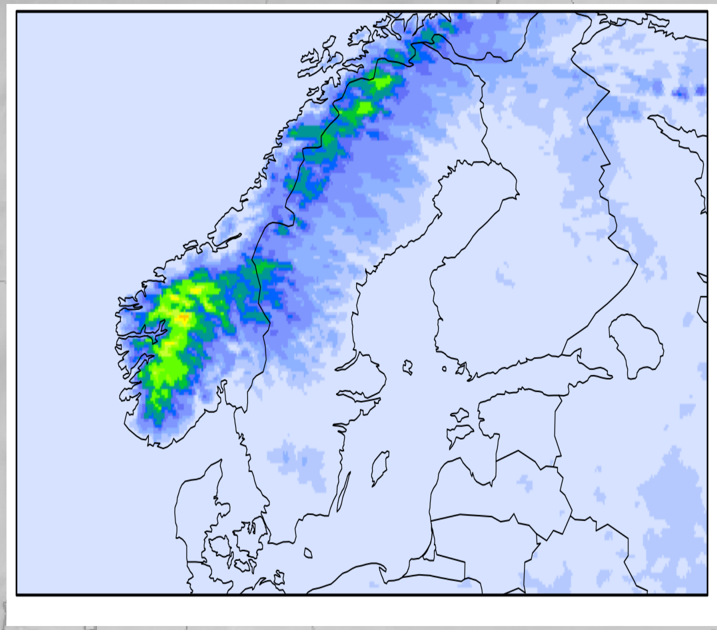
- **HIRLAM FORECAST MODEL:**
  - Assess the 3D state of the atmosphere
  - Captures many fine-scale features important for icing
  - Vertical: 65 levels (20 in lowest 1 km)
  - Hourly forecasts (0 to +54 hours)
  - Initialized with ECMWF model
  - Grid spacing of 7,5 km

- Comparison with observations:
  - Temperature & Wind speed
  - Sometimes significant biases!

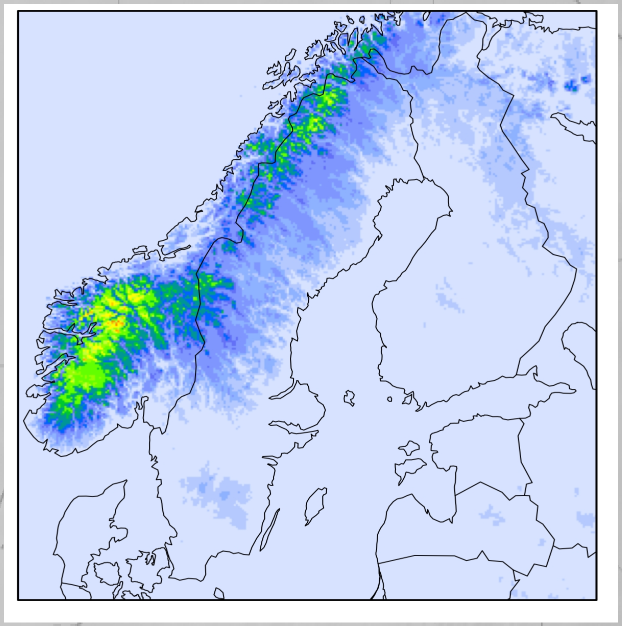


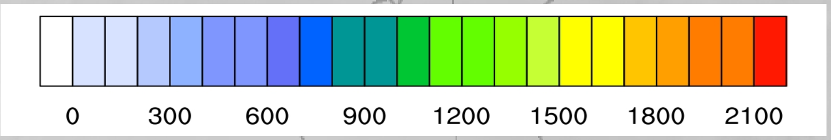
HIRLAM and LAPS Grids; Terrain

HIRLAM topography



LAPS topography





HIRLAM (subset):

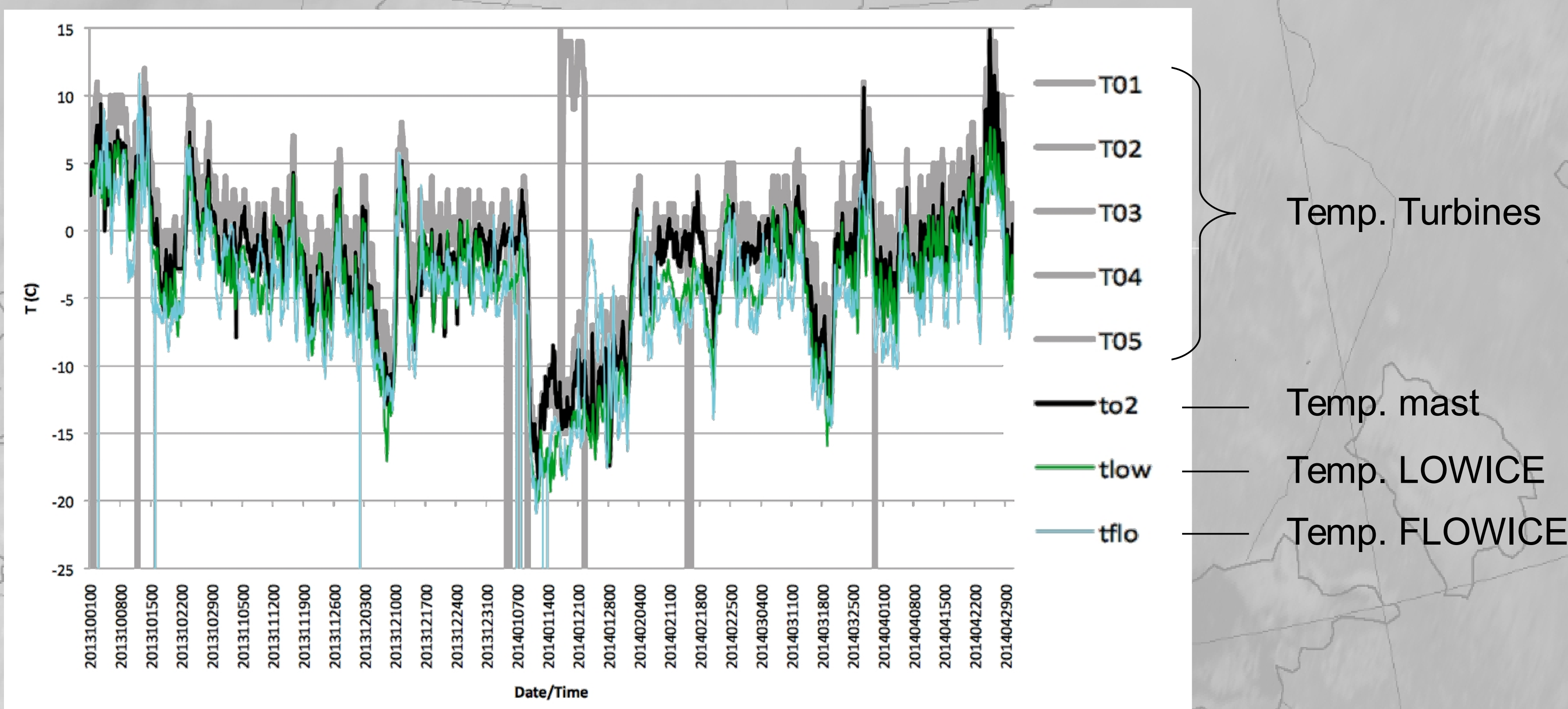
- 7,5 km spacing,
- 65 vertical Levels
- Topography: decently resolved
- Initialized every 6 h (FLOWICE: 24h)

FMI LAPS:

- 3 km spacing
- 44 vertical Levels
- Topography: highly resolved
- Updated every hour, using obs.

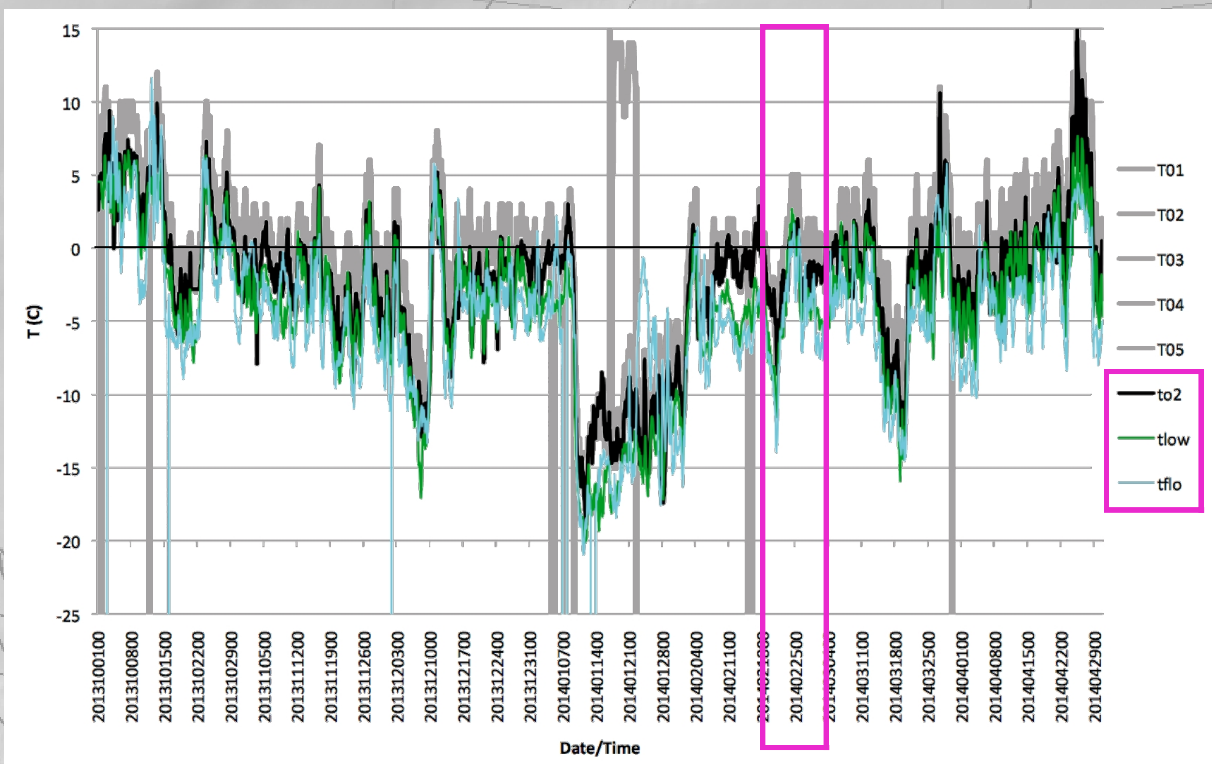
Temperature Comparisons

- Both systems did well for most periods and locations, however…
  - Persistent cold bias – strength of bias is site dependent.
  - Which ground truth T is correct?
    - Black (mast) or grey lines (heated probes in turbines)?



Downstream Effects of T errors

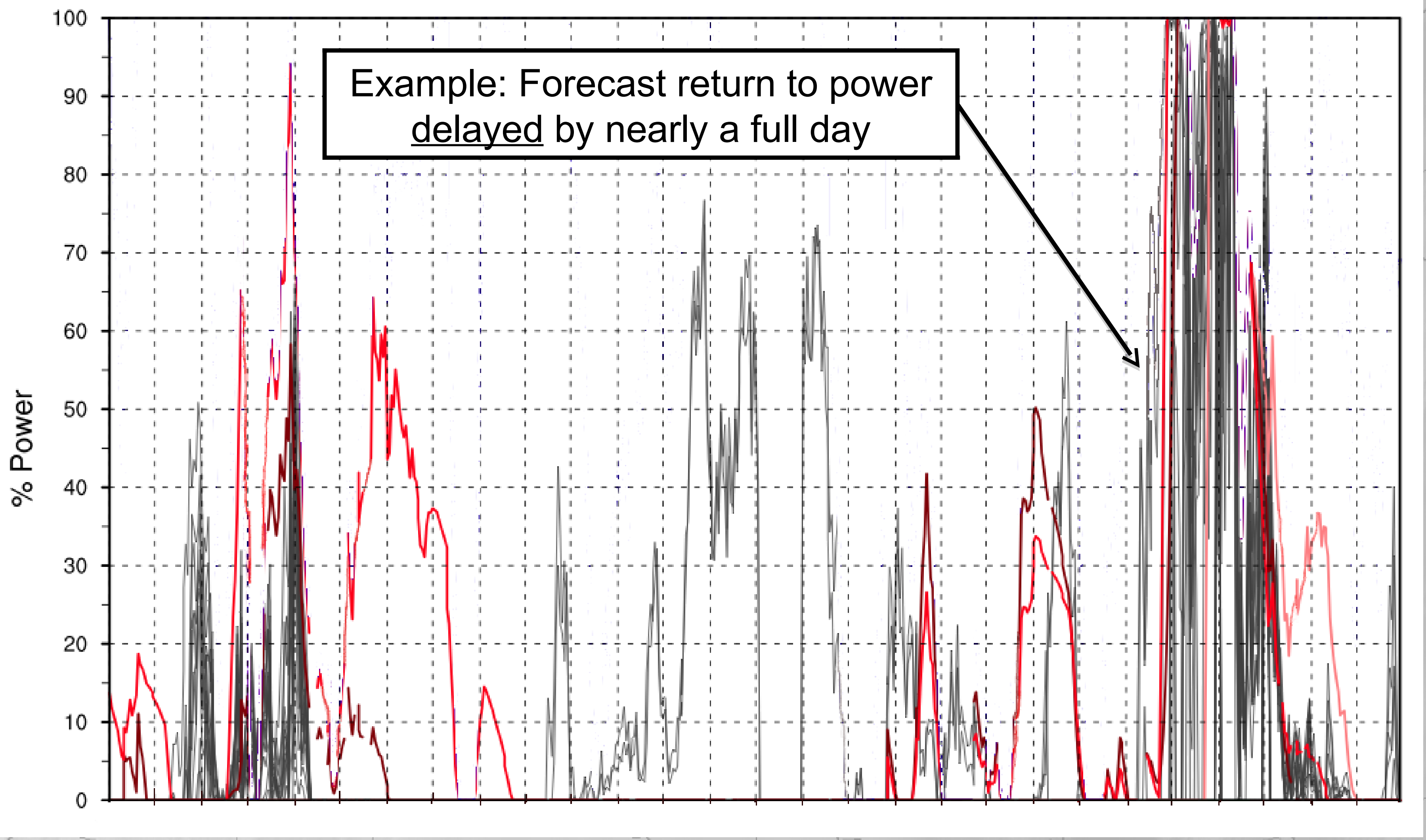
- Overestimate of ice presence at T ~0ºC
- Example: Melting event at one site
- T rise beyond 0ºC by 25 Feb – melting
- Models lagged the observations



Date: 20/2-2014

Date: 25/2-2014

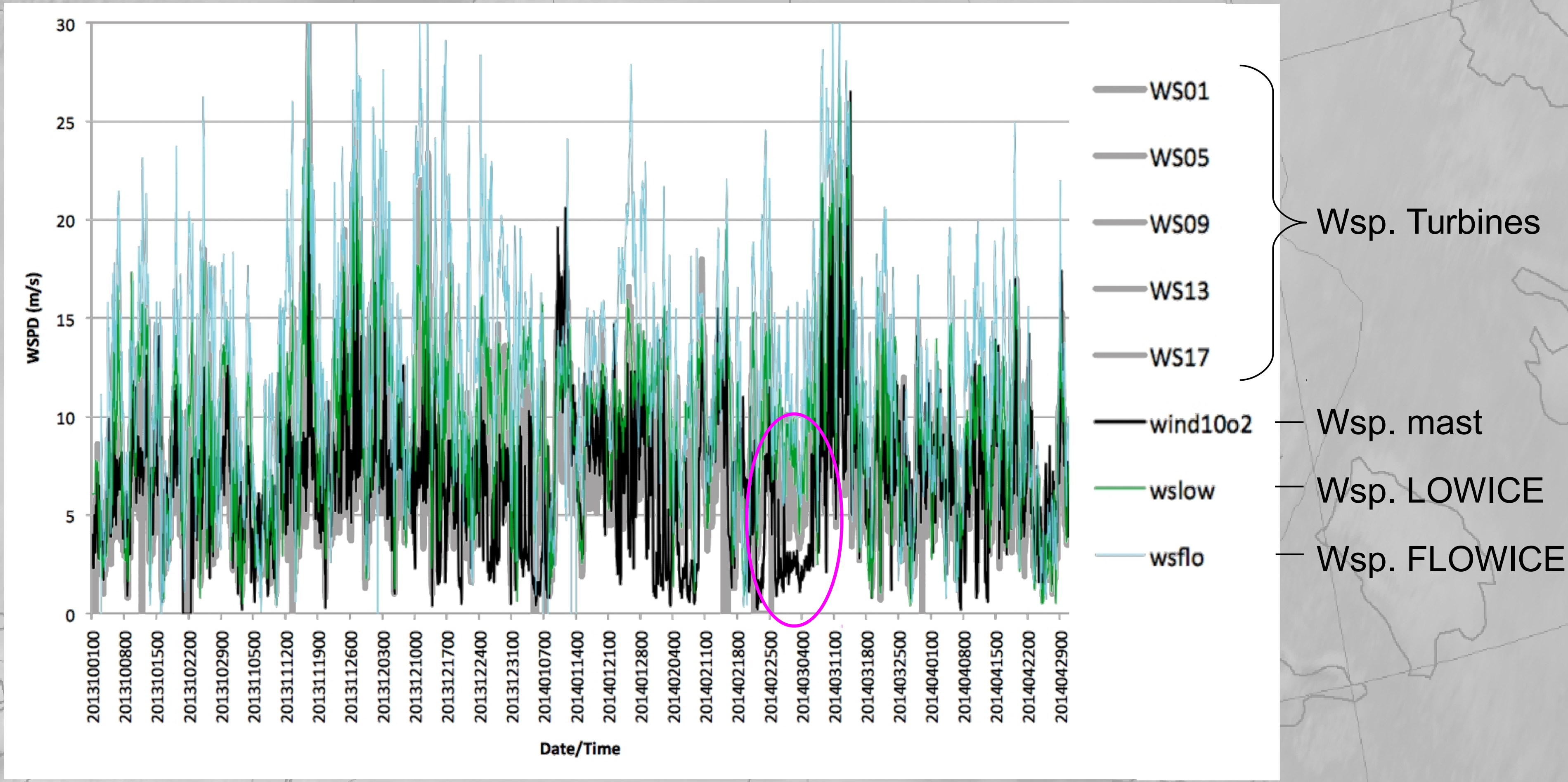
Downstream Effects of T errors



- Problem not unique to F-LOWICE; Observed in other systems

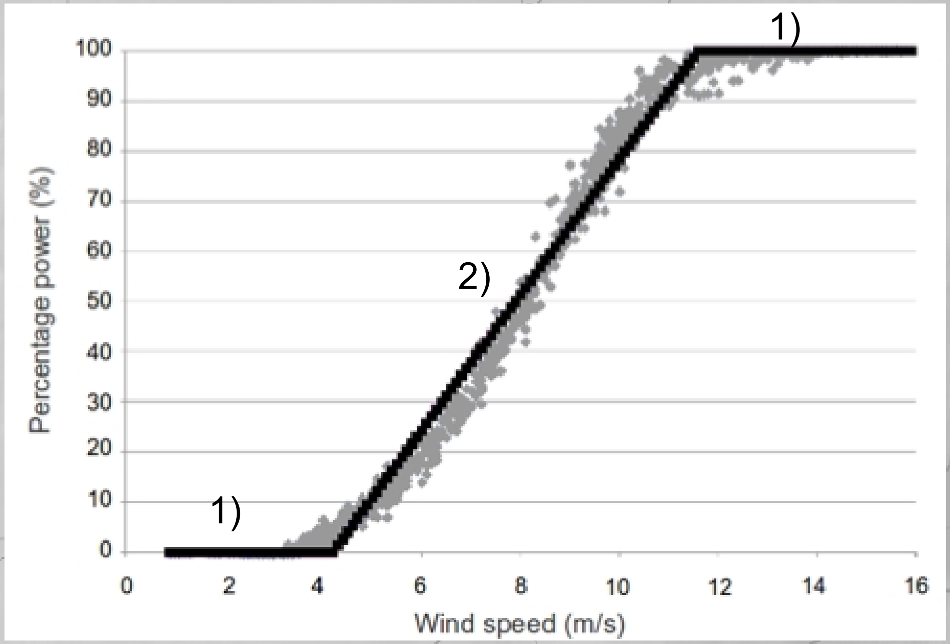
Wind Errors

- Winds present greater challenge
  - High bias, especially for HIRLAM/FLOWICE (less in LAPS/LOWICE)
  - Some of bias due to icing on “mast obs” (compare to turbines)



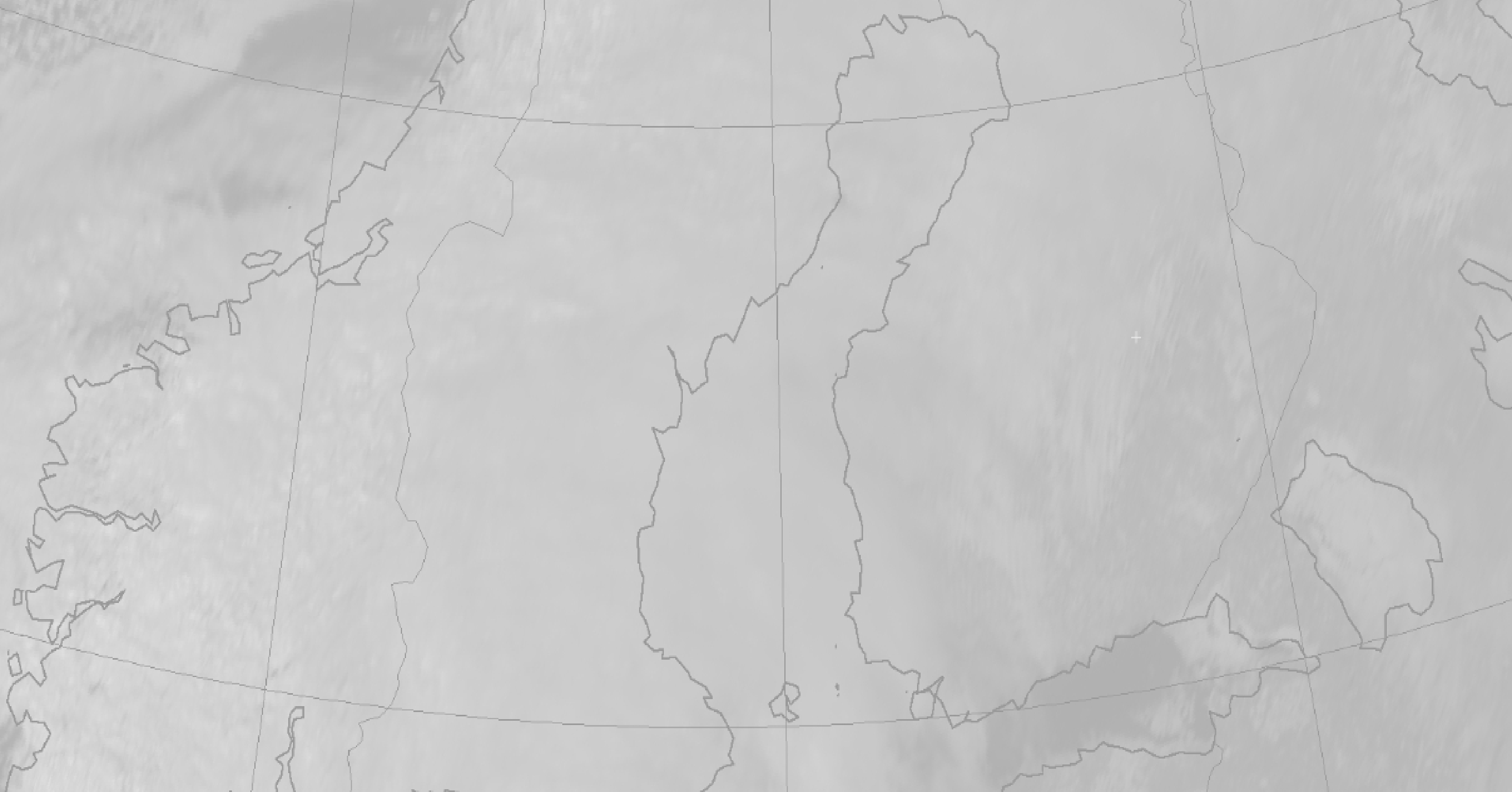
Downstream Effects of U errors

- Anomalously high wind speeds and biases
- Result in overestimated power
  - Effect depends on where you are in the power curve
  - 1) Observed and expected winds are very low or high?
    - Power curves are generally flat
    - Expected power = observed power
  - 2) Observed and/or expected winds in sloped region?
    - Significant power differences may exist



FLOWICE Upgrades

- **1) Adjust/correct HIRLAM forecast data**
- 2) Provide users with probabilistic information



<u>1) ADJUSTING HIRLAM FOR ERRORS</u>

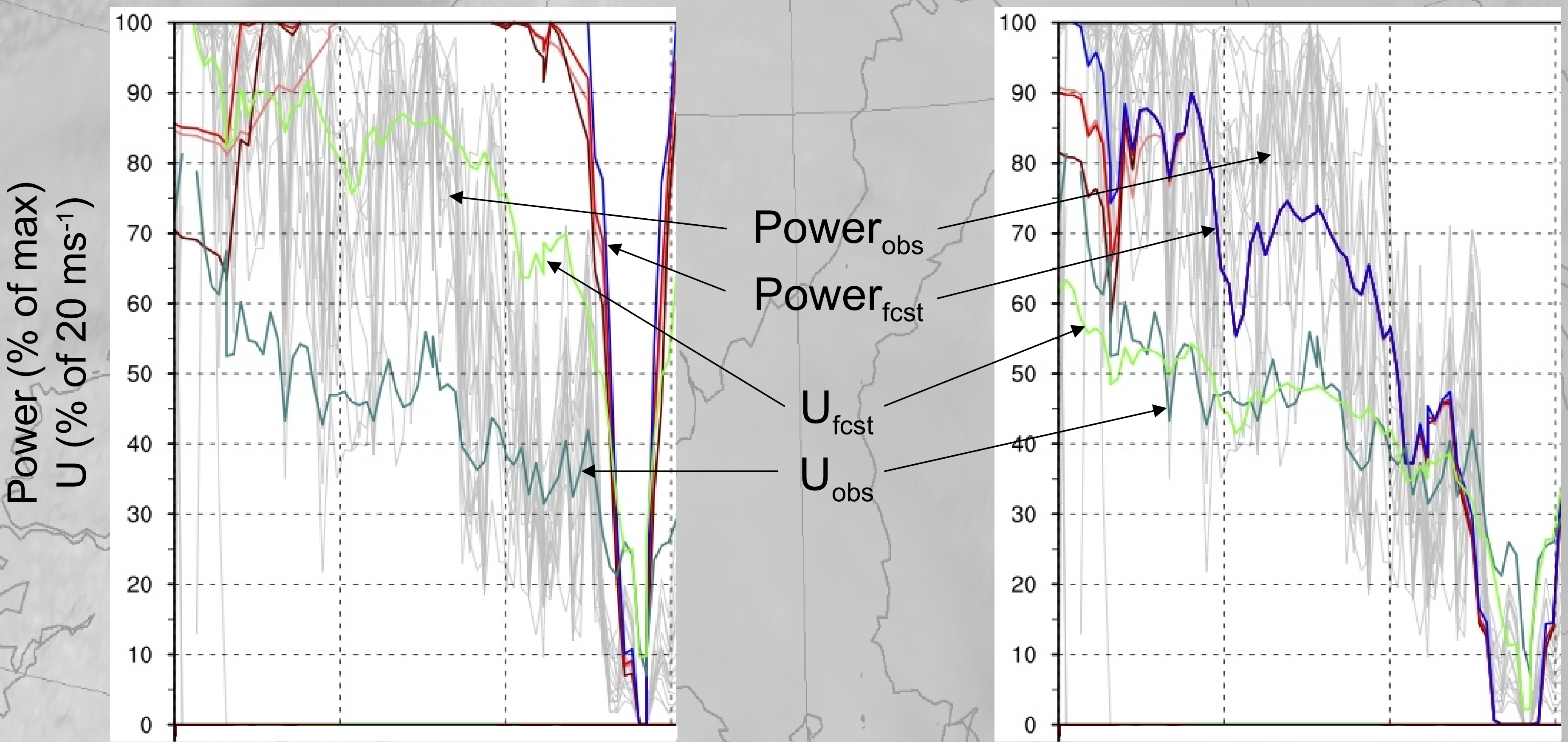
- Available real-time data:
  - Observations from wind turbines
  - LAPS-LOWICE grids
- Compare HIRLAM forecasts to TURBINE observations
  - Forecast hours +1 through +6 h
  - Calculate differences for wind speed and temperatures

    Example: $U_{diff} = (U_{observed} - U_{forecast})$
  - Calculate ratios for winds

    Example: $U_{ratio} = (U_{observed} / U_{forecast})$
- Calculate <u>weighted adjustment to U and T</u> for rest of forecast length (+7 to +48h)
  - If no observations? Then we still have LAPS
  - We are considering using historical/climatological data

RESULTS

- ADJUSTMENT TO HIRLAM:
  - T, U are improved and, thereby, the FLOWICE POWER forecasts
    - Statistical assessment underway
    - The use of air density needs to be implemented (simple..)



Original (+24-48h)

Adjusted (+24-48h)

FLOWICE Upgrades

- 1) Adjust/correct HIRLAM forecast data
- **2) Provide users with probabilistic information**

PROBABILISTIC INFORMATION

- Icing is a complex problem
- Significant differences can show up in time and 3-D space
- Gridded forecasts have inherent inaccuracies

  Examples:
  - Mis-timed fronts, wind maxima/minima
  - Strong inversions
  - Wind profile issues
  - Local variability in T, U
  - Terrain differences (reality vs. model)

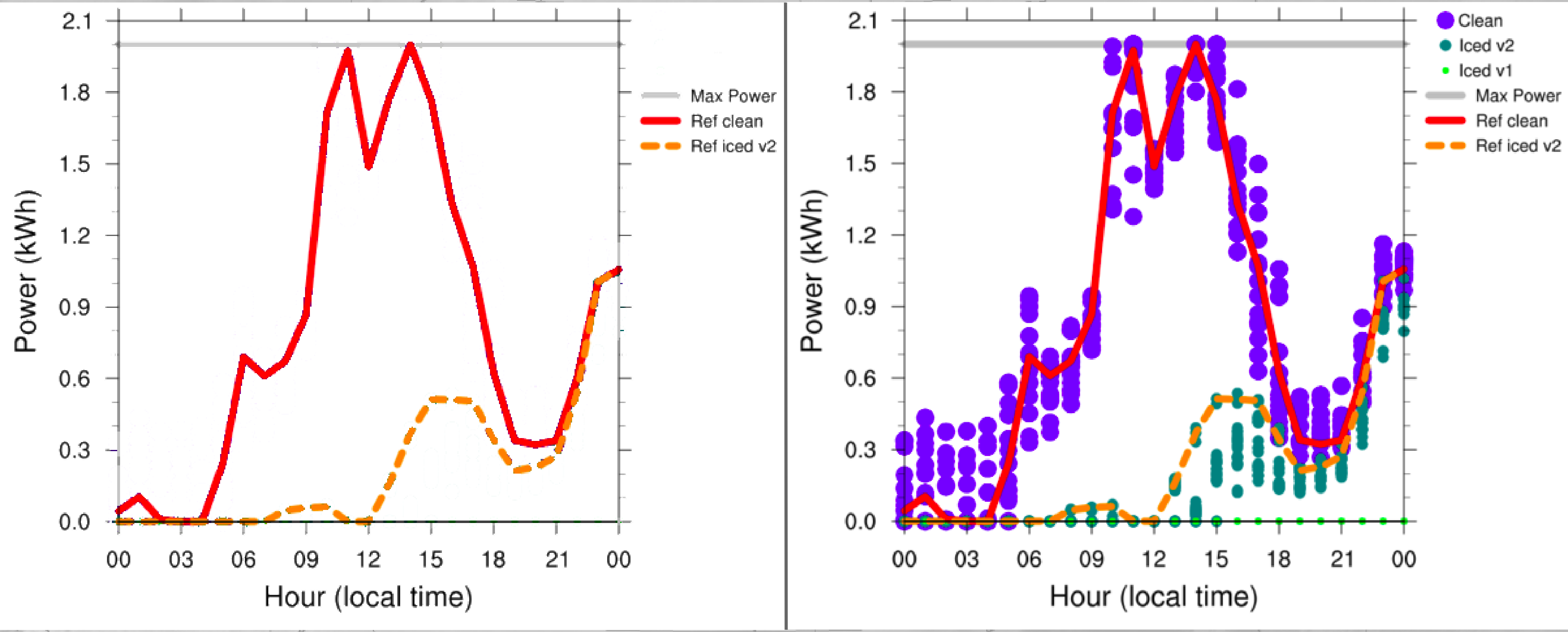
- Small differences in T, U, icing rate, melting, etc.
  - *CAN HAVE LARGE IMPLICATIONS FOR POWER!*

- Single point answers (in x,y,z,t space) give a simplistic answer
  - *Don’t represent the meteorological uncertainty*

- Provide users with probabilistic information
  - Better represent forecast errors, variability and CONFIDENCE

One run; Two perspectives

- Forecasts of clean and "iced" power
  - Left: closest point to turbine hub (single answer)
  - Right: shows cloud of points around the turbine (probabilistic answer)



<u>FEEDBACK – PROBABILISTIC INFO</u>

- Interesting and <u>VALUABLE</u>
- Users want a sense of the reliability of a forecast
- Example: Power traders are putting money on the line
  - *How much can we trust the values that they are given?*
- Things to consider:
  - What is the best way to represent this information?
  - Can value be quantified?
  - How good is the probabilistic information?
    - Giving the variability around a “bad answer/solution” may still give a bad answer.

Conclusions

- Icing is a difficult phenomenon to predict well
- Effects on turbines, power add big layer of complexity
- We're making advances understanding and predicting them both, however...
- Nature and Physics keep providing lessons

Still much to learn!

Gregow, E., B.C. Bernstein, I. Wittmeyer and J. Hirvonen, 2015: LOWICE: A real-time system for the assessment of low-level icing conditions and their effect on wind power. Journal of Atmospheric and Oceanic Technology, In Press.

Thank you! Questions?

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