Tools for Daily Operational Forecasting of Wind and Wind Power

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CEATI Workshop: Utility-scale Renewable Energy Operations and Optimization
6.0 Technical Presentation

Aspects of Daily Wind-Power Forecasting

1. Ensemble of many numerical weather (NWP) models
   - Reduces random errors associated with chaotic atmosphere
2. Post-processing of individual ensemble members
   - Reduces systematic errors (biases) associated with local terrain
3. Combine into deterministic & probabilistic wind fcsts.
   - Gives the best forecasts, and has most economic value
4. Verify the hub-height wind forecasts
   - Measures skill & identifies potential problems
5. Convert to wind power forecasts
   - Includes variations across each wind farm
6. Case studies
   - Enables discovery of alternative / better forecast methods
7. Recommendations
   - To enable more-accurate wind-power forecasts

photo credit: Mark Stull

1. Ensemble Approach

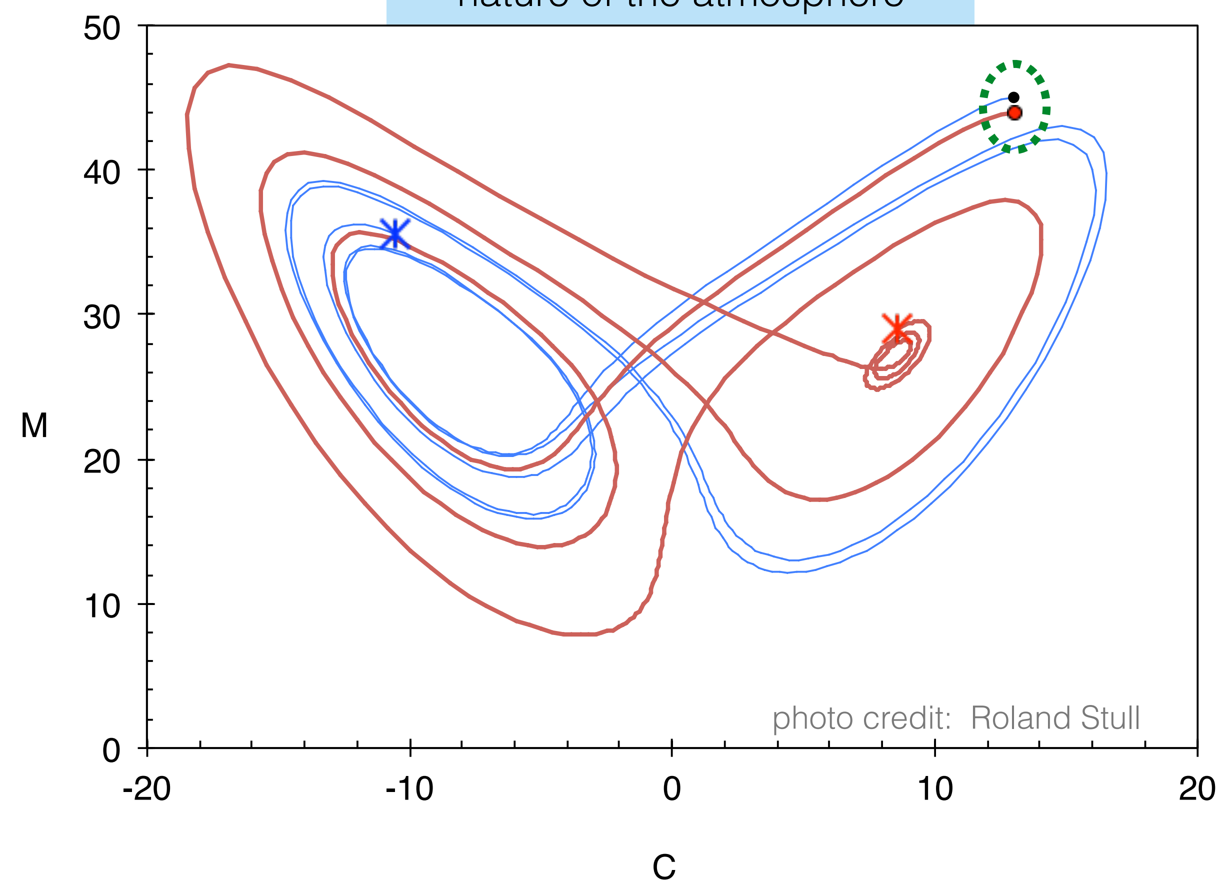
Reduces random errors associated with chaotic atmosphere

<u>Generic Method</u>: Run numerical weather prediction (NWP) models solving the fluid-dynamics eqs. for the full 3-D atmosphere over W. Canada.

But no single NWP model is always the best over all seasons and all wind farms, because of the sensitive dependence to initial conditions and to model approximations (i.e., chaos).

Instead, the **best practice** is to **<u>run multiple models daily</u>** to get an **<u>ensemble</u>** of forecasts for each wind farm.

simplified example of chaotic nature of the atmosphere



1. Ensemble Approach

Reduces random errors associated with chaotic atmosphere

UBC Example: 26 ensemble members run each day on our 448 core computer cluster + additional members run on cloud computers

- Multi NWP models
  WRF, MM5
- Multi model versions
  WRF-ARW, WRF-NMM
- Multi Initial Conditions (ICs)
  GFS, NAM, GEM/GDPS
- Multi grid sizes
  108, 36, 27, 12, 9, 4 km horiz.
- Multi boundary-layer physics
  YSU, ACM2

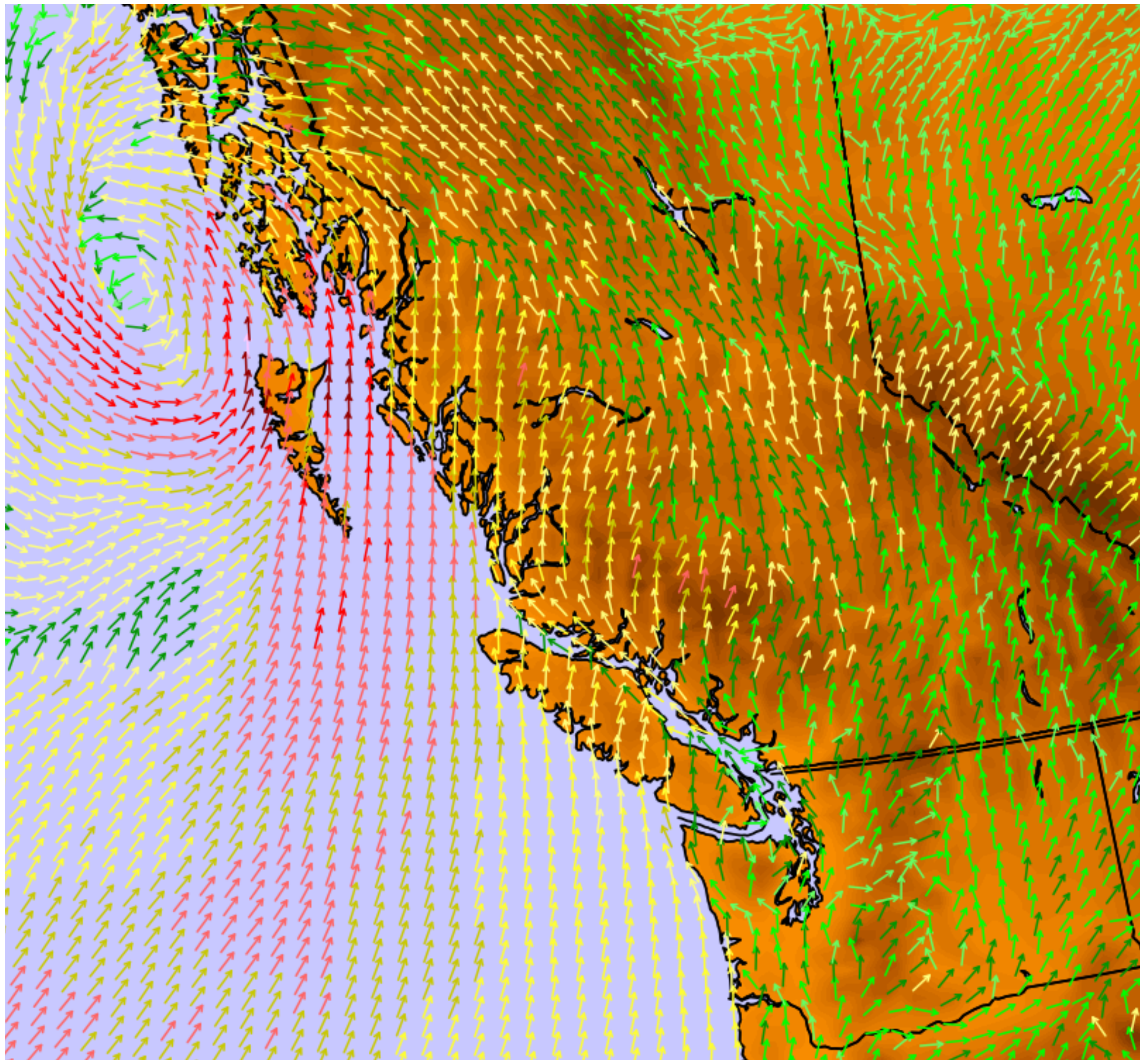


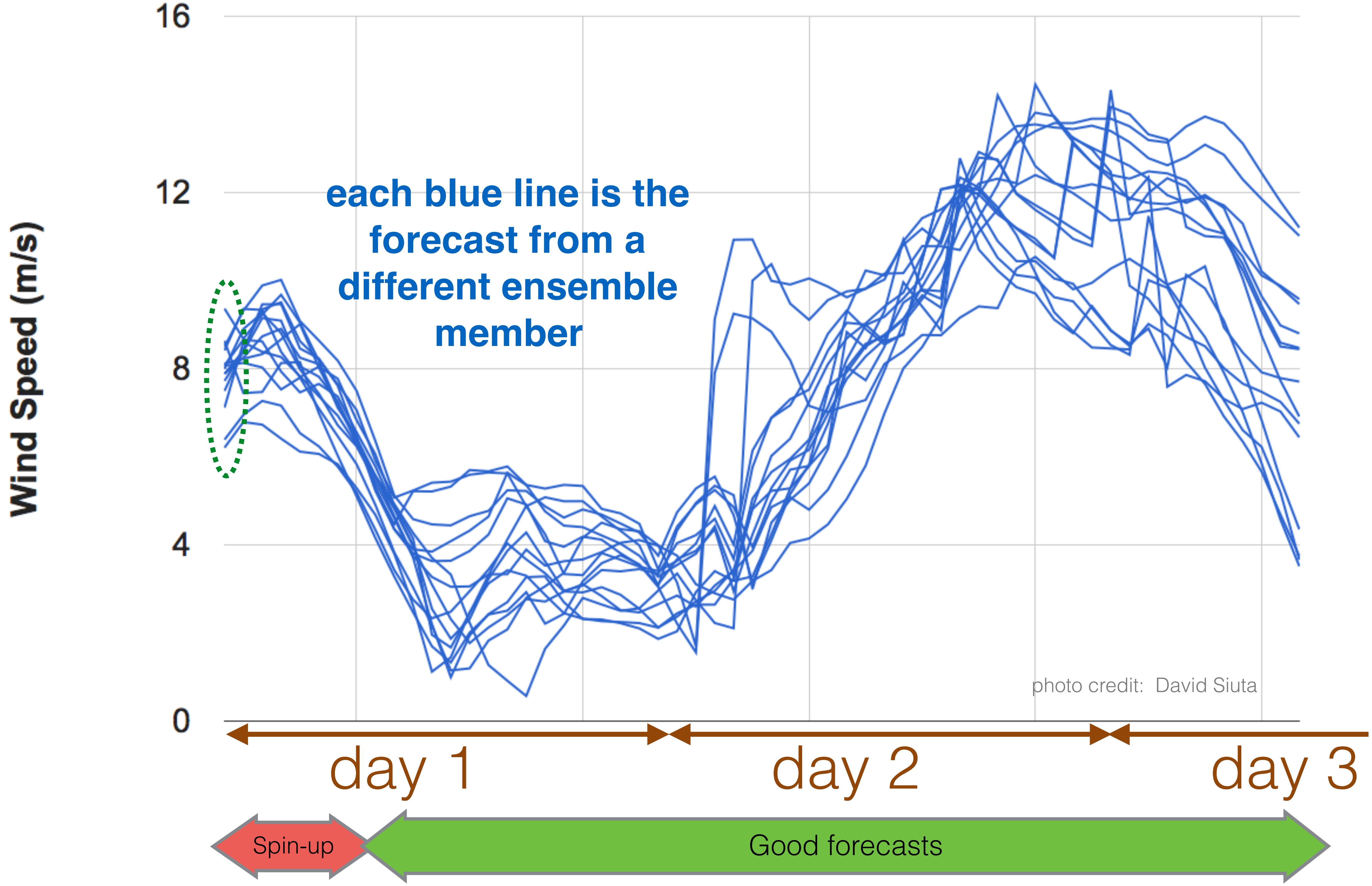
photo credit: Greg West

(UBC: 9 members with 7-day fcst horizon, remainder with 3.5 day horizon)

1. Ensemble Approach

Reduces random errors associated with chaotic atmosphere

Sample: ensemble of hub-height wind forecasts at one site



2. Post-Processing

Reduces systematic errors (biases) associated with local terrain

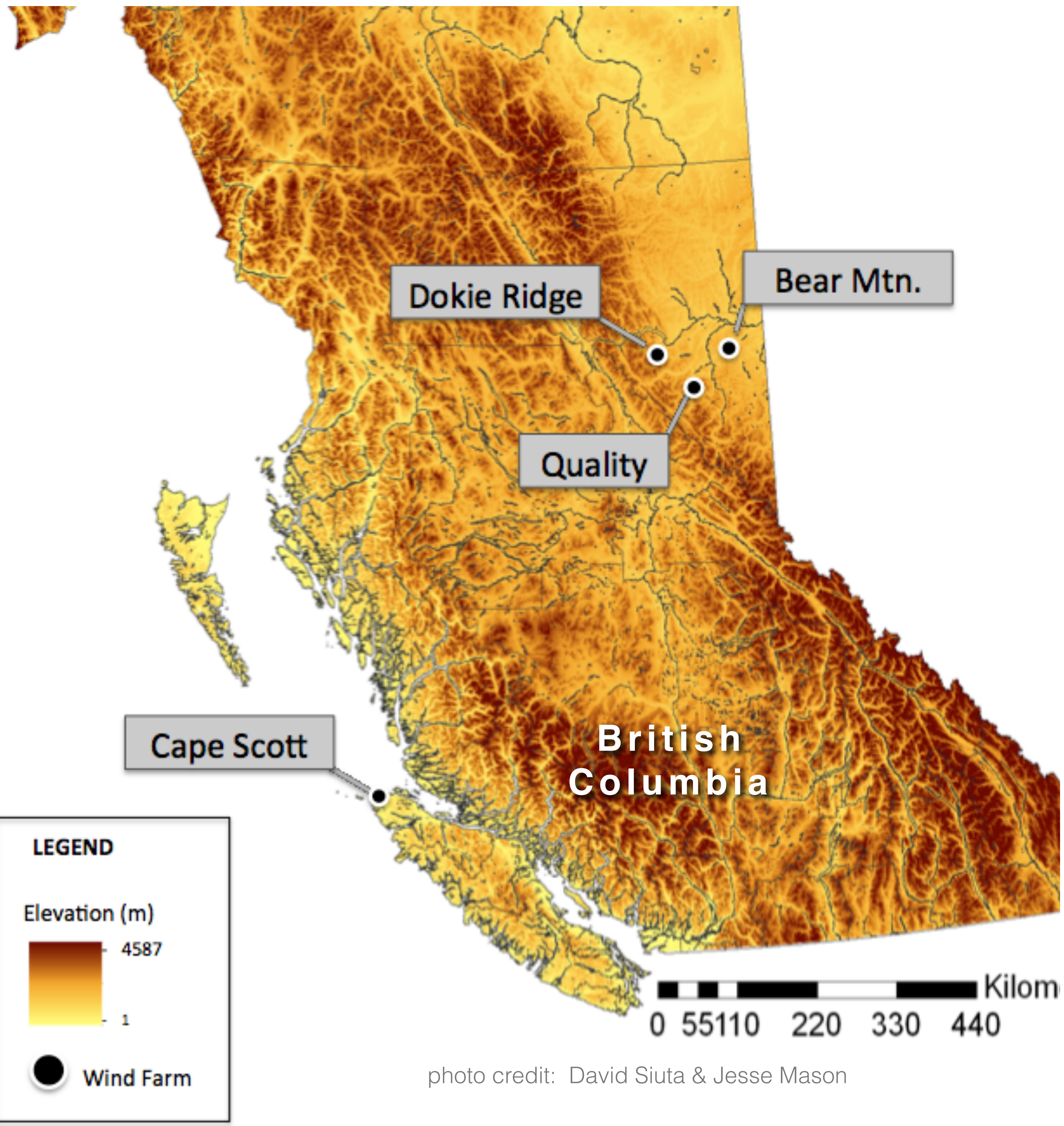


photo credit: David Siuta & Jesse Mason

Generic Methods:

- Use statistics of past errors to calculate biases.
- Apply these biases to correct future forecasts for each individual ensemble member BEFORE you use them in ensemble averages.

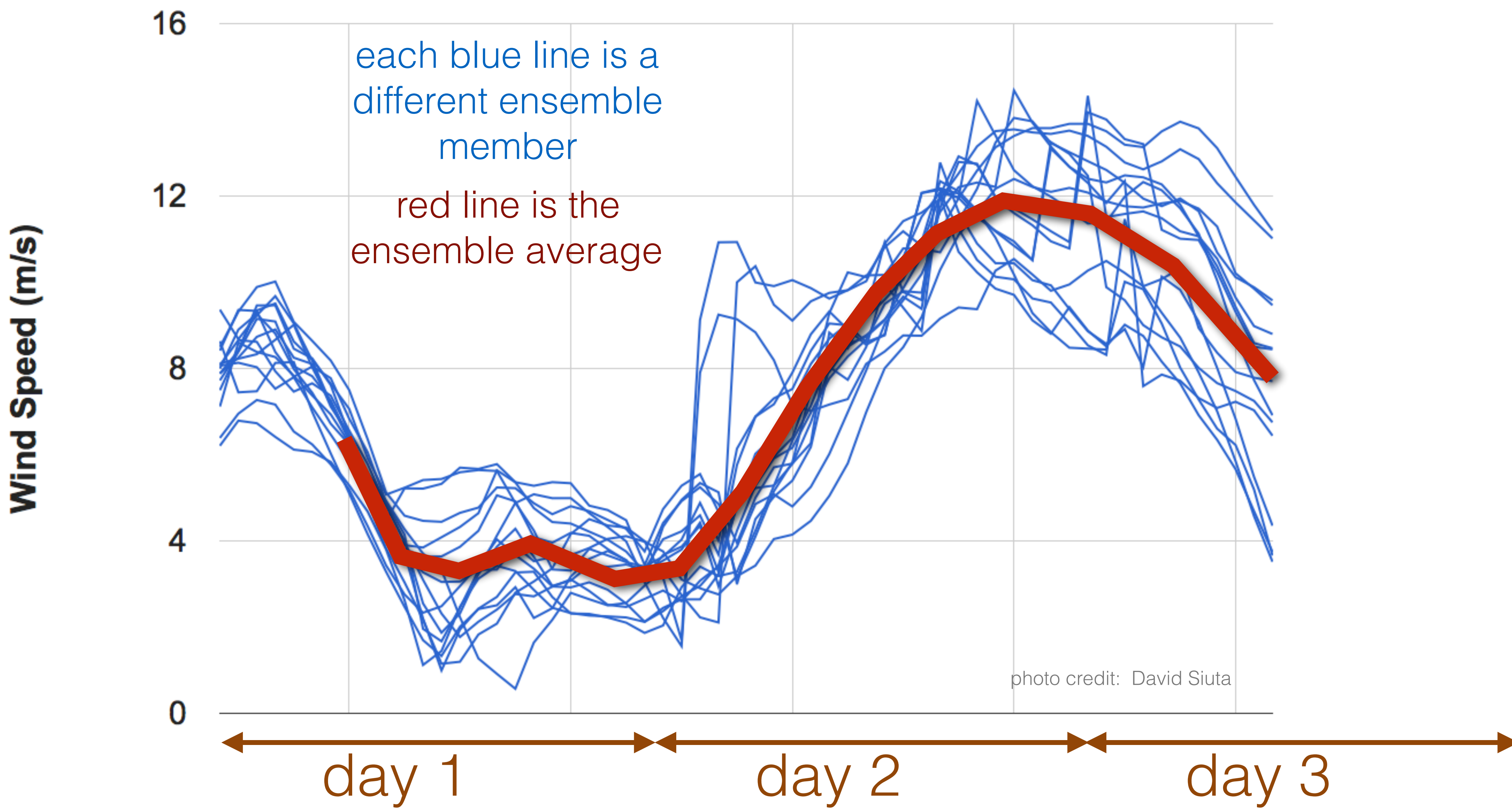
UBC Example:

- running averages
- linear regression
- Kalman filters
- artificial neural nets
- genetic programming
- Gaussian process modelling

3a. Ensemble Average or Median

Gives the best **deterministic** forecasts

Generic Methods:



3a. Ensemble Average or Median

Gives the best **deterministic** forecasts

UBC Example:

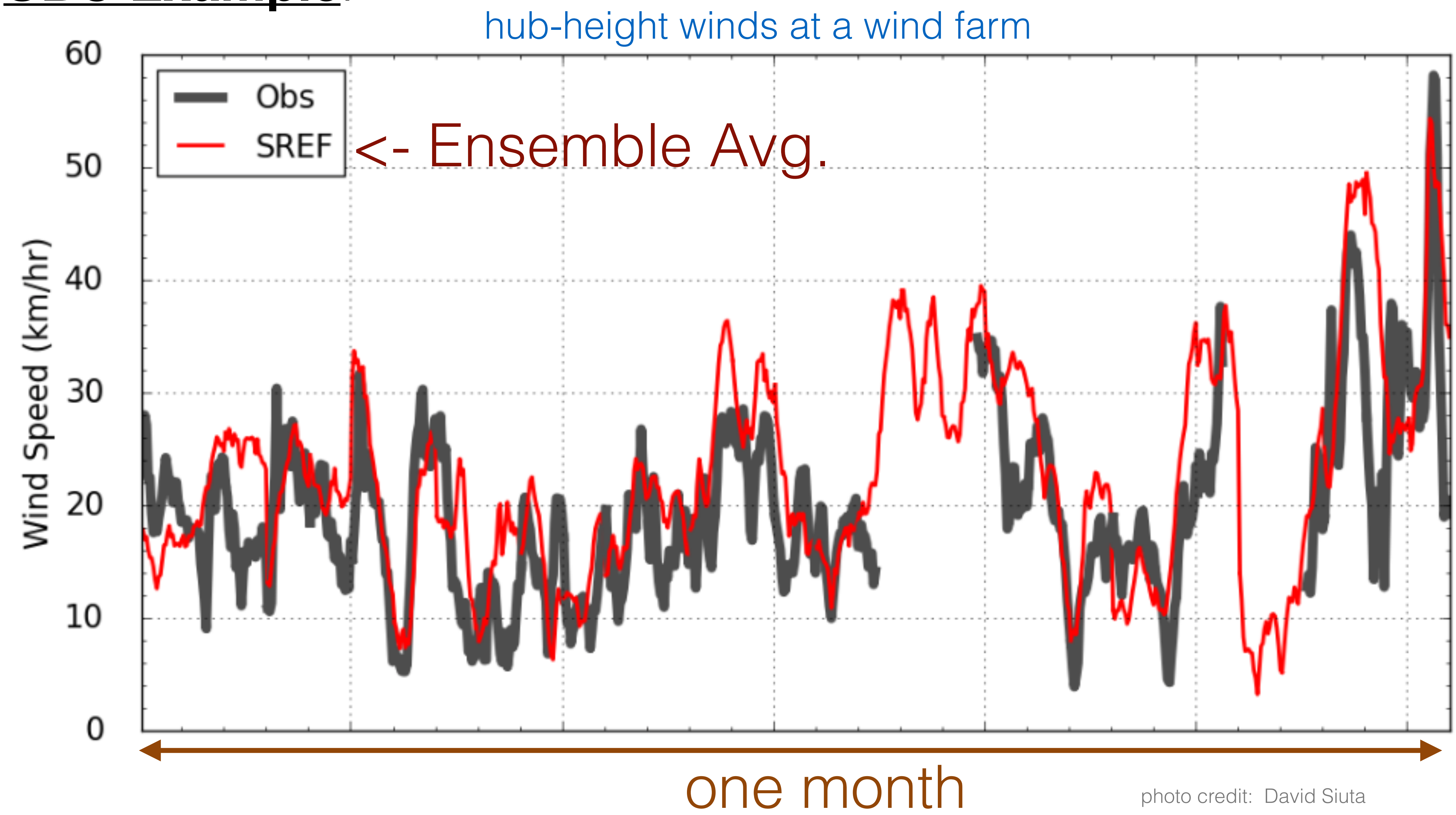


photo credit: David Siuta

4a. Verification

Measures skill & identifies potential problems

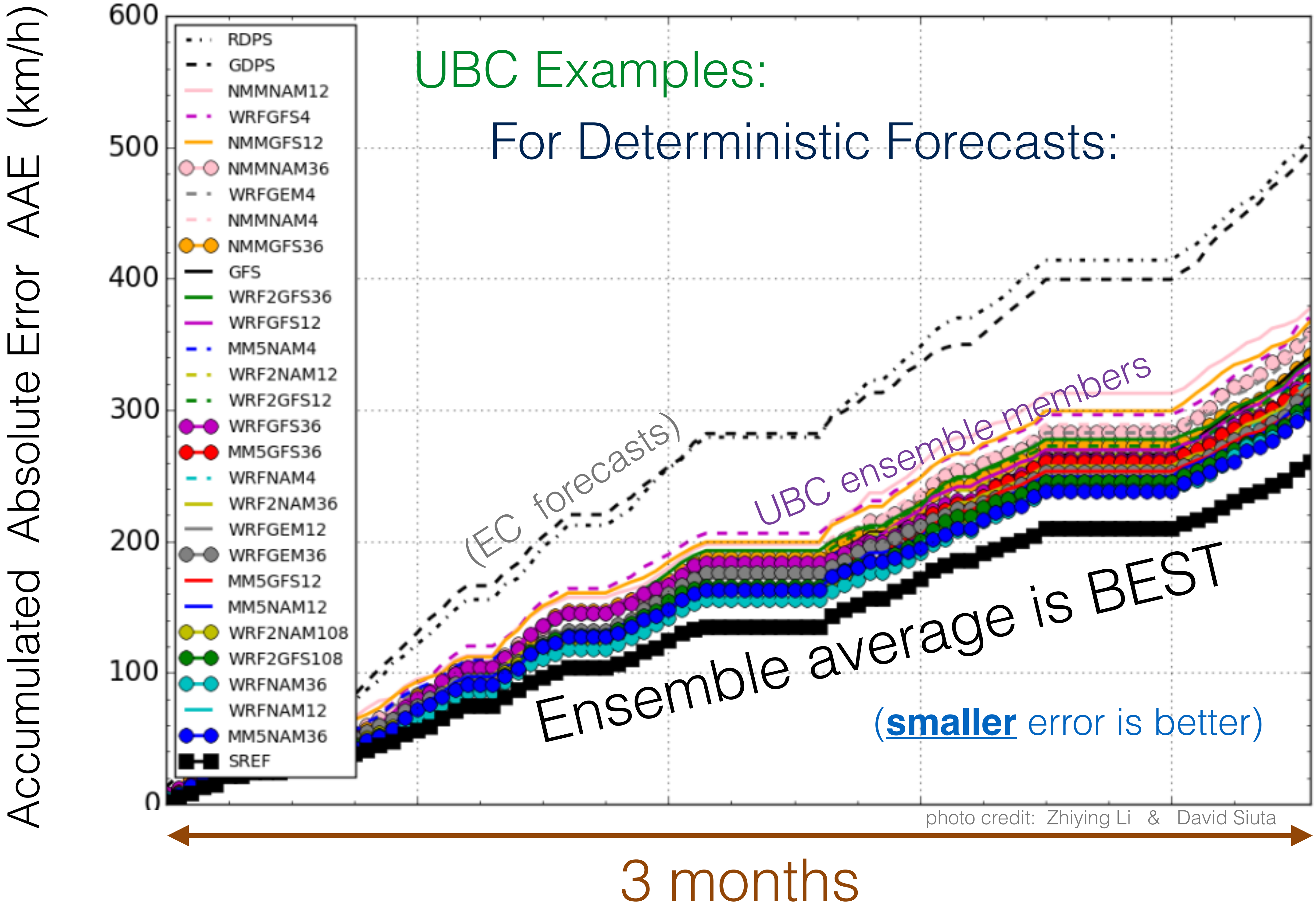
For Deterministic Forecasts:

- Mean absolute error (MAE)
- Root mean squared error (RMSE)
- Bias
- Correlation coefficient
- Accumulated absolute error (AAE)

photo credit: Mark Stull

4a. Verification

Measures skill & identifies potential problems

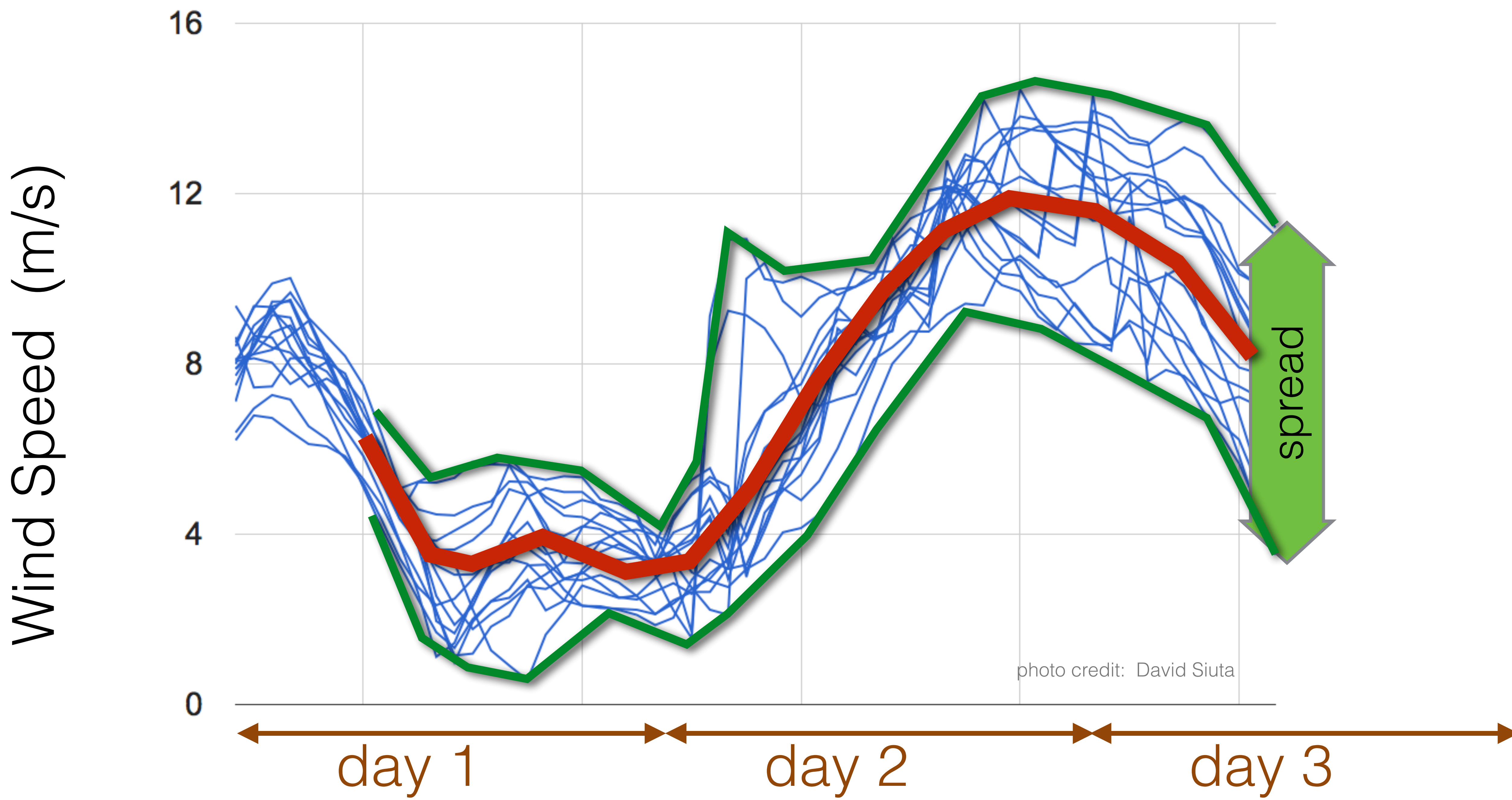


3b. Ensemble Spread

Gives one estimate of forecast uncertainty.

<u>Generic Methods</u>:

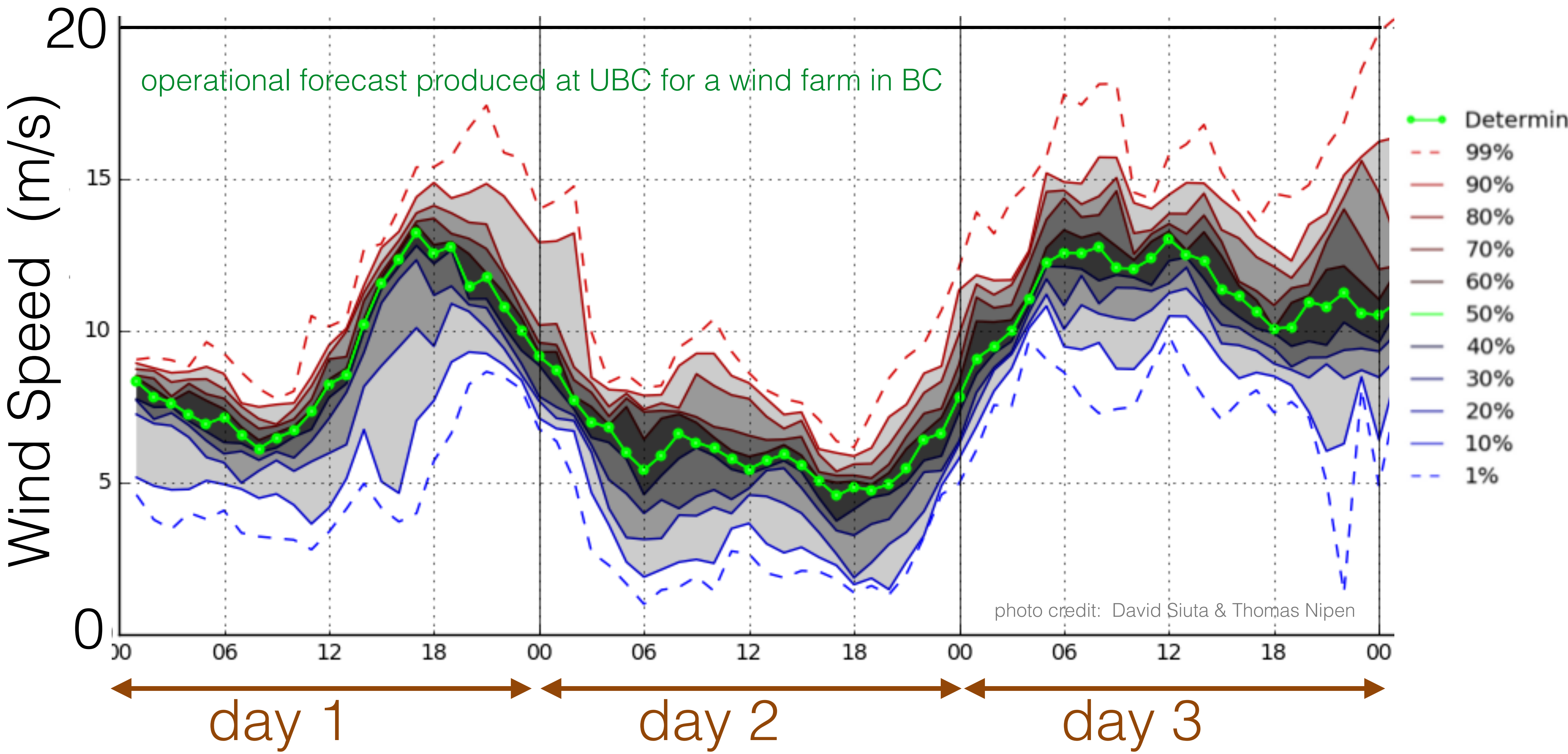
(But <u>un</u>calibrated spread has little value.)



3c. Ensemble Probabilities

<u>Next, sort into bins to get raw probabilities</u>:

(But <u>un</u>calibrated probabilities have little value.)

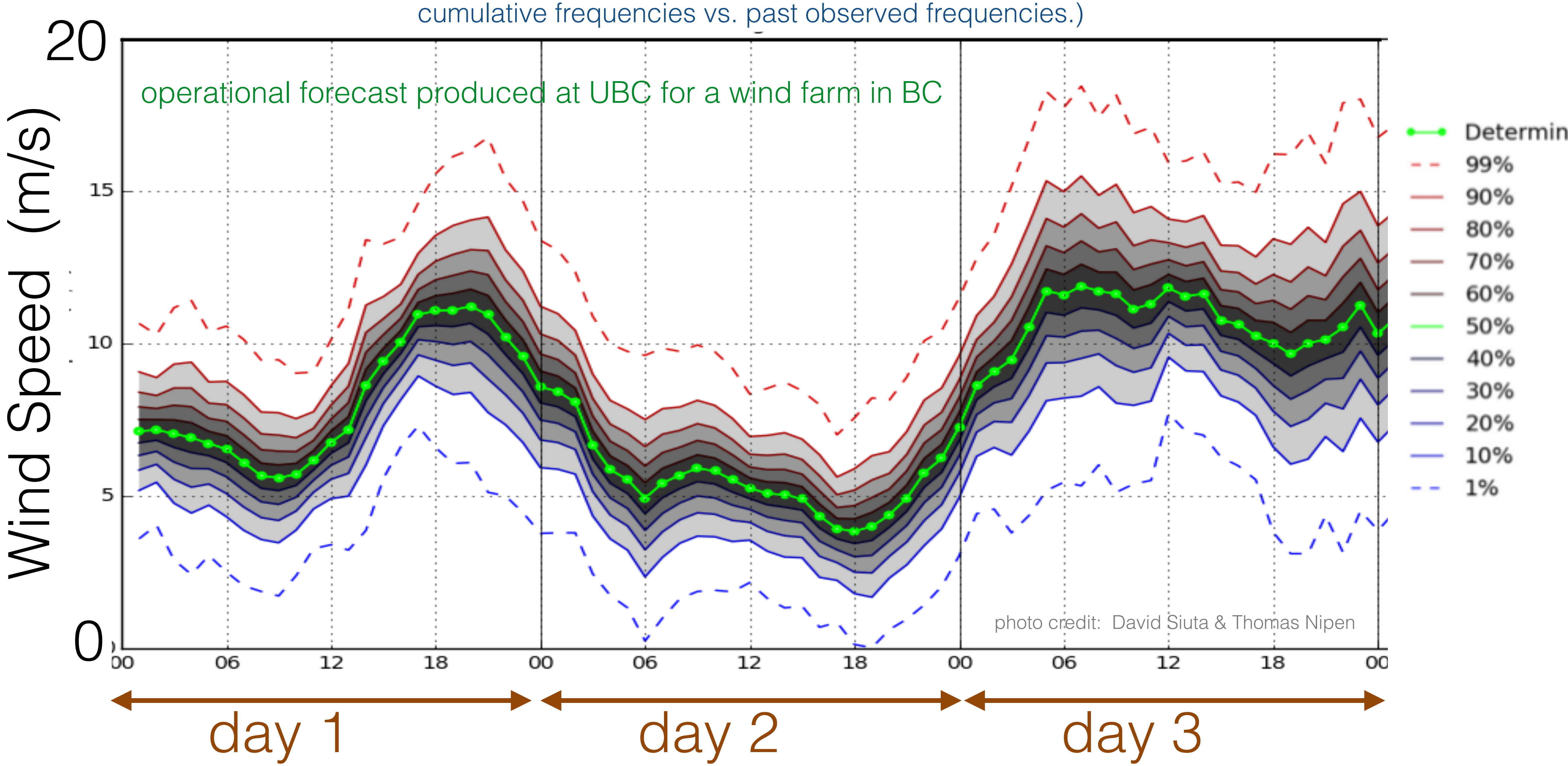


3c. Ensemble Probabilities

<u>Finally, calibrate the probabilities</u>:

Calibration means the predicted probability matches the observed frequency.

(Calibrated using the Nipen method: based on a mapping of past forecast cumulative frequencies vs. past observed frequencies.)



3d. Economic Value of Wind Probability Forecasts

- Predicting wind threshold exceedance (to avoid equip. failure) by wind-farm operators.
- Valuable for utility companies to anticipate reasonable bounds on incoming power.
- Etc.

Simplified cost / loss **example** for blade-replacement maintenance decision:

<u>Issue</u>: Should you schedule the blade replacement for 18 local time today when 4 m/s winds are predicted deterministically?
Next slow winds in 2 days.

Assumptions: 2 MW turbine costs \$4M installed. Blades = 18%. Crane rental = \$80,000/day. If selling at 5c/kWh, then downtime cost = \$2,400/day. Max wind speed for crane safety ~ 5 m/s.

http://www.windustry.org/community_wind_toolbox_8_costs

photo credit: Mark Stull

Simplified cost / loss **example** for blade-replacement maintenance decision:

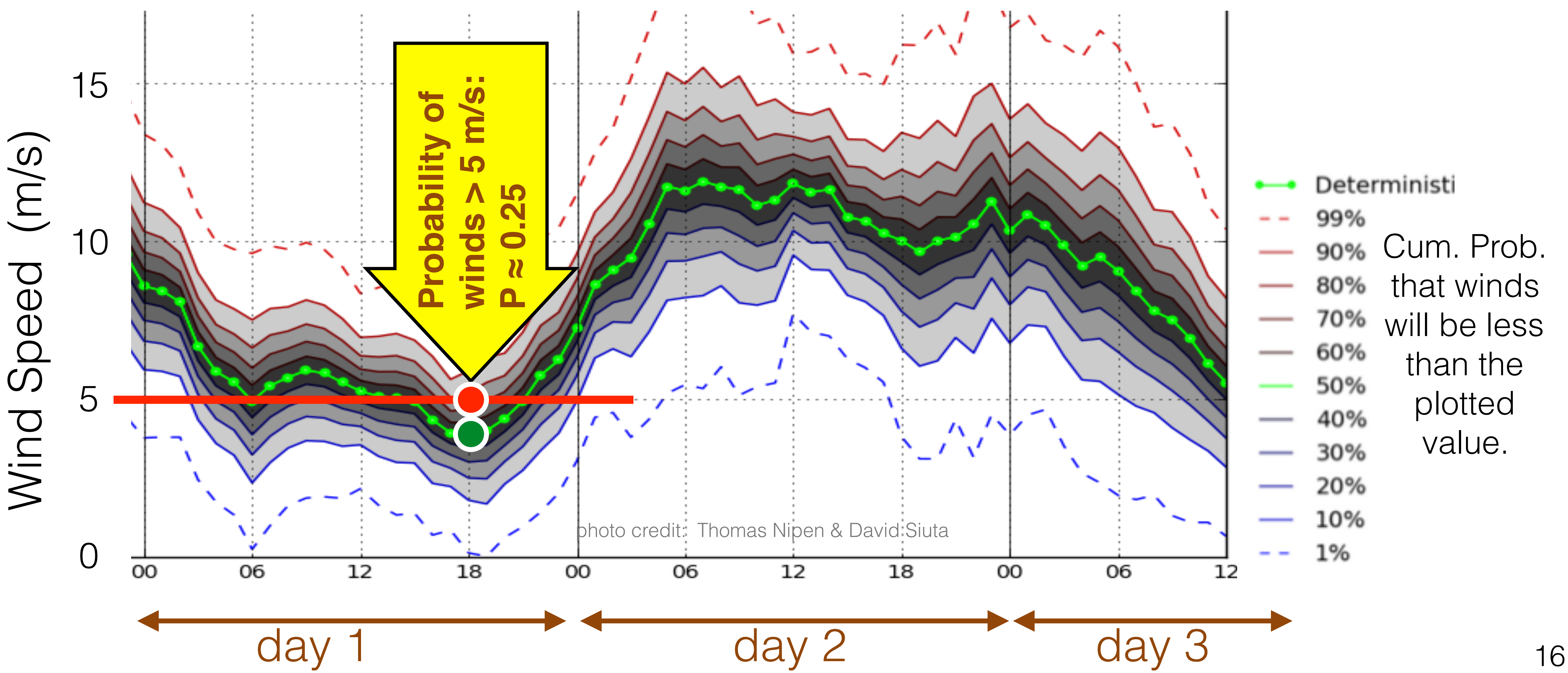
Solution:

Cost to protect the blades (postpone the replacement) ≈ $165k.

Loss if blades damaged during attempt ≈ $970k.

Cost/Loss ratio R ≈ 0.17

P > R, Therefore do not replace today.



4b. Verification

Measures skill & identifies potential problems

For Probabilistic Forecasts:

- Mean of continuous ranked probability score (CRPS)
- Reliability diagram
- Relative operating characteristic (ROC) diagram of hit rate vs. false-alarm rate
- Probability integral transform (PIT) histogram (Talagrand diagram)
- Taylor diagram

photo credit: Mark Stull

4b. Verification

UBC Examples: For Probabilistic Forecasts:

Reliability Diagram

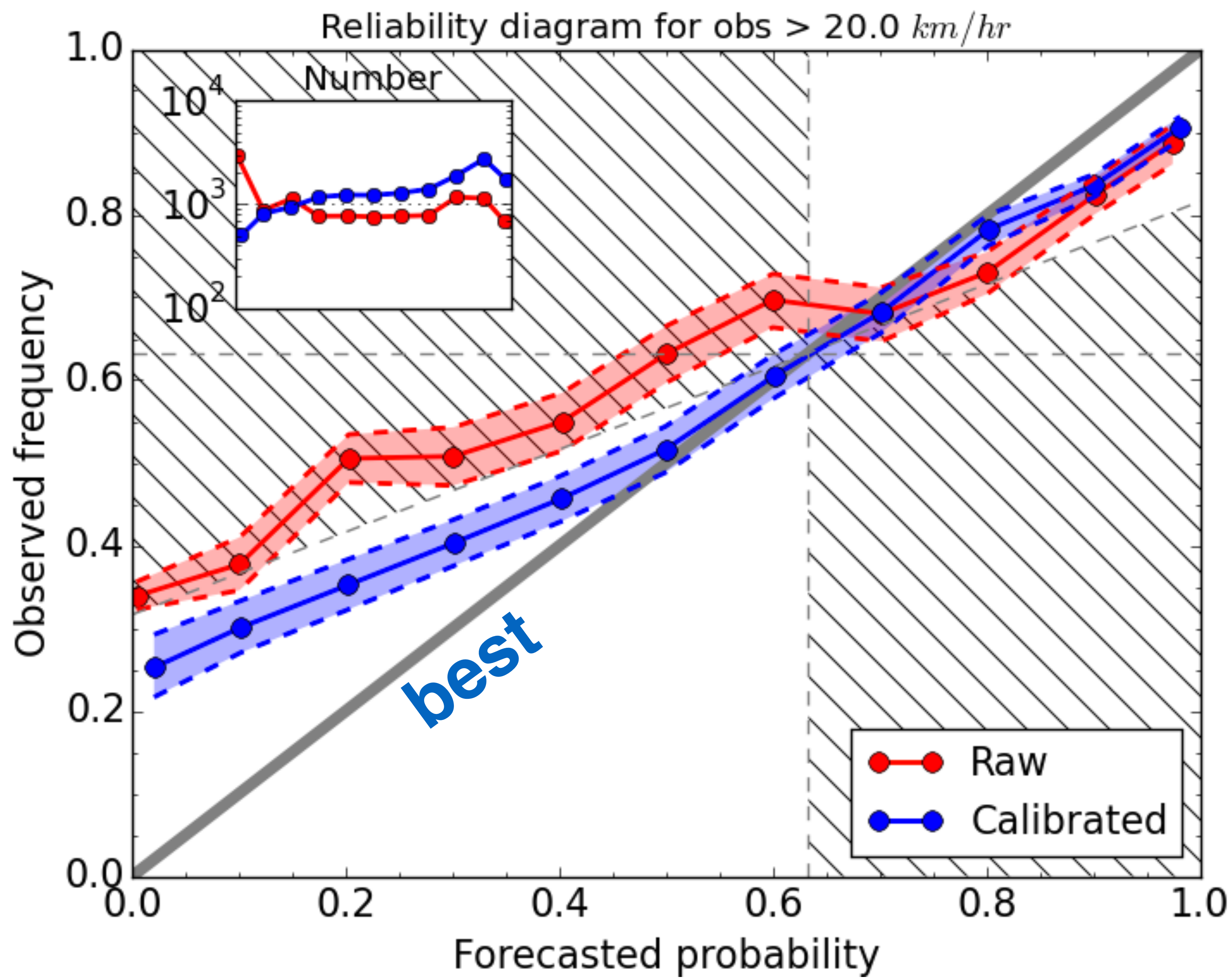
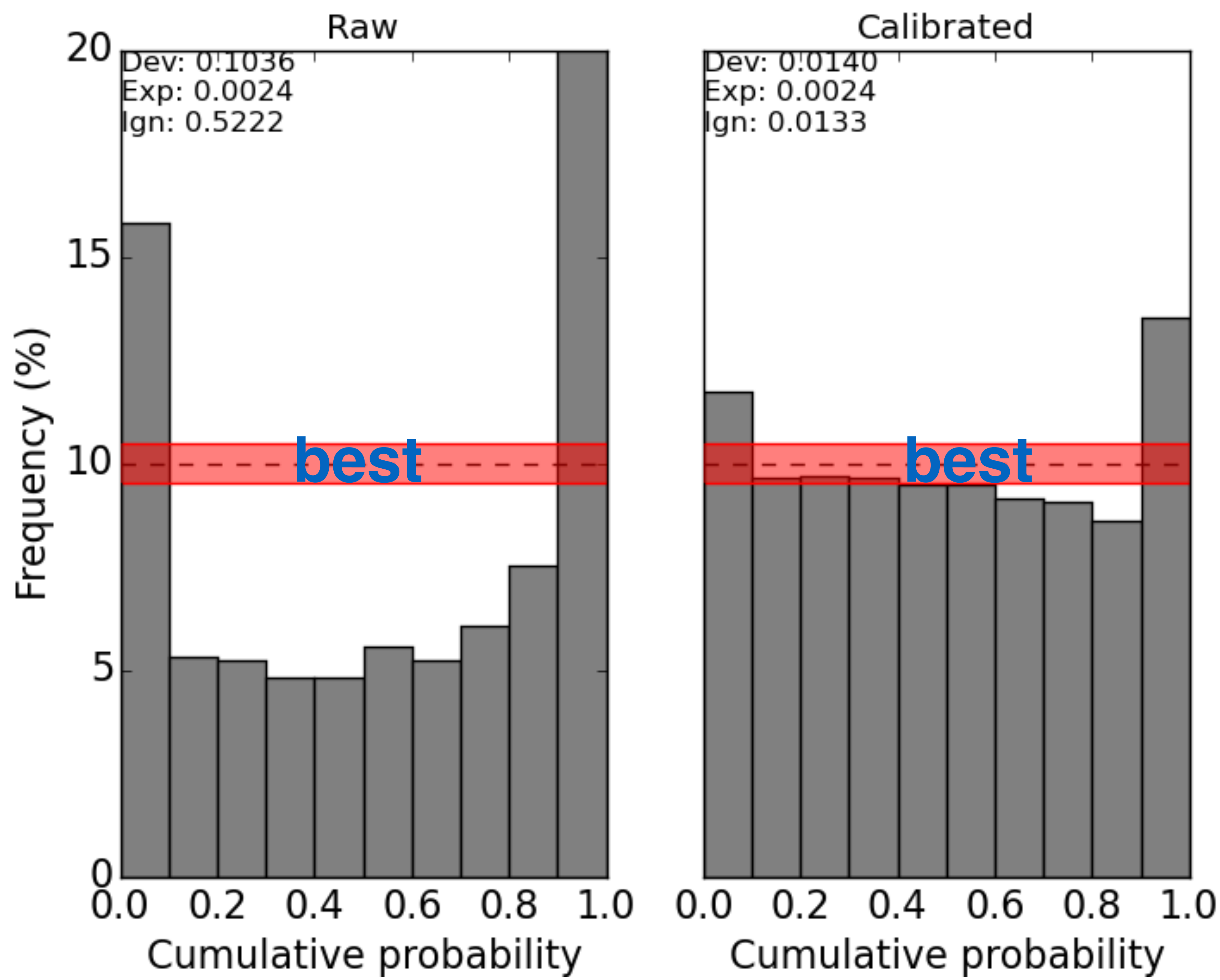


photo credit: David Siuta & Thomas Nipen

4b. Verification

UBC Examples: For Probabilistic Forecasts:

PIT



Ranked Ensemble Members

photo credit: David Siuta & Thomas Nipen

4b. Verification

UBC Examples: For Probabilistic Forecasts:

Taylor Diagram

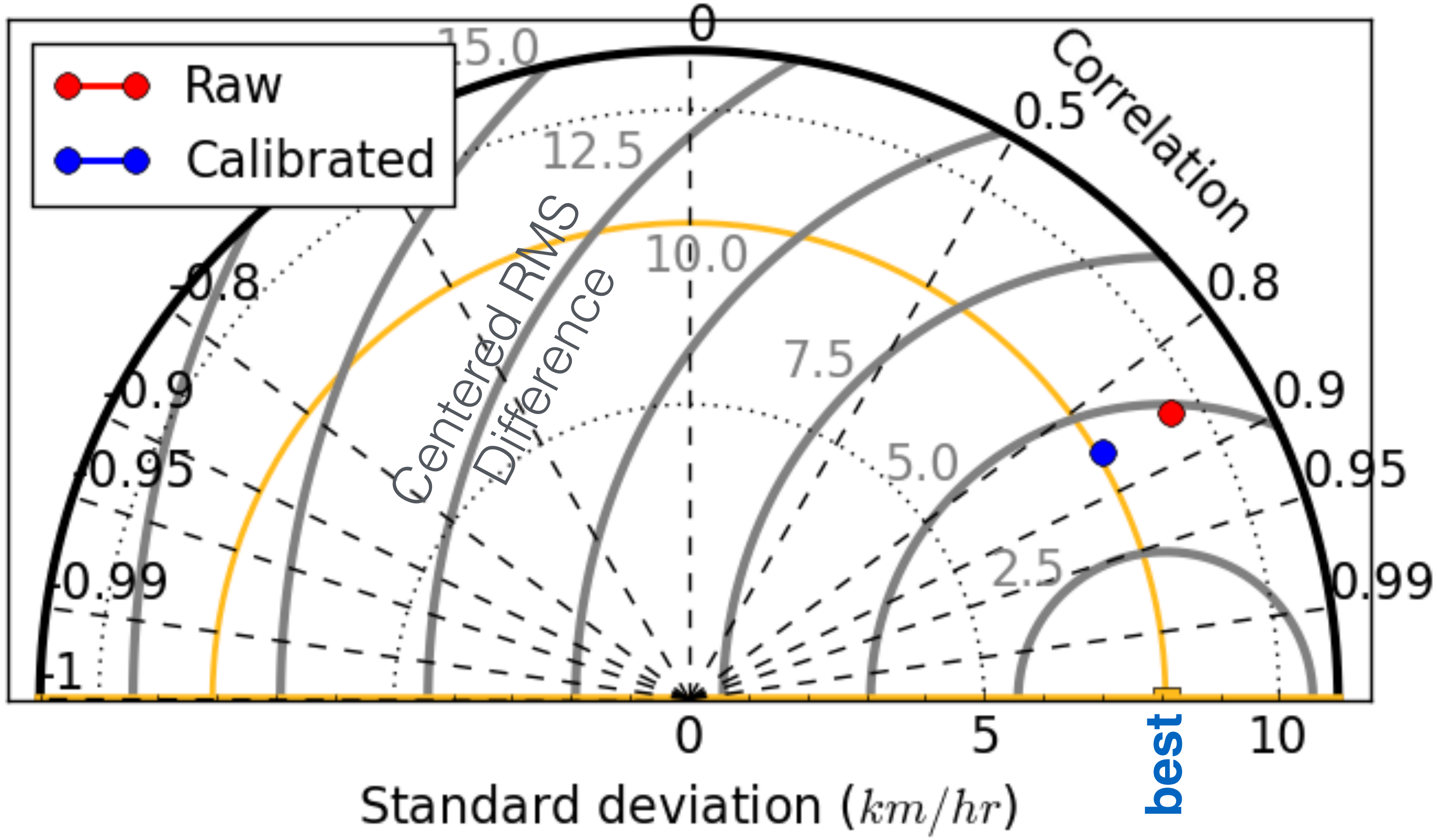


photo credit: David Siuta & Thomas Nipen

5. Convert to Wind Power

Includes variations across each wind farm

Generic Methods:

Idealized power curve for one turbine

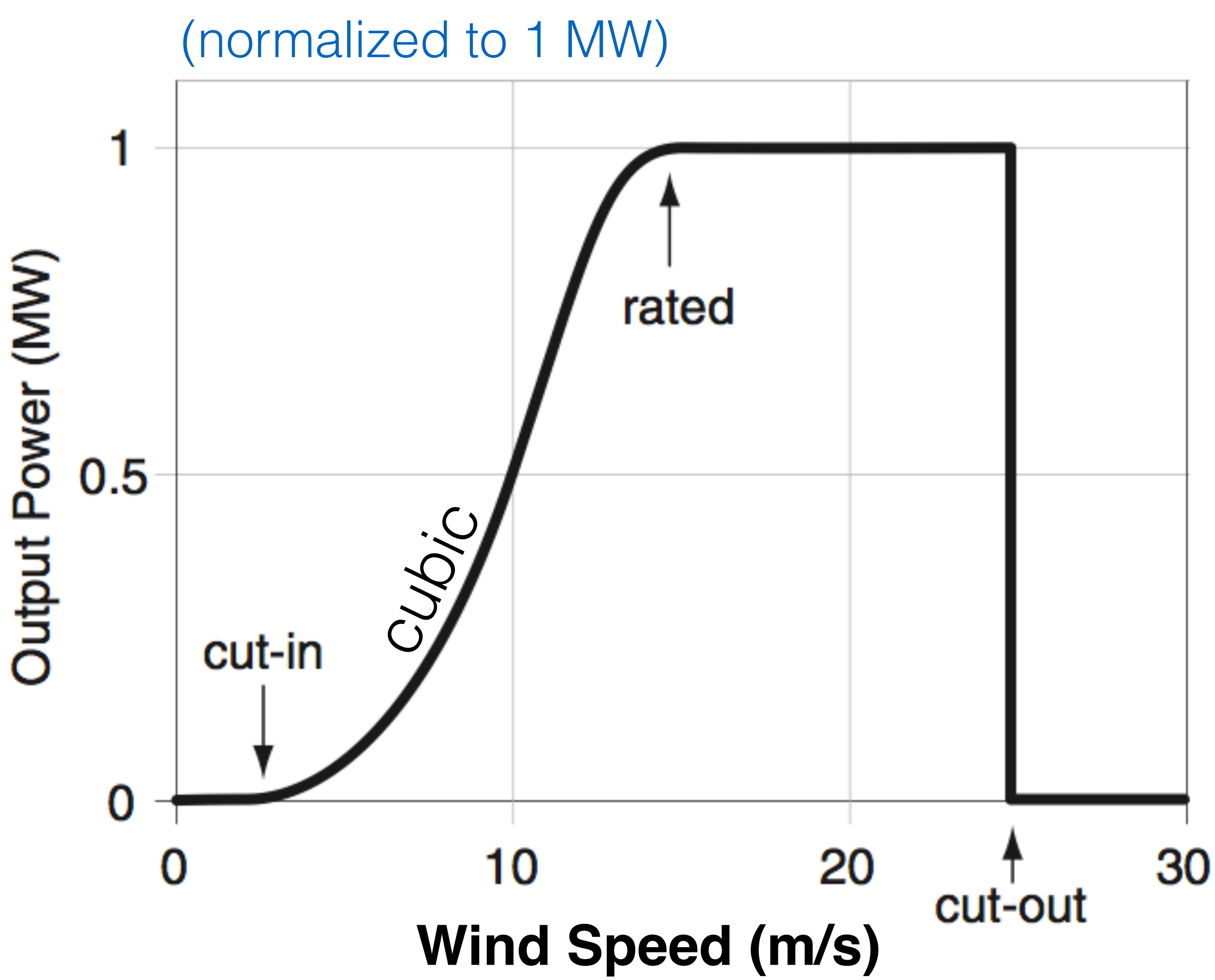


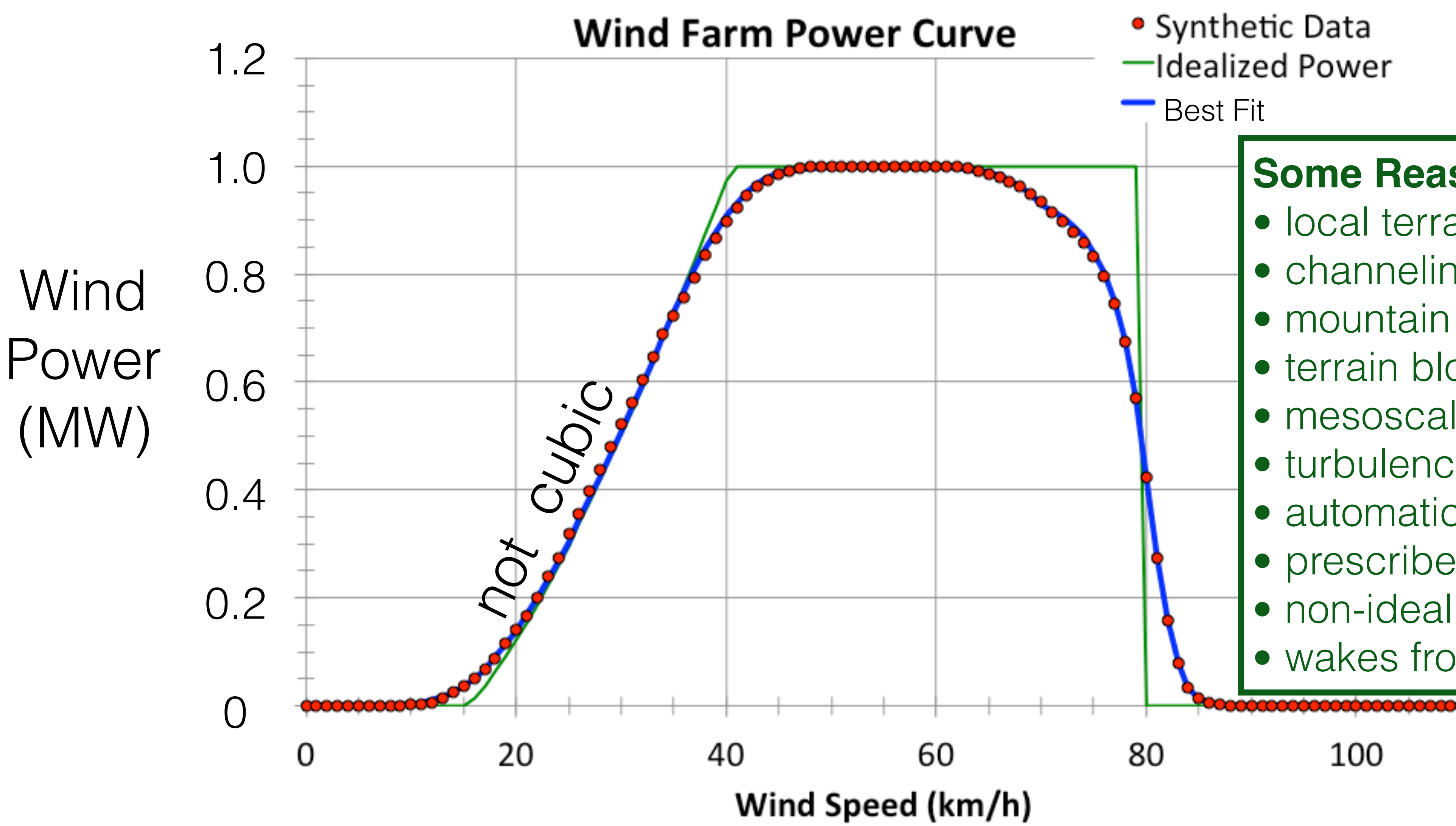
photo credit: Roland Stull

5. Convert to Wind Power

Includes variations across each wind farm

UBC Examples:

Average power curve for whole wind farm
(normalized to 1 MW)

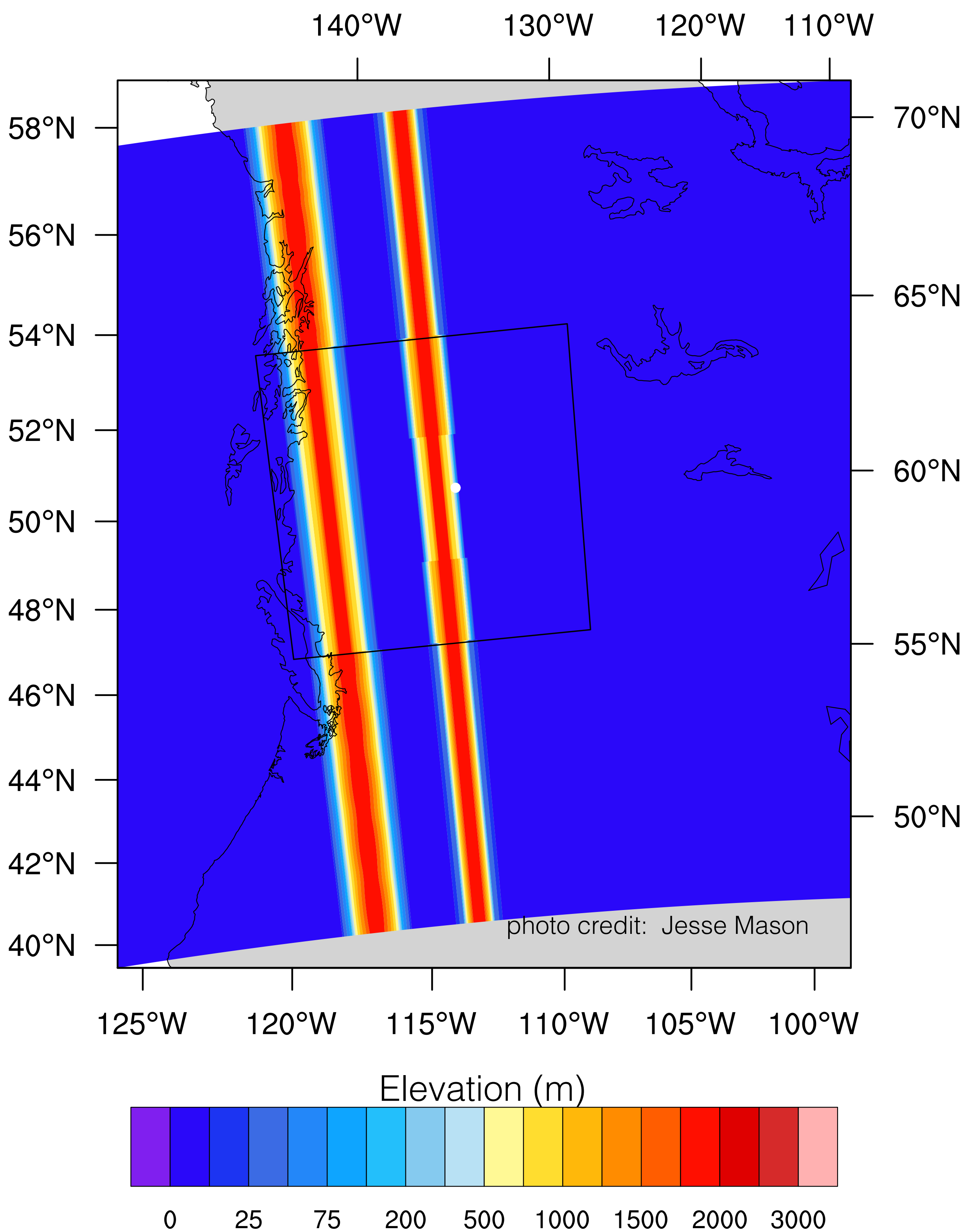


Some Reasons:
- local terrain variations
- channeling
- mountain waves
- terrain blocking
- mesoscale gradients
- turbulence
- automatic cutout algorithms
- prescribed maintenance
- non-ideal turbines
- wakes from upwind turbines

photo credit: Roland Stull

6. Case Studies

Enables discovery of alternative / better forecast methods



Numerical Simulations of Idealized Terrain

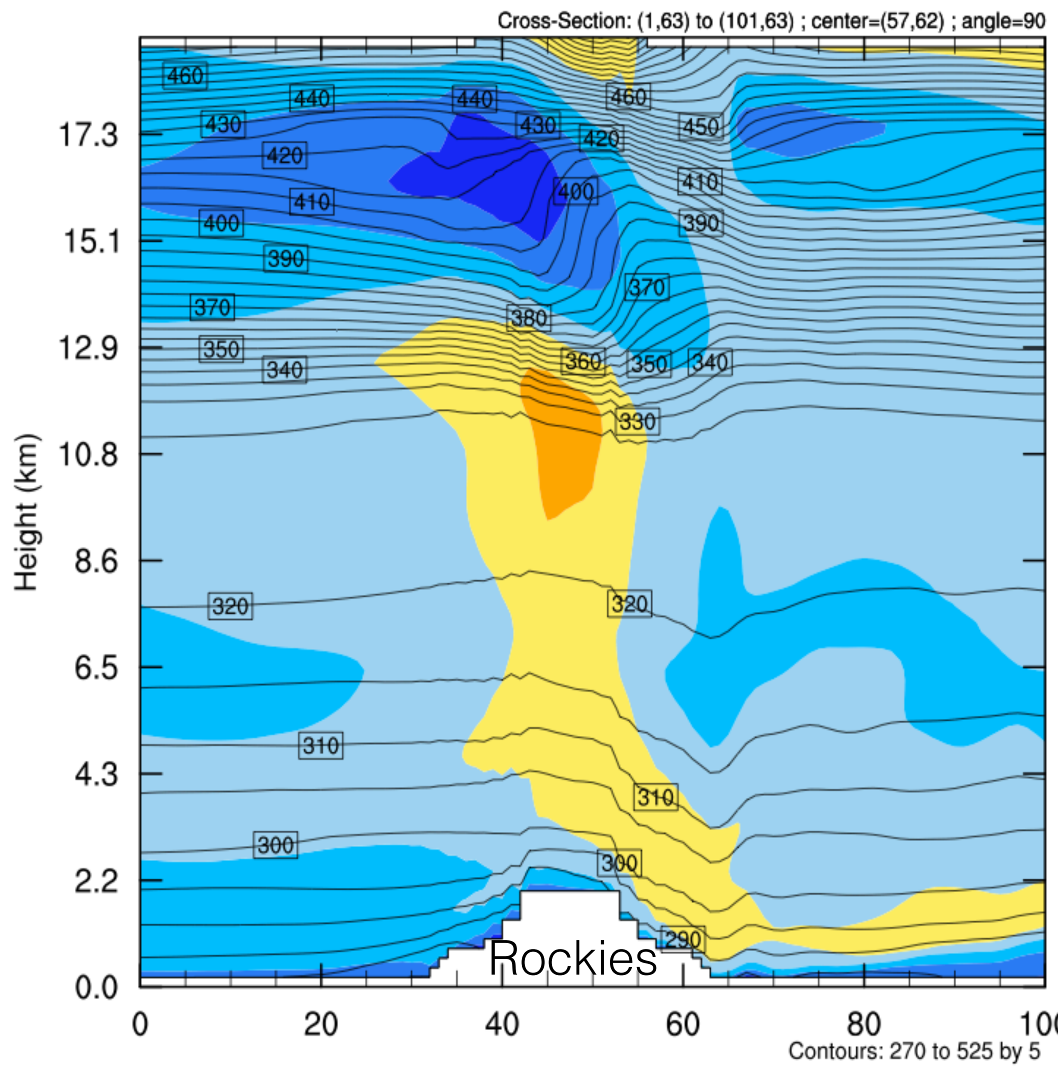
for a wind-ramp event**:**

- Rocky Mtns (add / remove)
- Coastal Range (add / remove)

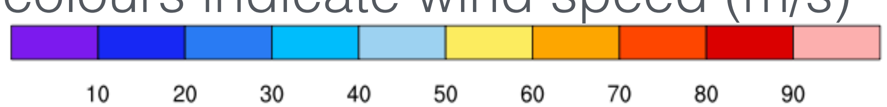
6. Case Studies

Enables discovery of alternative / better forecast methods

Idealized Rockies Only



colours indicate wind speed (m/s)



Both Idealized Ranges

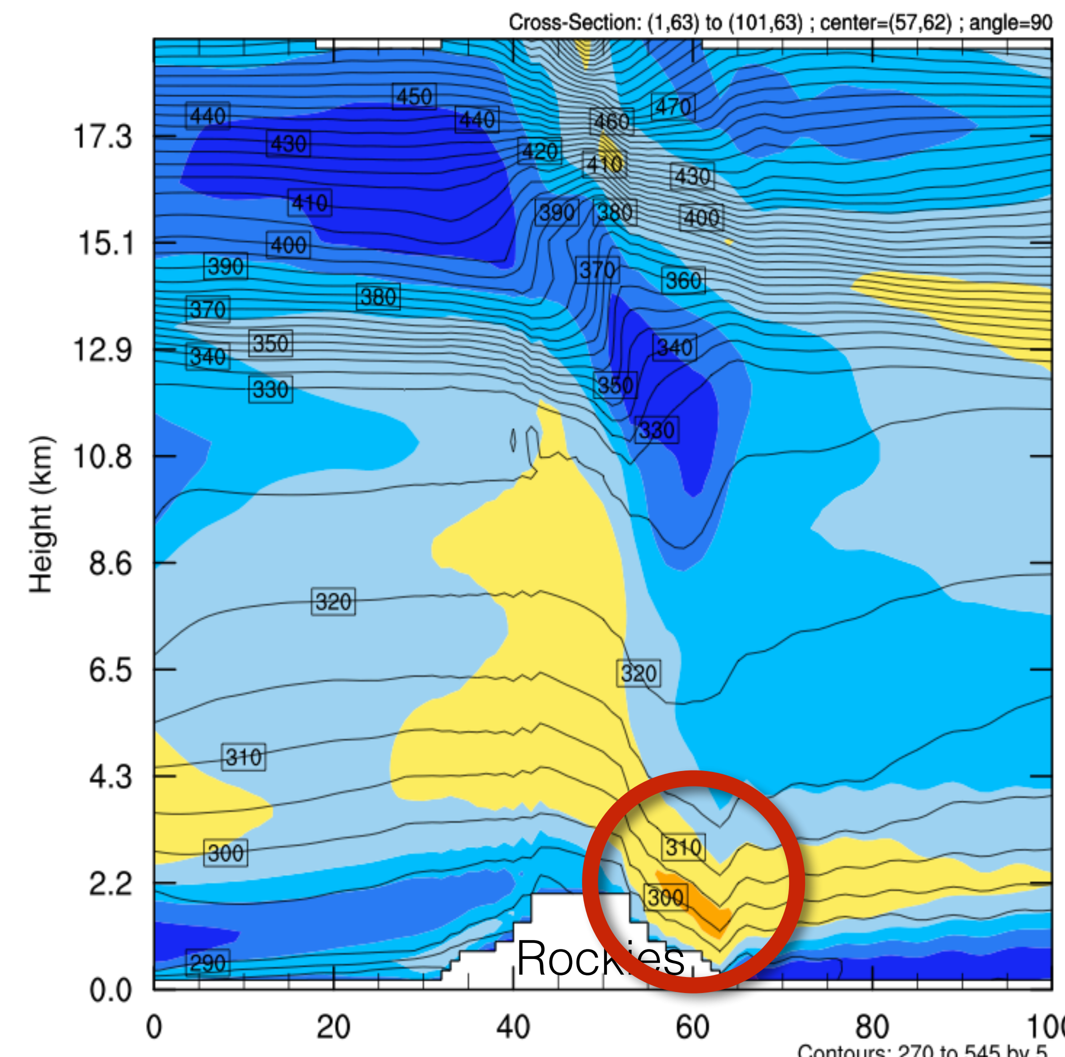
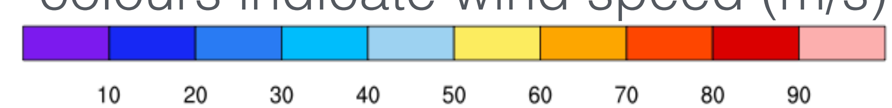


photo credit: Jesse Mason

Is more accurate for this wind-ramp event

colours indicate wind speed (m/s)

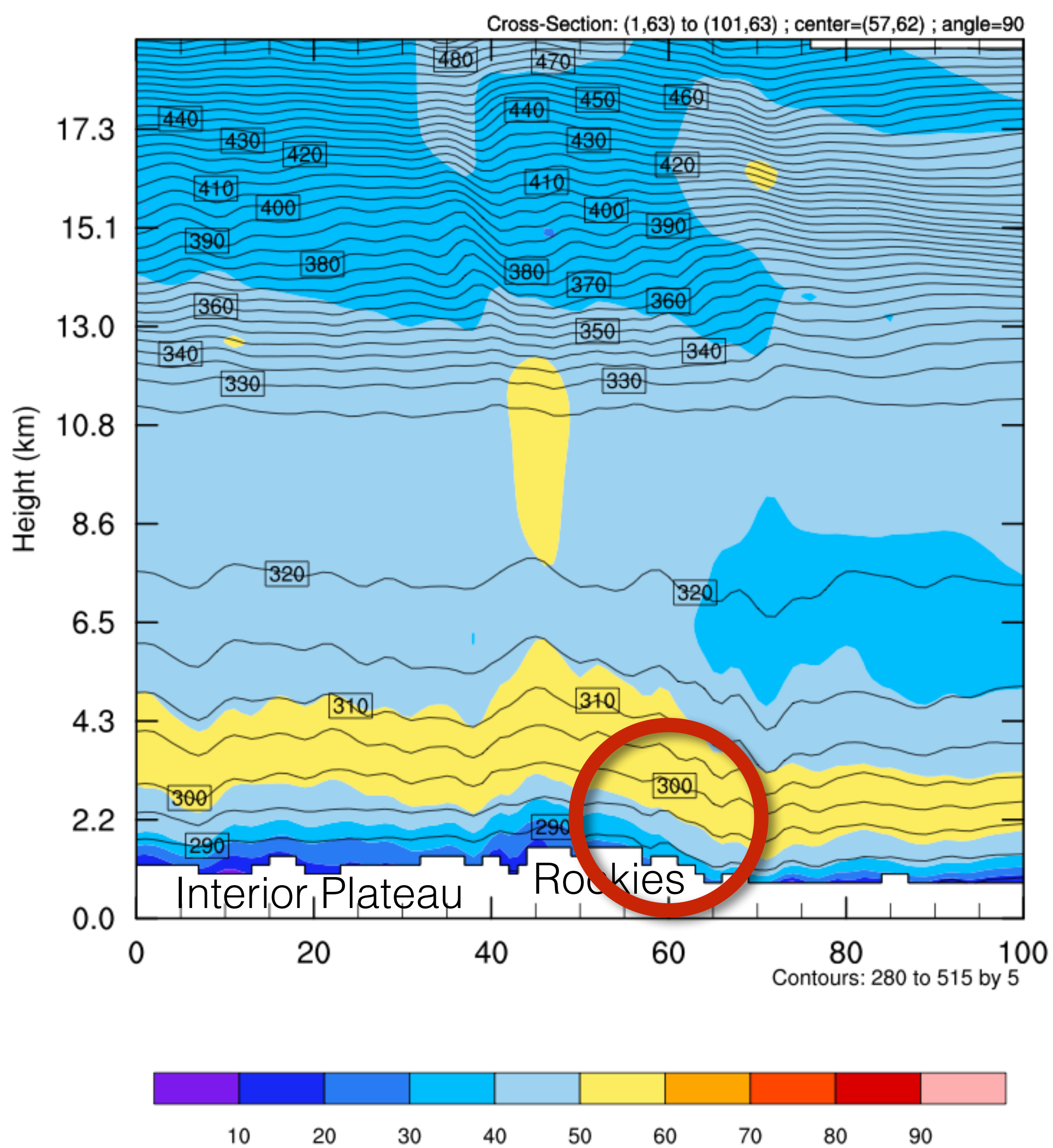


Inference: need sufficiently <u>large</u> NWP forecast domain to capture upwind effects.

6. Case Studies

Enables discovery of alternative / better forecast methods

Actual terrain (for 4 km WRF run)



Inference: need moderately fine resolution NWP forecast domain to capture interference between mountains and hills of many scales.

Thus: need both moderately fine resolution and large forecast domain if you want a good forecast.

photo credit: Jesse Mason

7. Recommendations

1. Use ensemble forecasts from multi-model Numerical Weather Prediction (NWP) runs.

    a. Bias correct each individual ensemble member first.

    b. Then calculate the ensemble average (or weighted ensemble average) to get the best deterministic forecast.

    c. Create probability forecasts from the ensemble, and calibrate them to get more reliable probability values.

    d. Use the probability forecasts to make economically optimal decisions.

photo credit: Roland Stull

7. Recommendations

To enable more-accurate wind-power forecasts

2. The more info wind operators give to weather forecasters, the more accurate will be the forecasts.

Give forecast providers real-time hourly observations of:

a) Wind and power from each turbine or feeder

b) Temperature profile in the bottom 10 to 20 m (to estimate atmos. static stability)

c) Solar radiation from inexpensive sunshine sensor (for static stability)

d) Outage / shut-down flag at same detail as for 1a.

photo credit: Roland Stull

7. Recommendations

To enable more-accurate wind-power forecasts

3. Deploy a denser network of permanent atmos.-sounding stations to routinely measure wind, temperature & humidity vertical profiles in whole troposphere.
(to aid forecasting of mountain waves, downslope windstorms, low-level jets, and wind-ramp events)

   a) New rawindsonde launch sites on land & in the near-Pacific

   b) CEATI might have the political clout to motivate the Canadian Gov't

   c) Other sensors: satellites, lidar, drones, tethersondes, etc.

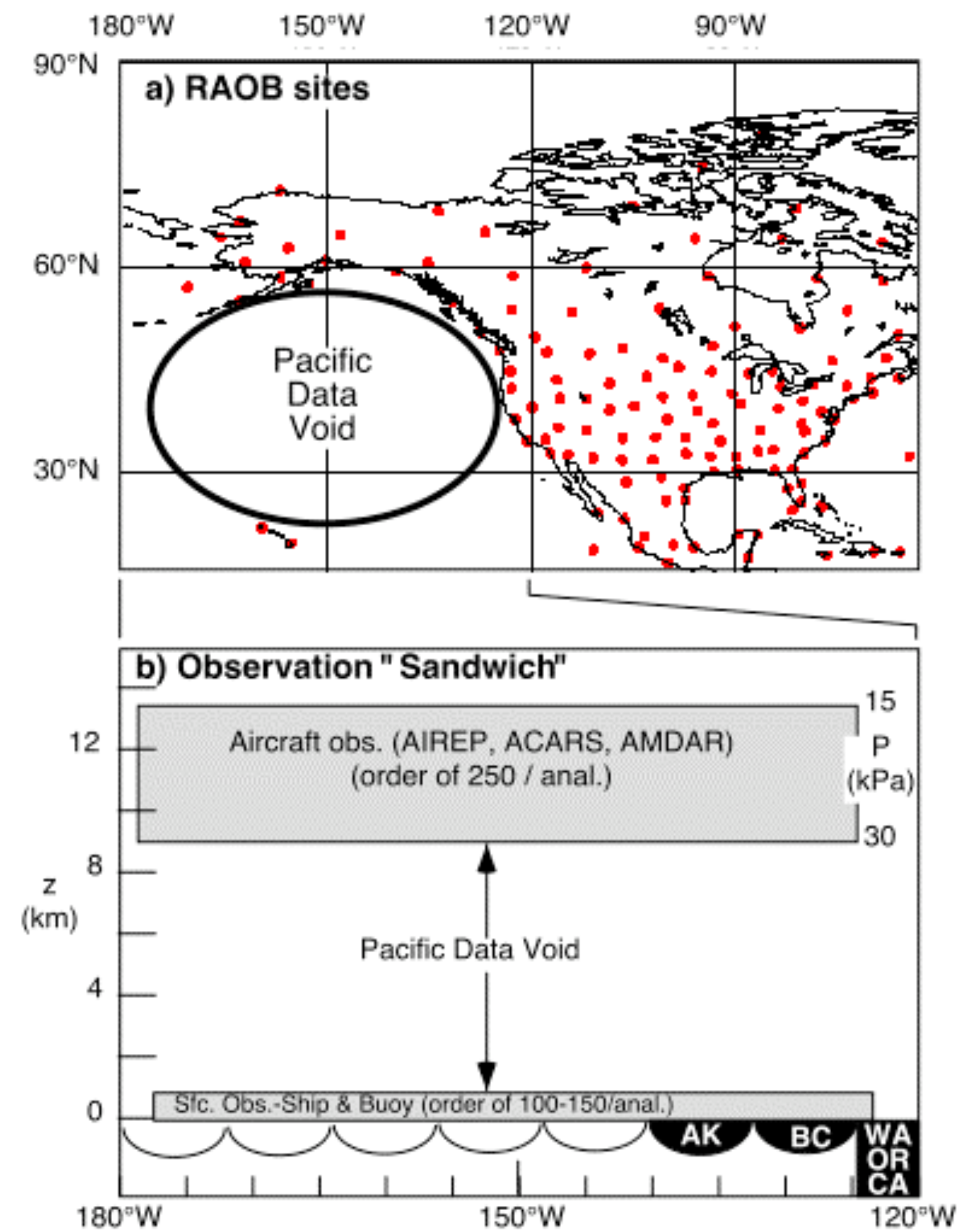


photo credit: Roland Stull

7. Recommendations

To enable more-accurate wind-power forecasts

4. For the NWP model runs:

   a) Each model domain must extend far enough upwind to capture terrain and land-use influences.
   (100 km upstream helps short-range forecasts. Greater distances are needed for medium-range forecasts.)

   b) More NWP ensemble members generally give better forecasts.

   c) Ultra-fine resolution forecasts (less than about 9 km horizontal grid spacing) are not necessarily more accurate.

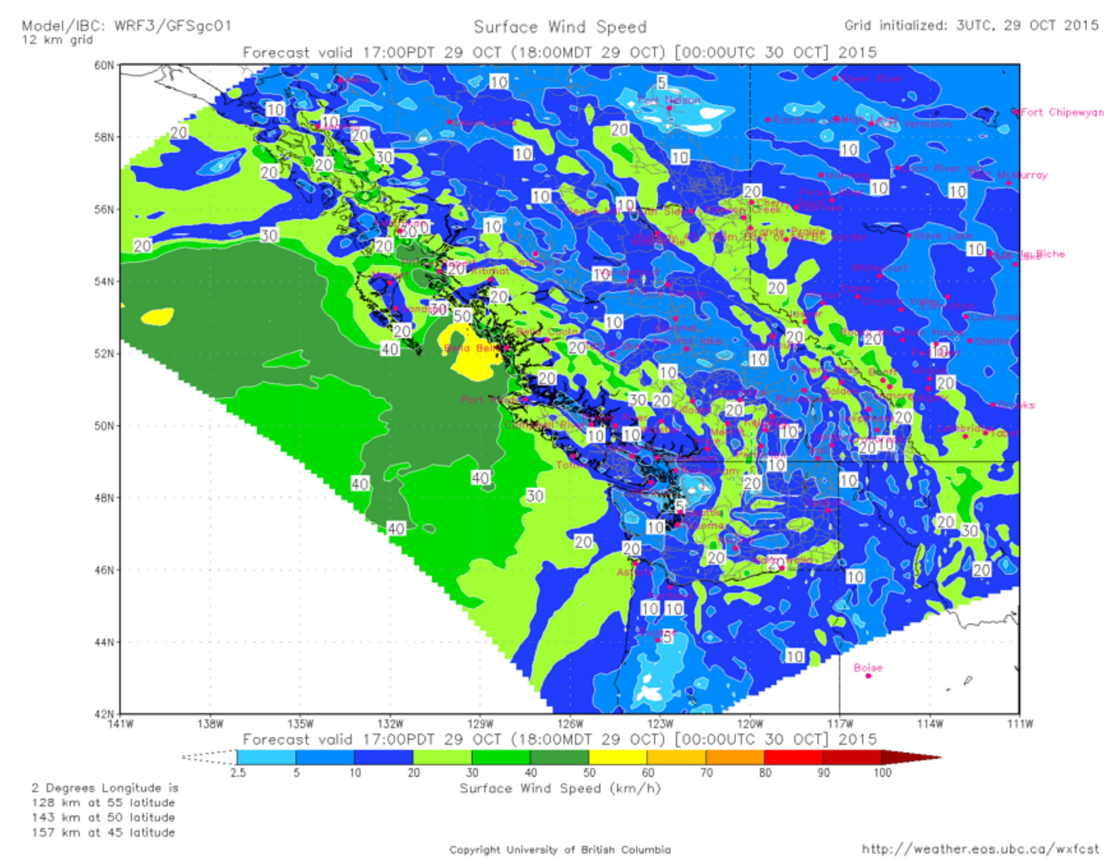
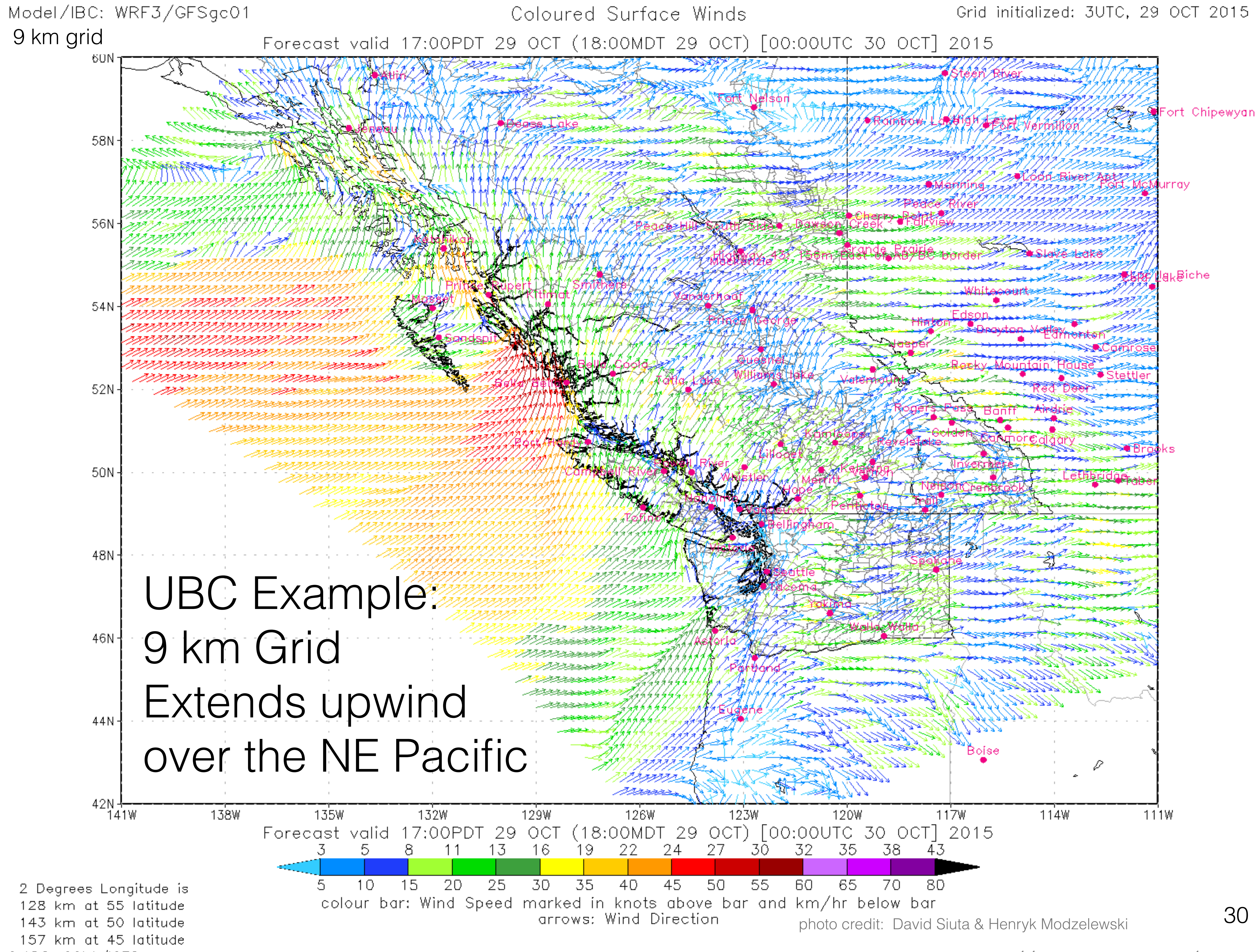


photo credit: David Siuta & Henryk Modzelewski

9 km grid



UBC Example:
9 km Grid
Extends upwind
over the NE Pacific

photo credit: David Siuta & Henryk Modzelewski

Tools for Daily Operational Forecasting of Wind and Wind Power

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- Numerical Weather Pred.
- Post-processing
- Ensemble average, probability & economics
- Verification
- Wind power
- Case studies
- Recommendations

We will provide two months of free daily real-time hub-height wind-speed forecasts as a sample to wind-farm operators.

For info on our research team, go to:
www.eos.ubc.ca/research/geodisaster_cfd/

Thanks to our Sponsors: BC Hydro, Mitacs, NSERC & others

the end

Glossary

Operational Models run at UBC

- Weather Research & Forecast (WRF)
  - Advanced Research WRF (ARW) core
  - Nonhydrostatic Mesoscale Model (NMM) core
- Mesoscale Model version 5 (MM5)
- Short-range Ensemble Forecast system (SREF)

Initial & boundary conditions from:

- Global Forecast System (GFS)
- North American Mesoscale (NAM)
- Global Environmental Multiscale (GEM) =Global Deterministic Prediction System (GDPS)

Boundary-layer physics schemes:

- Yonsei Univ. (YSU)
- Asymmetrical Convective Model - v2 (ACM2)