2014-10-28

Wind Farm Production Variation

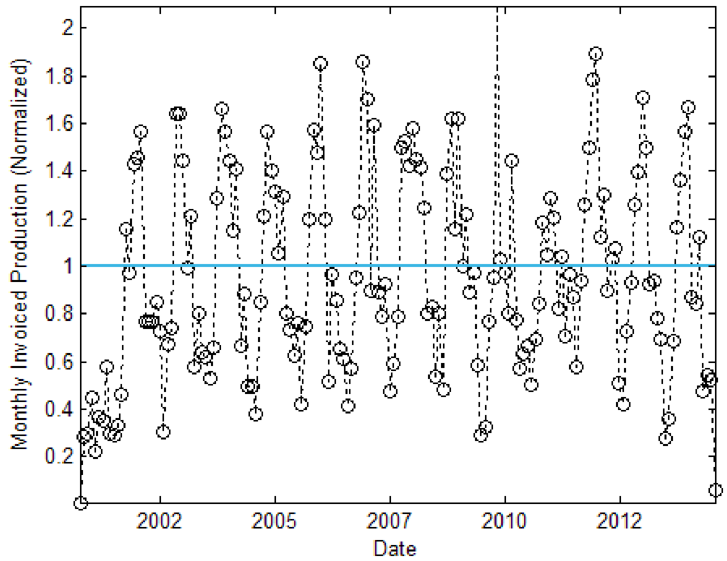
A Case Study of Net Production Variation of Alberta, Ontario and the USA

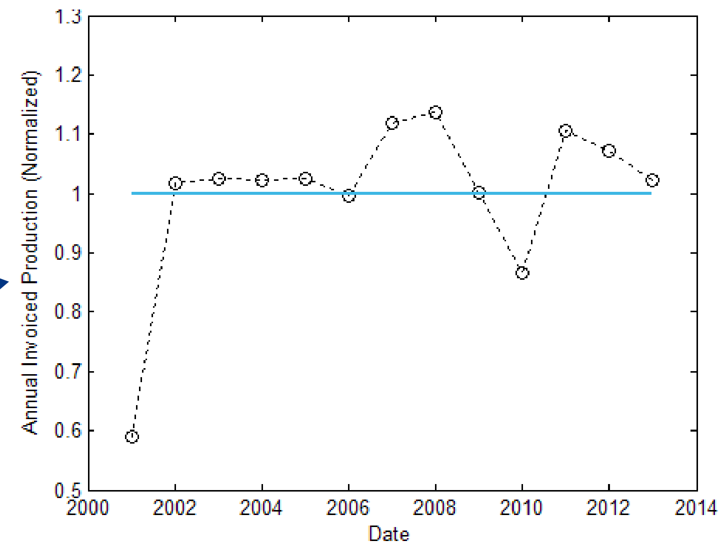
WSP

Outline

1. **What is production variation?**
2. **Why is production variation important?**
3. **North American Case Study**
4. **Summary and Conclusions**

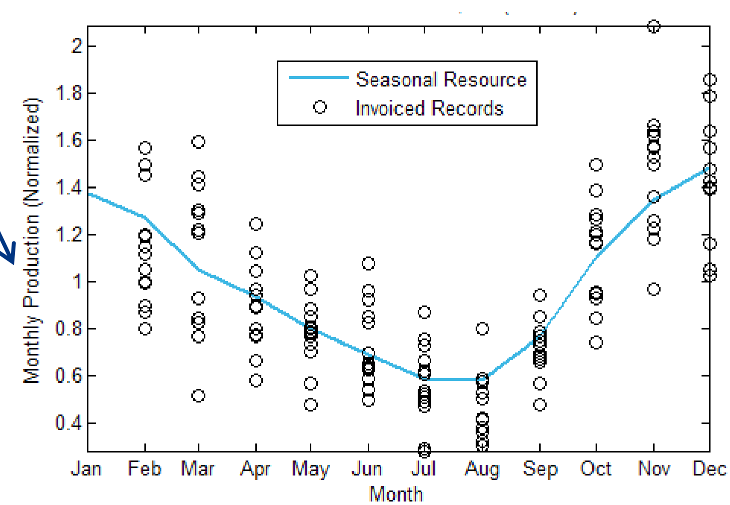
What is Production Variation?





IAV

- → **Variation in <u>net energy production</u>**
  - Resource (wind speed, air density)
  - Losses
  - Excludes start-up period
  - Power Curve - Production sensitivity
- → **Inter-Annual Variation (IAV)**
- → **Inter-Monthly Variation (IMV)**
  - Seasonal patterns



IMV

WSP

Why is Production Variation Important?

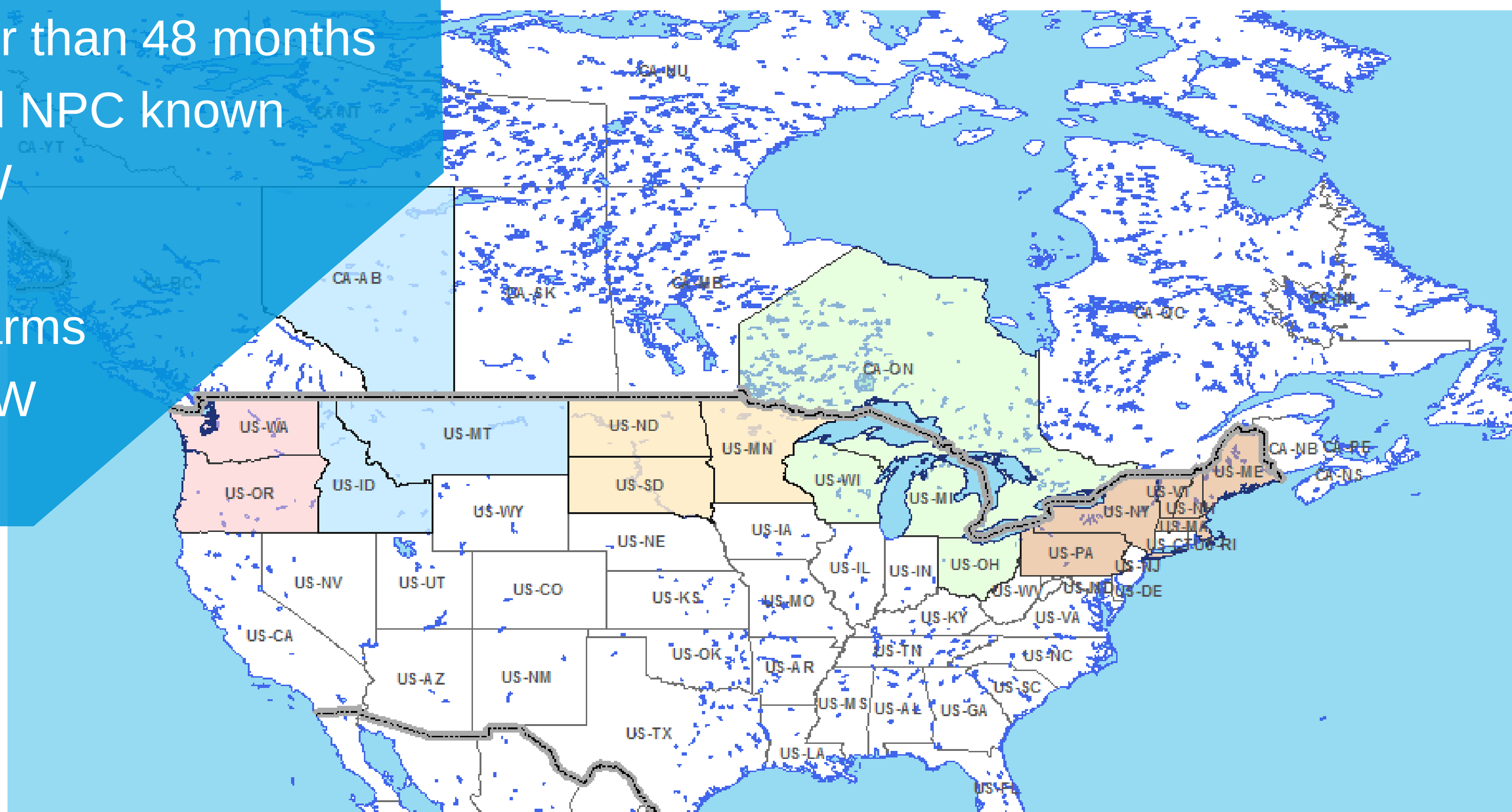
- **Inter-annual Variation (IAV)**
  - Used in production uncertainty calculations
  - IAV is the largest contributor to the 1-year uncertainty
  - The smaller the P50 to P90 spread, the lower financing costs
  - IAV can be mitigated through project design
- **Inter-monthly Variation (IMV)**
  - Invoices are monthly
  - Defines variation of revenue → probability of default
  - Helps to define realistic production expectations

WSP

North American Case Study: Monthly Net Invoiced

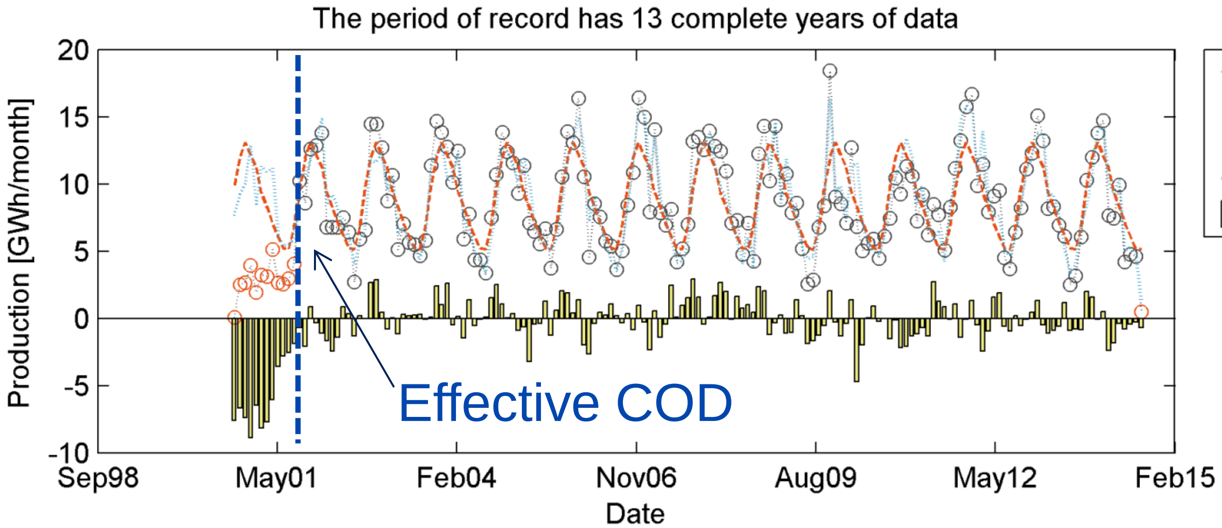
- Study Population
  - USA[1], Alberta[2] & Ontario[3]
  - 851 Wind Farms
  - Records start 2001
- Filter by:
  - Period longer than 48 months
  - Location and NPC known
  - NPC > 9 MW
- Filtered to:
  - 344 Wind Farms
  - NPC 30.5 GW

1. West Coast (WA,OR) – 25, 2.9 GW
2. Foothills (AB,ID,MT) – 17, 1.0 GW
3. Great Plains (ND,SD,MN) – 56, 4.0 GW
4. Great Lakes (ON,WI,MI,OH) – 18, 1.7 GW
5. East Coast (PA,NY,NH,VT,ME,MT) – 32, 1.9 GW

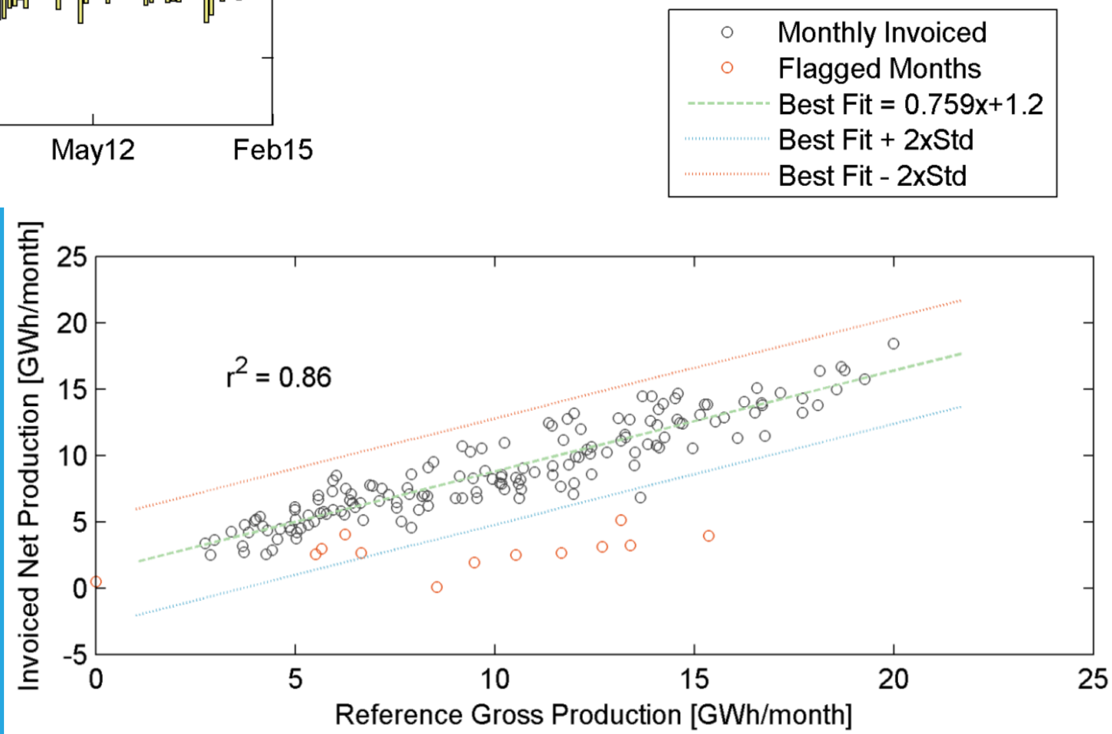


[1] EIA, 2014/09
www.eia.gov/electricity/data/eia923/
[2] AESO, 2014/08
http://ets.aeso.ca/ets_web/
[3] IESO, 2014/09
http://www.ieso.ca/

North American Case Study: QC and Prediction

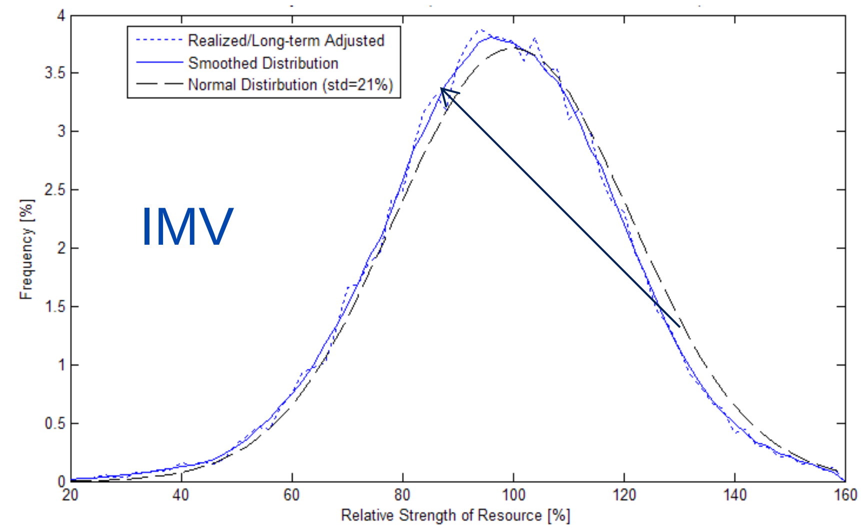


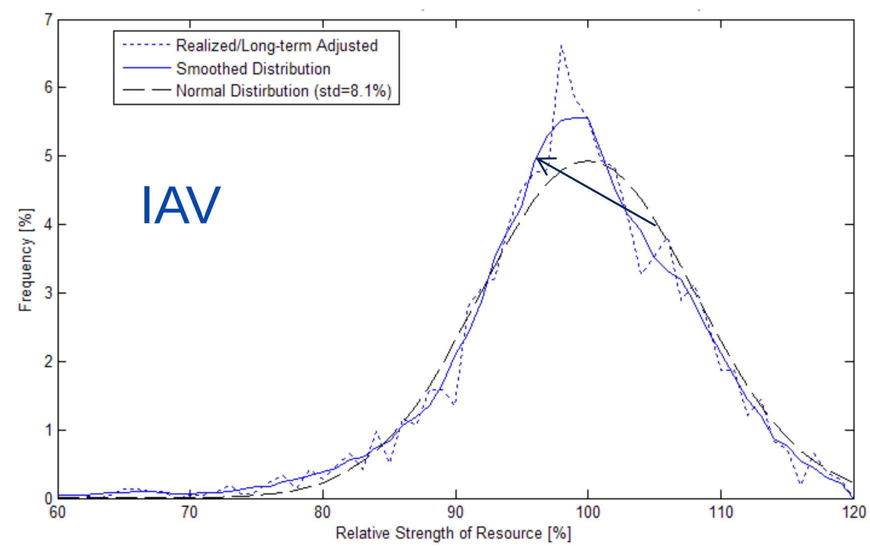
- → Generate reference data set
  - MERRA Ws, Te & Bp
  - Generic power curve, air density corrected
- → Correlate to a reference
  - Identify step jumps and trends
- → Calculate long-term mean
- → Calculate seasonal profile



North American Case Study: Distribution

- Based on 339 Wind Farms (NPC 30.4 GW)
- Relative: $\frac{Invoiced}{Seasonal\ Trend} \times 100\%$
- What is the Distribution?
  - Wind resource
  - Losses (icing, availability)
- Is there a Bias?
  - Worse for IAV than IMV
  - Near normal in tails





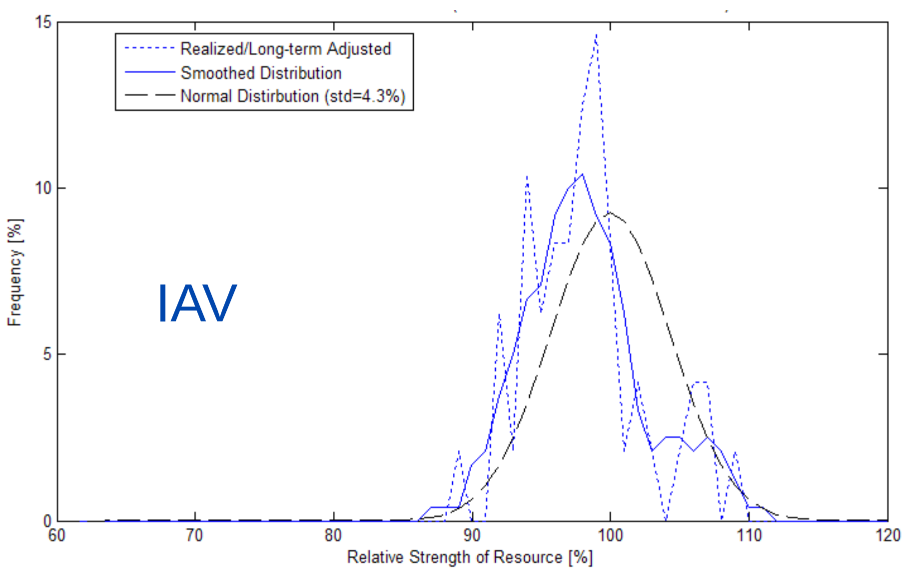
Canadian Examples

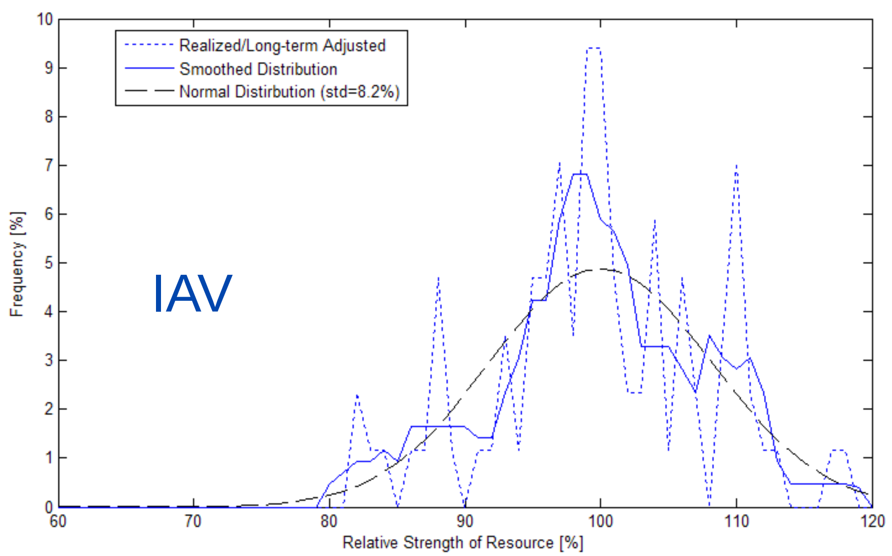
Ontario

- → 9 Wind Farms (of 25)
- → NPC of 1.13 GW
- → IAV = 4.3%
- → Bias more pronounced

Alberta

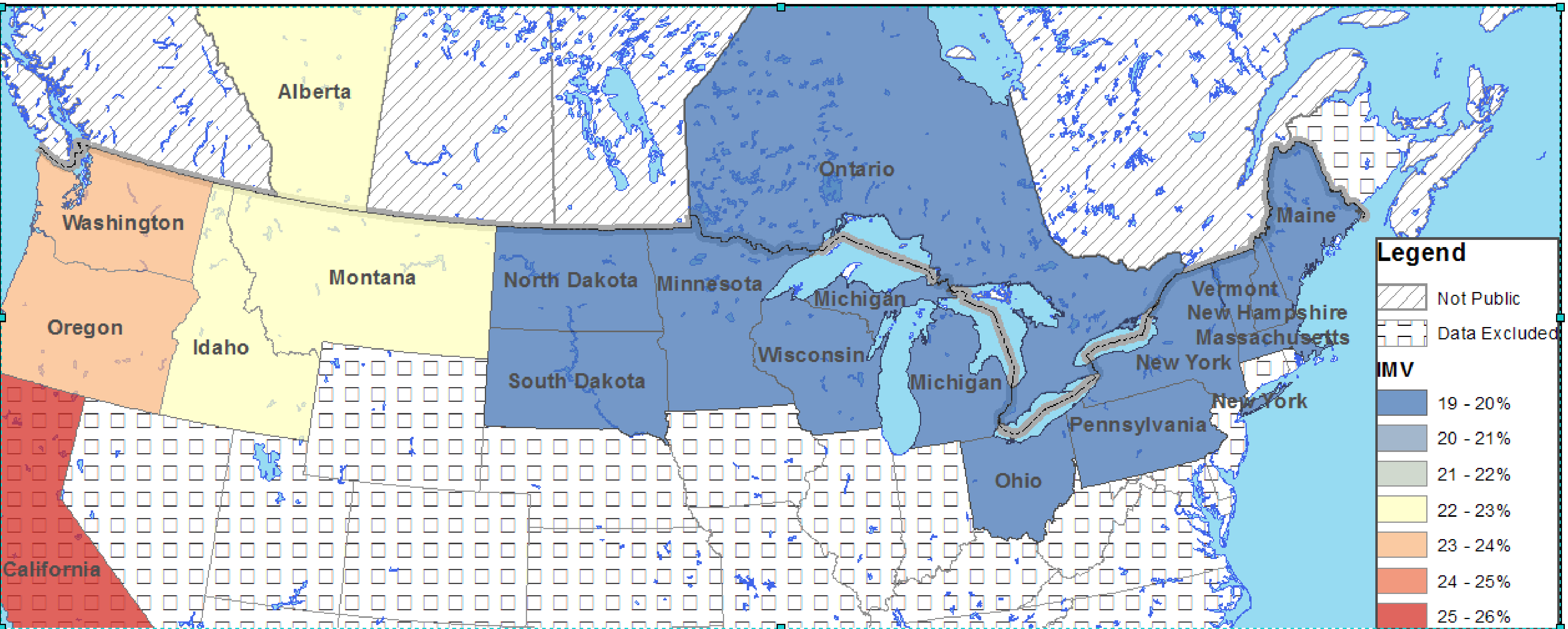
- → 11 Wind Farms (of 21)
- → NPC of 0.575 GW
- → IAV = 8.2%
- → Lots of noise





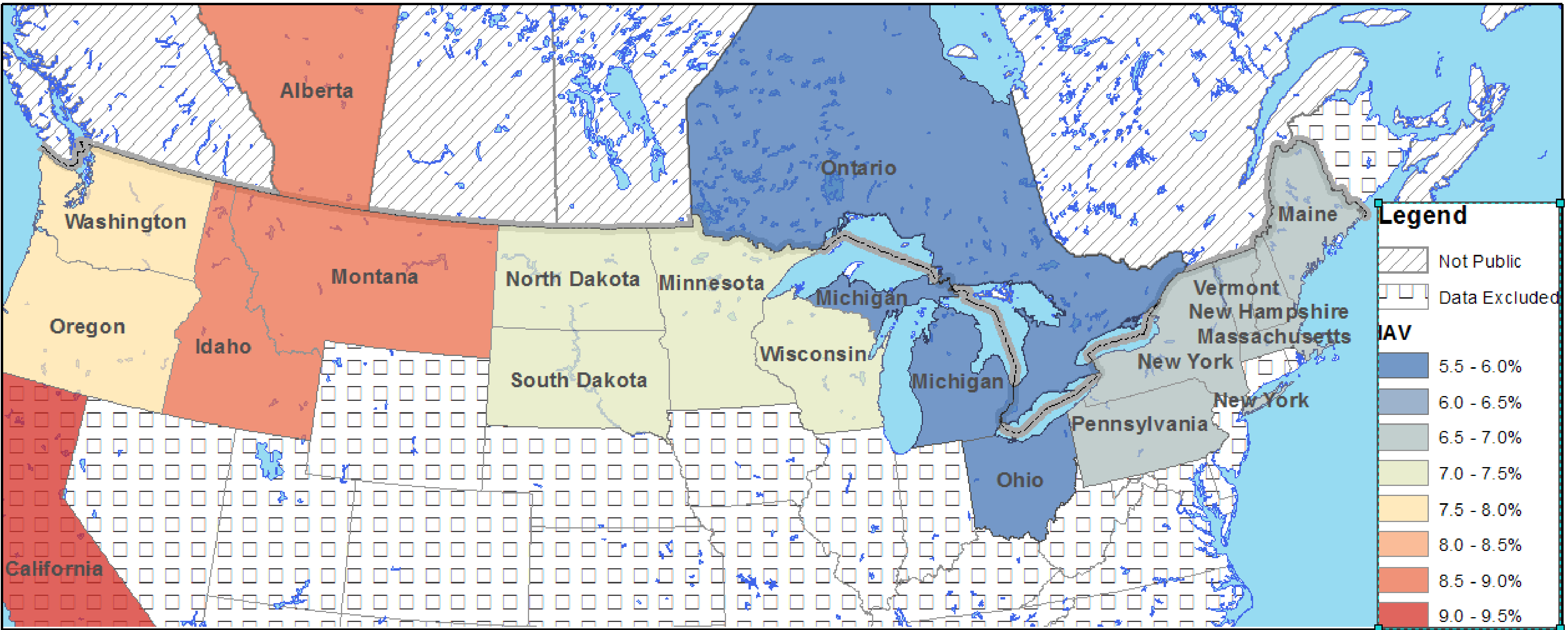
WSP

North American Case Study: IMV



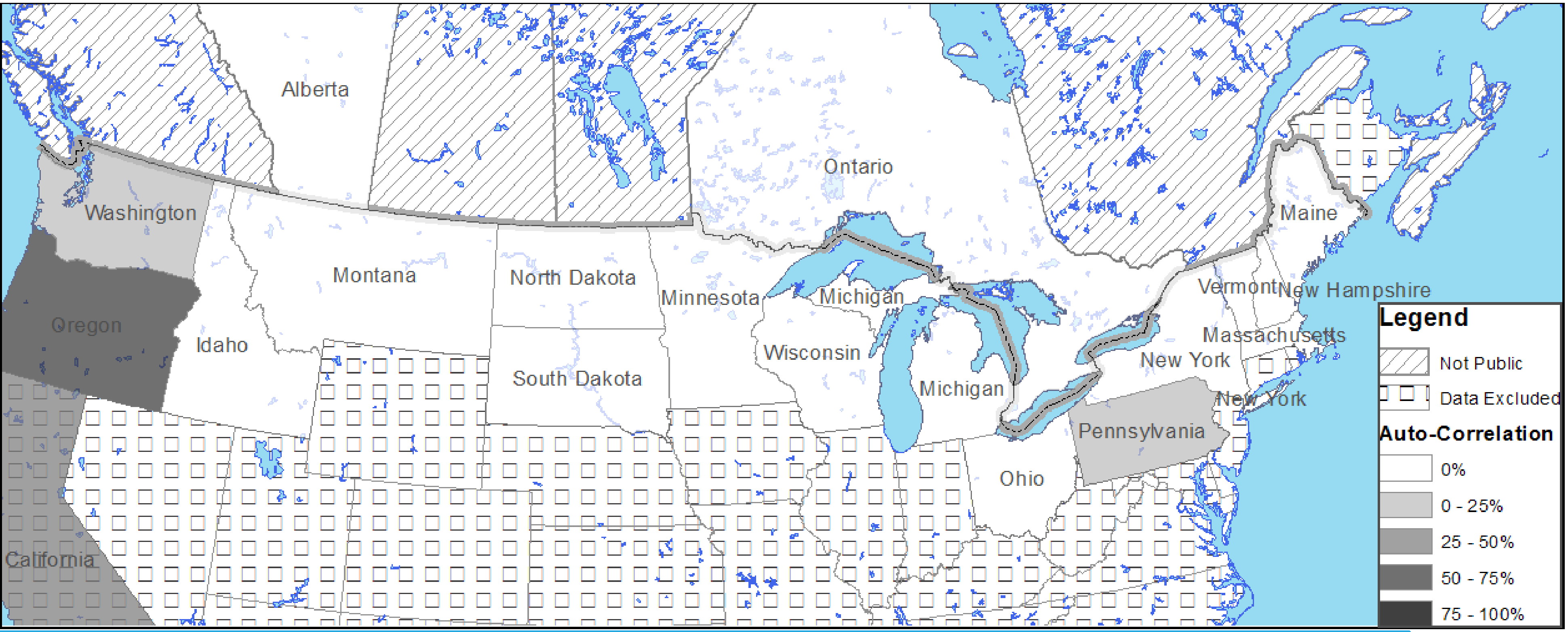
- Largest IMV calculated on the West Coast (24%)
  - Resource peaks in summer, opposite of all other regions
- Smallest IMV calculated in the Great Plains and Great Lakes (19%)
- IMV due to losses was 14% for the East Coast and 10-12% for the other regions.

North American Case Study: IAV



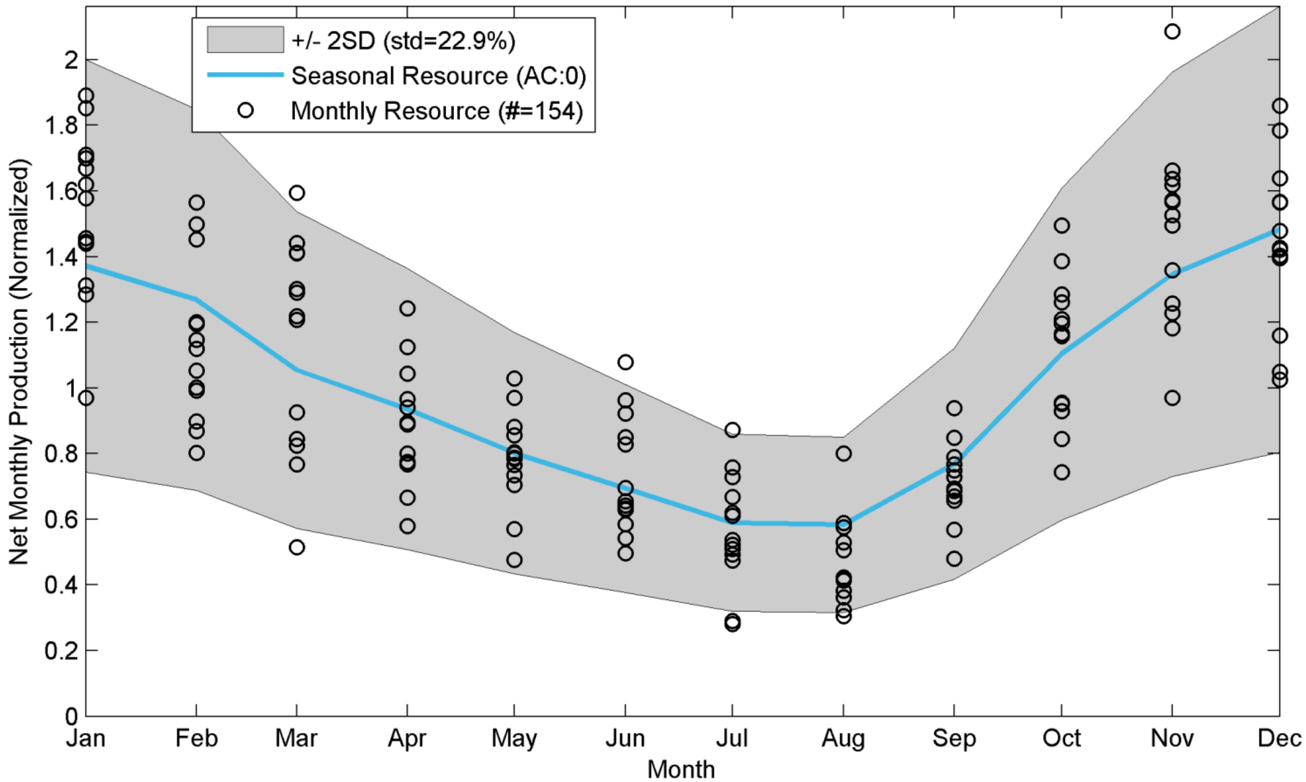
- IAV differs from IMV, but follows relative trends
  - Great Lakes shows lowest IAV (5.7%)
  - Foothills shows highest IAV (8.8%)
- Use to inform pre-construction IAV estimates
  - Production sensitivity will influence regional values
  - Variation due to losses are typically significant (3.3%)

North American Case Study: Auto-Correlation



- Is IMV ⇔ IAV?
  - Only if relative strength of invoiced production is random
- Calculate auto-correlation
  - Look at both net-invoiced and predicted long-term
  - Offset wind farm production by 1-3 months and calculate correlation
  - Compare correlation to variation → pass or fail
- Auto-correlation of resource strongest on West Coast
- Losses can cause auto-correlation

An Example of IAV from IMV

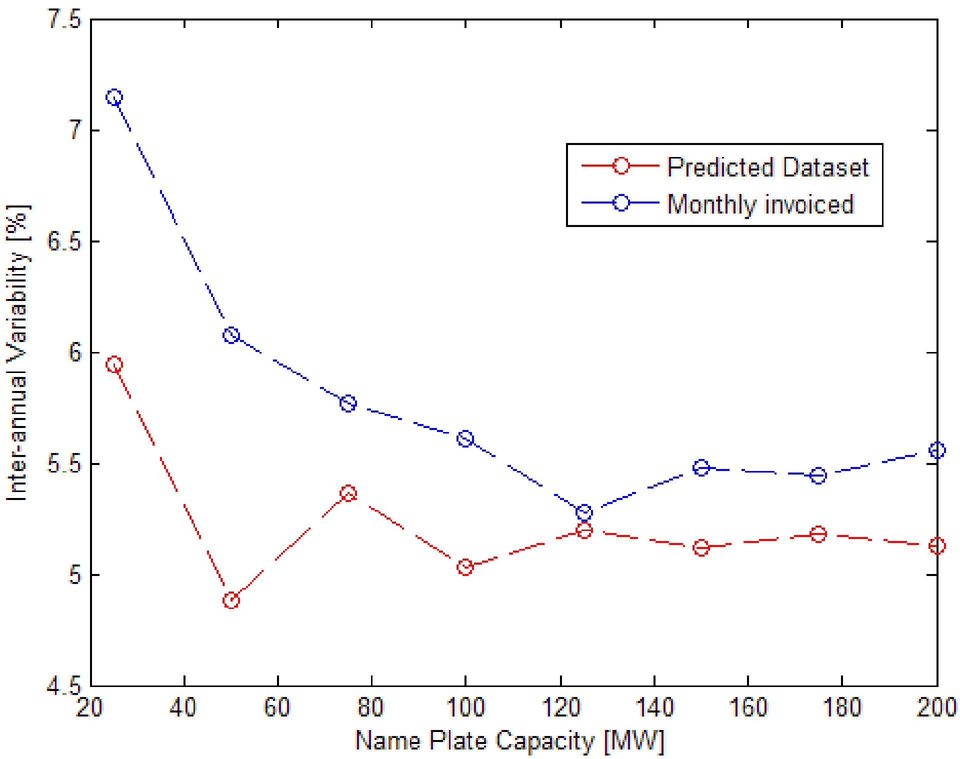


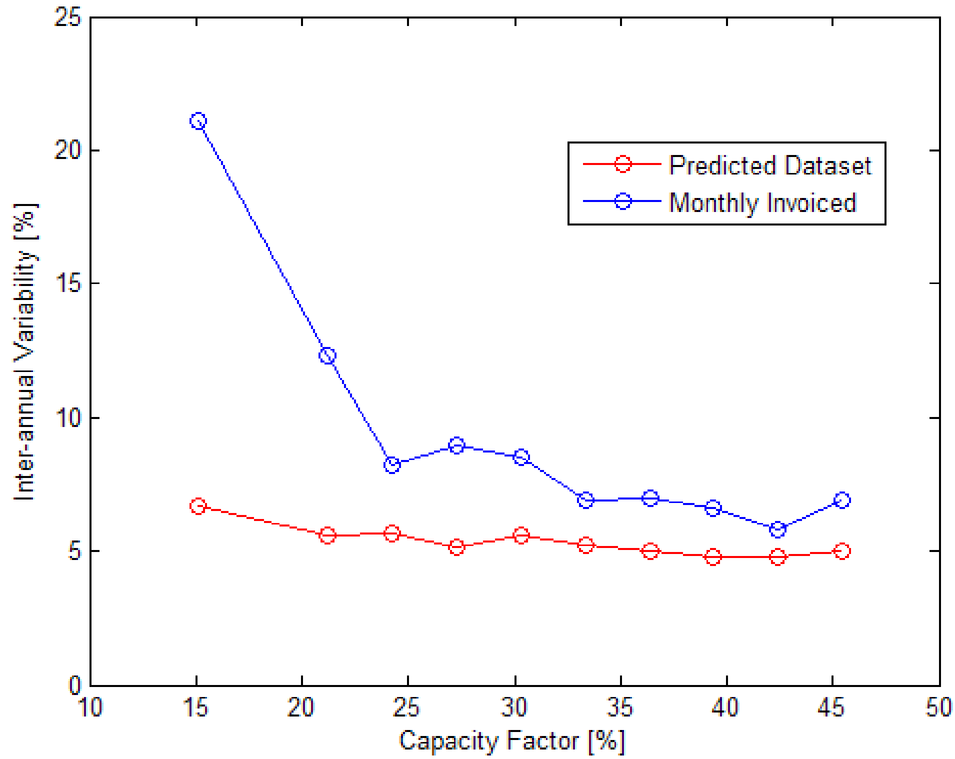
→ If data is not auto-correlated: IMV ⇔ IAV

IAV= $\frac{IMV}{\sqrt{12}}$ e.g., $\frac{22.9\%}{\sqrt{12}} = 6.6\% \sim \; Measured\ IAV\ of\ 6.9\%$

→ Better input to economic model than P90 Capacity Factor?

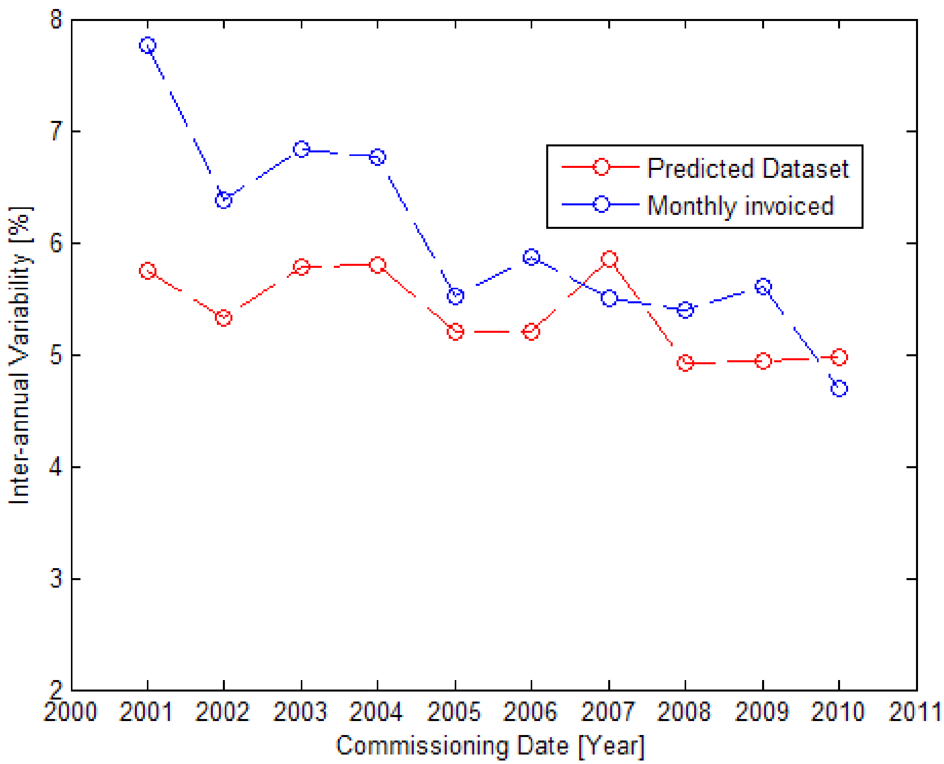
North American Case Study: Effect of NPC on IAV

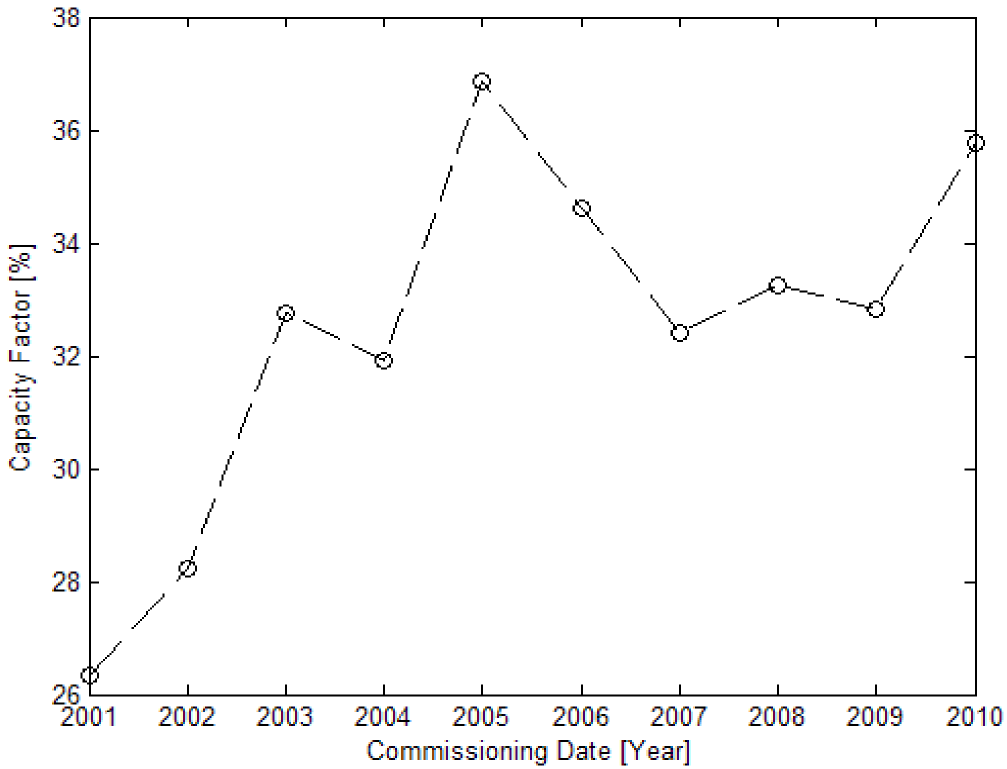




- → Predicted IAV ($\sigma_{resource}$) versus Invoiced IAV ($\sigma_{resource} + \sigma_{losses}$)
  - Predicted IAV not influenced by losses, used as baseline
- → Small wind farms have higher IAV
  - Dedicated staff, if one turbine breaks…
- → Low capacity factor wind farms have high IAV
  - Likely due to high losses → low CF → high IAV

North American Case Study: Effect of COD on IAV





- → IAV has decreased over time
- → Capacity factor has increased over time
- → Production Sensitivity ≈ Capacity Factor
  - – As production sensitivity increases, IAV decreases
- → Older projects have more chance for malfunction

Summary

- IAV is comprised of $\sigma_{resource}$+ σ_{losses} where:
  - IAV is near normally distributed for tails
  - $\sigma_{resource}$ + σ_{losses} = 5.7-8.8%
  - σ_{losses} = ~3.3%
- IMV is near normally distributed for tails
  - $\sigma_{resource}$ + σ_{losses} = 19-24%
  - σ_{losses} = ~11-14%
- IAV can be calculated from IMV in many cases
  - West coast is auto-correlated
  - High regional losses leads to auto-correlation

Conclusions

- → IMV and seasonal trend better defines revenue than P50/P90 annual net yield
  - Potential use in economic modelling
  - Better define production expectations for facility management

- → Developers can mitigate production variation by:
  - Lowering production sensitivity (turbine selection)
  - Increasing wind farm size
  - Targeting specific wind regions and/or system grids
  - Portfolio effect (regional diversification)

QUESTIONS?

IAV of Wind Speed Versus Production

→ **Production Sensitivity ~ 1.7**

Class	%
I	1.9
II	1.6
III	1.2

Class	IAV	Scaled 80 m
Predicted Wind Speed	2.3%	-
Class I Production	4.3%	4.3%
Class II Production	3.9%	3.7%
Class III Production	3.3%	2.8%

→ **IAV calculated from Wind Speed has some problems:**

- Variation of the distribution of wind speed and air density
- Effects of the Power Curve
  - Weighting: All $Ws > Ws_{rated} = Power_{rated}$
- What is the contribution of Losses to IAV?

→ **How do we validate variation of net invoiced production?**