

**Assessment of  
“GROUND TRUTH”  
for Icing Events and Product Evaluation**

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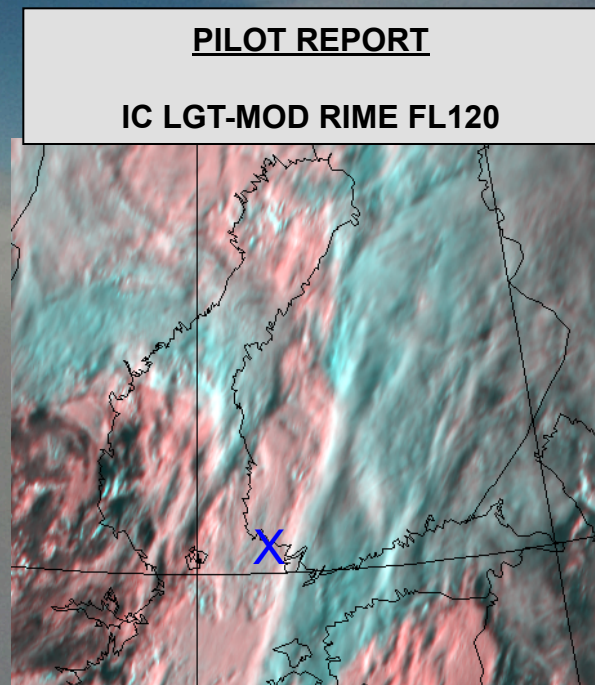
# Introduction

- O2 Wind Pilot Project
  - Icing products, observations
  - One goal: validation/verification
- What is an icing event, really?
  - When is it “active”?
    - Can be very subtle
  - How do we know?
- Observations
  - Multiple sources
  - Supporting evidence
  - Instantaneous, time-series data
  - Webcam images, loops
    - Growth, visibility, sense of situation
- Confidence?
- How to use it to judge icing forecast systems?



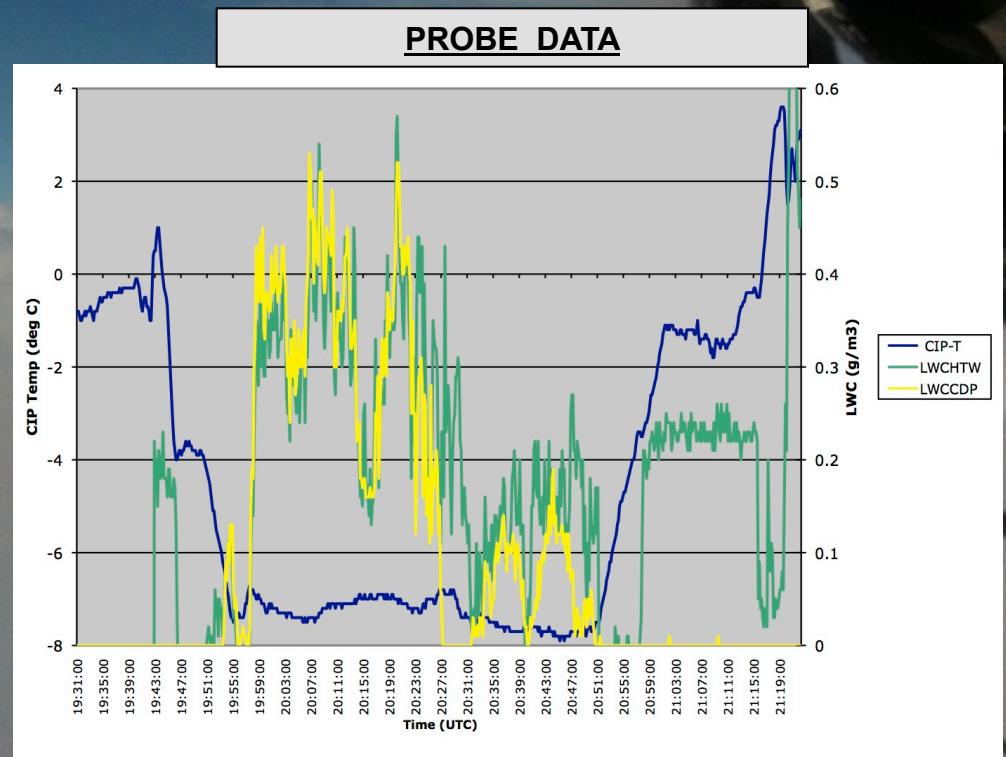
# In Flight Icing

- Flying through clouds
  - 4-D icing problem
- Typical
  - Occasional data point
  - Vague, product of:
    - Environment
    - Aircraft, protection
    - Flight history
    - Pilot perception
- A challenge to interpret
  - Still very useful for verification
  - Requires CARE, CONTEXT



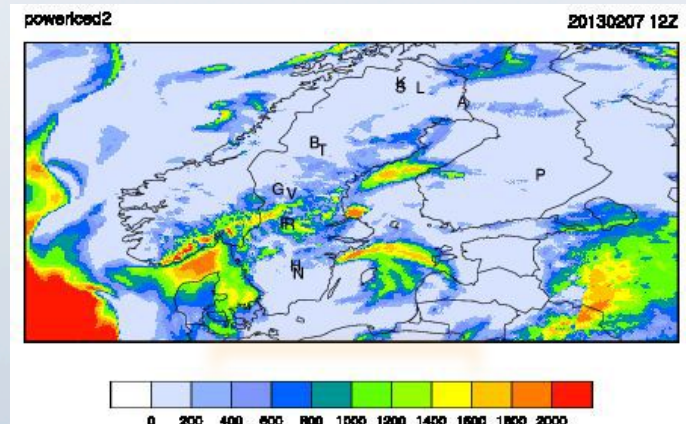
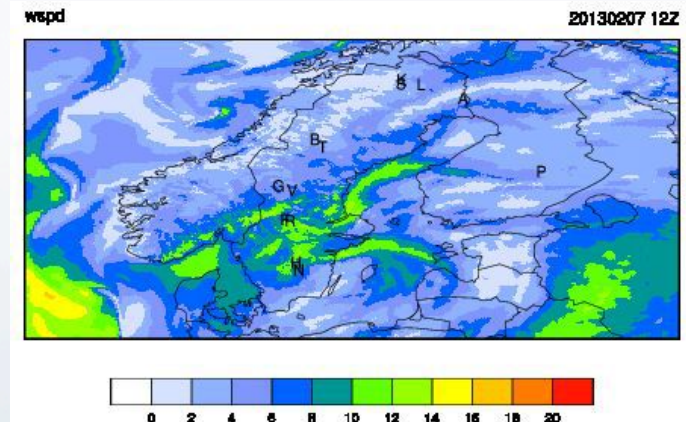
# In Flight Icing

- Best data: flight tests
  - Still 4-D
- Instrumented aircraft
  - Standard probes
  - Objective measurements
    - Temperature
    - Liquid Water Content, etc.
  - Relate to ice that forms
  - Data more useful, still flawed
    - Requires CARE, CONTEXT
- Icing for Wind Power
- Ground based measurements
  - Fixed location, down to 1-D
  - Should be easier, right?



# The Project

- O2 Wind Pilot Project
  - Swedish Energy Agency
- Icing Products
  - Four meteorological agencies
  - SMHI, WeatherTech, Kjeller, LEA/FMI
- Use weather models, observations
  - Diagnose/predict T, winds...
  - Estimate power
  - Impact of icing
  - Sites across Sweden



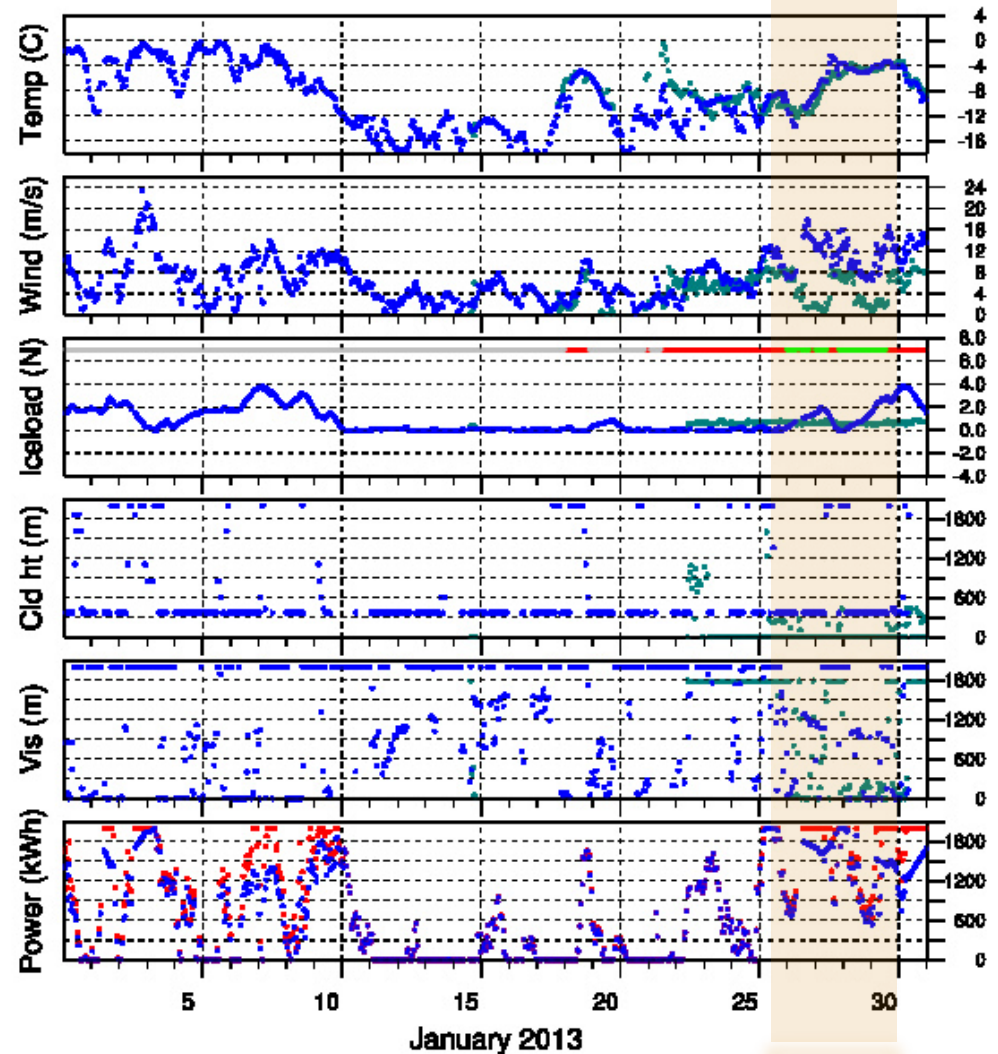
# Observations

- Combitech and In-Situ
  - Instrumented masts & turbines
  - Collect high-quality measurements
    - Meteorological parameters
    - Icing parameters: load, “glaciations”
  - Webcam images
    - Clouds
    - Ice presence/growth/decay
      - Mast, blades
- Power production (select sites)
- Look at the data every day
  - Get used to what it says/means
- Compare!
  - To forecast products
  - Validation, statistics
    - Reports, real-time (SMHI, LEA)



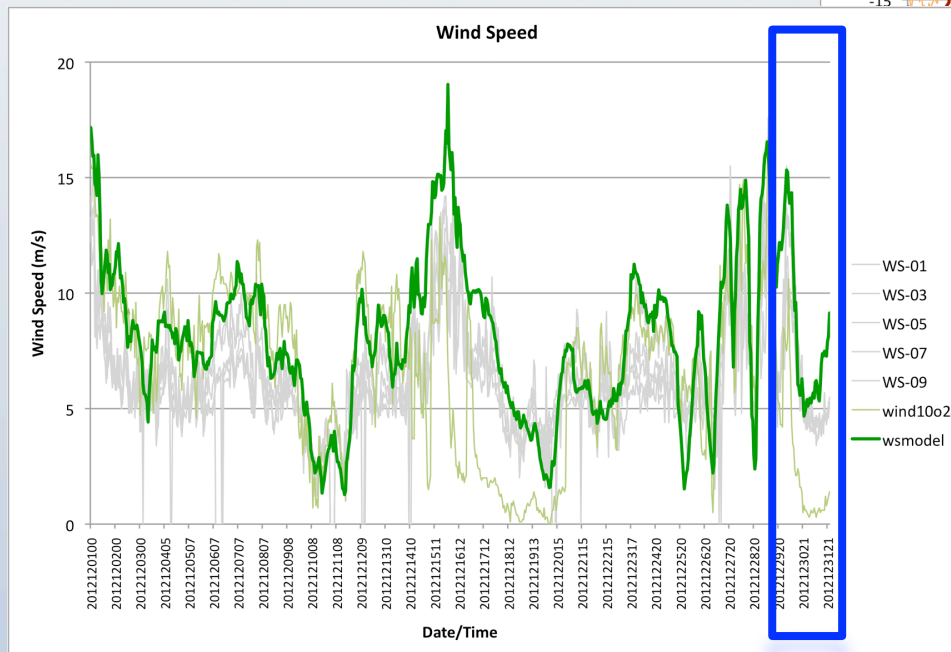
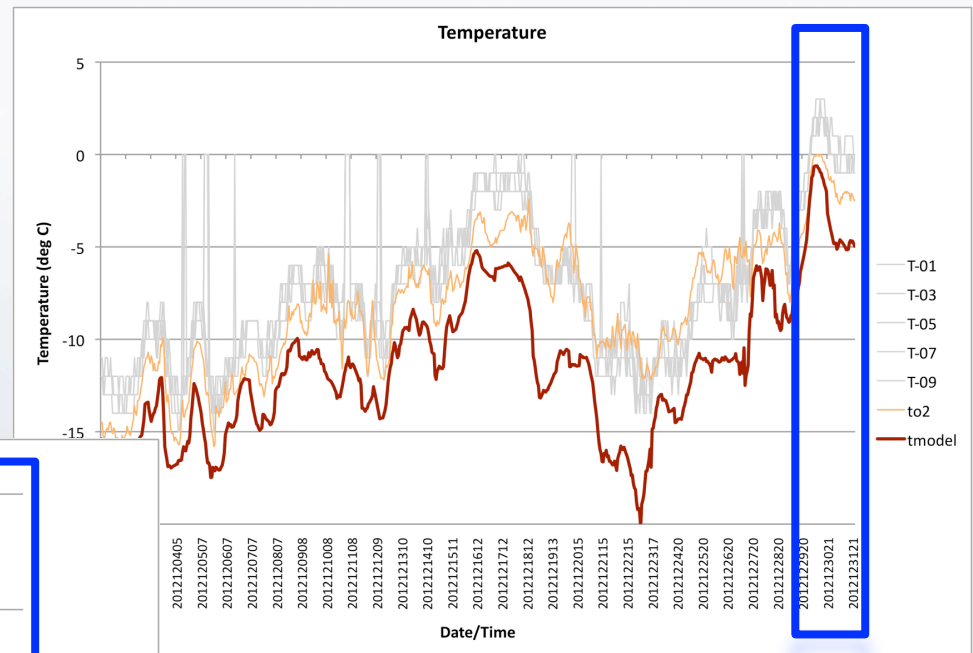
# A Quick Comparison

- Monthly time series
  - Icing off/on 4 days (cam)
  - Forecast, mast-observations
  - Temperature (good match)
  - Wind speed (matches at times)
  - Icing Load (flat)
  - Power (forecast only shown)
- “Good forecast”?
  - For which fields?



# Closer Look: Basic Fields

- Temperature, wind speed
  - Calculate: Bias, RMSE, etc.
    - Compare model to
    - Multiple measurements
      - Similar, different. Why?

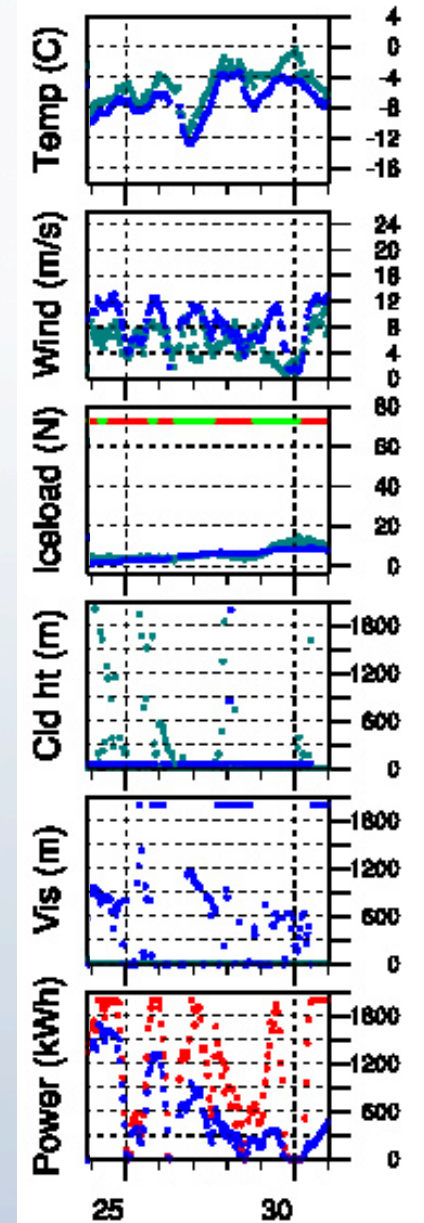
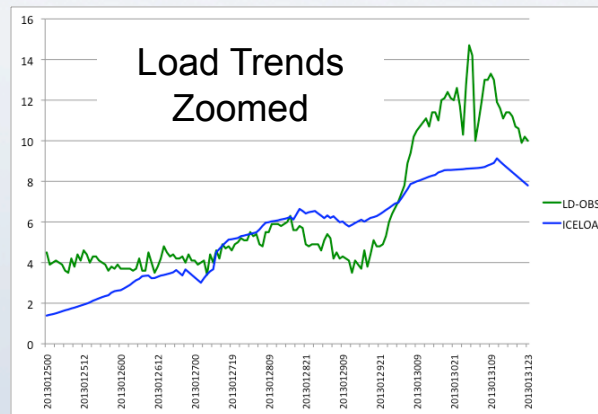


**\*\*NOTE:** Data from a different station & time period shown for demonstration.



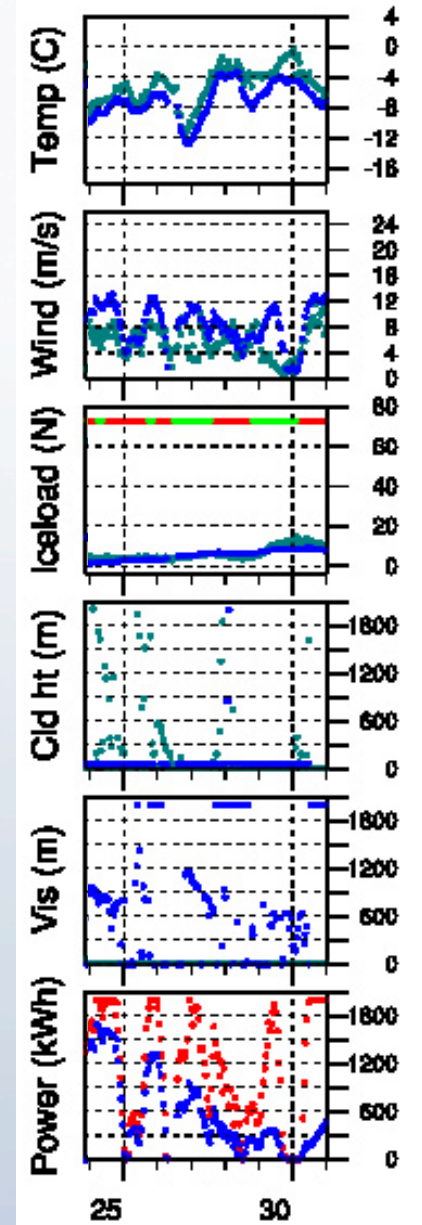
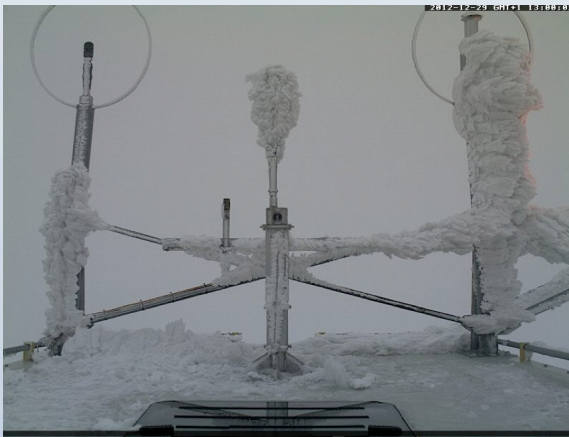
# More Complex: Icing

- Change in load (time span?)
  - Short vs. long events - BOTH can affect power
  - Load doesn't always go UP during icing
    - Site to site
- $T < 0^{\circ}\text{C}$ , low visibility, ceiling
- Underestimated WSPD
- DEPLETED POWER
  - Measured vs. Expected
    - wind -> power curve
- Objective, but flawed
  - Can code this, calculate values
  - Generate statistics
- Which signals can you trust? When?
  - Requires CARE, CONTEXT
  - How do we meet that need?

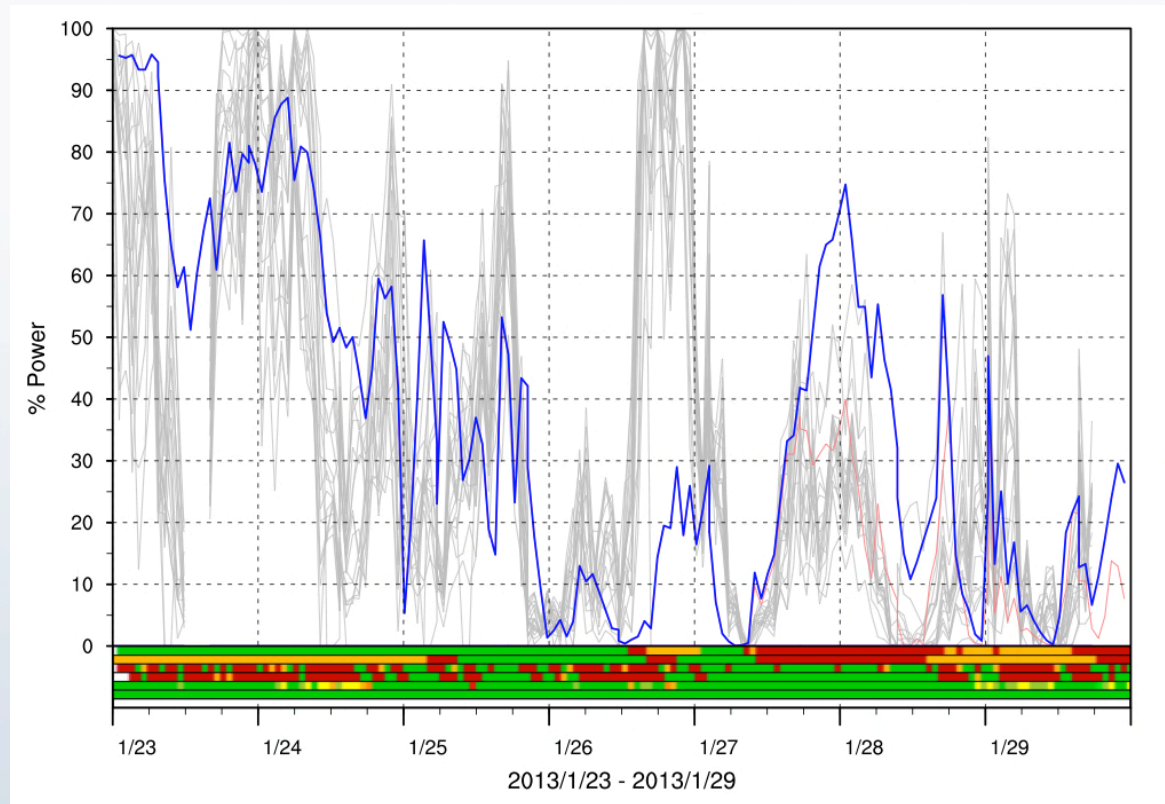





# Manual Assessment




- Look closely at data
  - Same fields described above + others
  - Webcams
    - Some things seen better with the eyes.
- Labor intensive, subjective
  - QUITE EFFECTIVE
  - More often "correct"








# Real-Time Analysis



OBSERVED POWER - TURBINES   
 CLEAN POWER - MODEL   
 ICED POWER - MODEL 

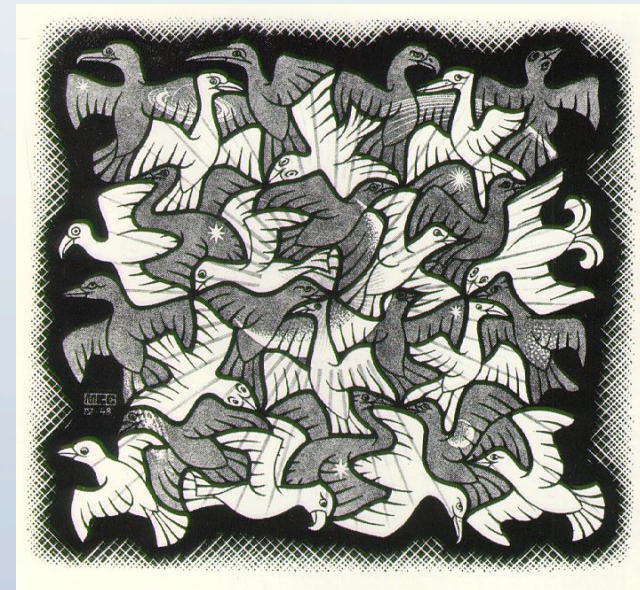
1<sup>st</sup> COLOR BAR - MODEL ICING  Active Icing  
 2<sup>nd</sup> COLOR BAR - MANUAL ASSESSMENT  Ice Present, Not Active  
 No Ice  
 No Data

3<sup>rd</sup> COLOR BAR - dLOAD/dt (1 hr)  Icing Likely  
 4<sup>th</sup> COLOR BAR - dLOAD/dt (3 hr)  Icing Possible  
 5<sup>th</sup> COLOR BAR - Temp & Visibility/Ceiling  Icing Unlikely  
 6<sup>th</sup> COLOR BAR - Temp & Glaciations  Icing Unlikely  
 7<sup>th</sup> COLOR BAR - Ratio WSPDmast:WSPDturb  No Data

# Statistics

- “Objectively” compare icing fields
- “Ice Presence”
  - Predicted vs. observed load or MANUAL
  - Observed load vs. MANUAL
    - Test the observations (i.e. test the test)!
- “Active Icing”
  - Predicted Icing Rate vs.
    - Observed  $\Delta\text{Load}/\Delta t$ , MANUAL
  - Observed  $\Delta\text{Load}/\Delta t$  vs. MANUAL
    - Test observations
- POD-y ( $YY/(YY+NY)$ ), POD-n, FAR, CSI...
  - Tradeoffs
  - Choice of threshold matters
  - Results vary by method – sometimes quite a bit!
- It depends what you focus on
  - What is most important to you (e.g. cost/loss)

TST/CRT	ACTIVE	DLOADDT3	TVIS	LOSS-V0
THRSH-M	0.9	0.9	0.9	0.2
THRSH-O	0.5	0.6	0.25	0.8
PODy	0.823	0.585	0.737	0.795
PODn	0.568	0.564	0.539	-9.999
FAR	0.698	0.527	0.802	0.045
CSI	0.284	0.354	0.185	0.766
TSS	0.391	0.148	0.276	-9.999
VDAT	702	708	711	248
YDAT	130	284	95	239
NDAT	572	424	616	9
YY	107	166	70	190
YN	247	185	284	9
NY	23	118	25	49
NN	325	239	332	0



# Is There Hope?

- Yes!
  - Effects of icing are critical
    - In flight
    - For power
- Need standards
  - There is no perfect answer
    - Also no perfect model/system
  - Even if observations (and models) are flawed
  - At least we can compare
    - Must interpret results with care
- Numbers are not enough
- Must dig deep, think hard
  - Understand why the answers look like they do.



**PLEASE NOTE:**

**2014 SAE International Icing Conference  
June 2014 – Prague  
\*Structural Icing Session Planned\***

**Opportunity for Two Related Communities to  
Learn From Each Other**

**QUESTIONS?**

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