Offshore wind siting considerations for grid value

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Work conducted by Dalhousie University Renewable Energy Storage Laboratory
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Project

- Model and **simulate offshore wind** farms in Nova Scotia waters
- Project **future provincial load** and net load
  - Increasing population
  - Additional onshore wind generation
  - Rooftop and commercial solar PV generation
  - Maritime link NS block
  - Changing uses (Electric vehicles, heat-pumps etc.)

- **Compare** OSW power production to future domestic electrical load in timeseries,
  - as a function of location (geography) and wind farm size (MW)

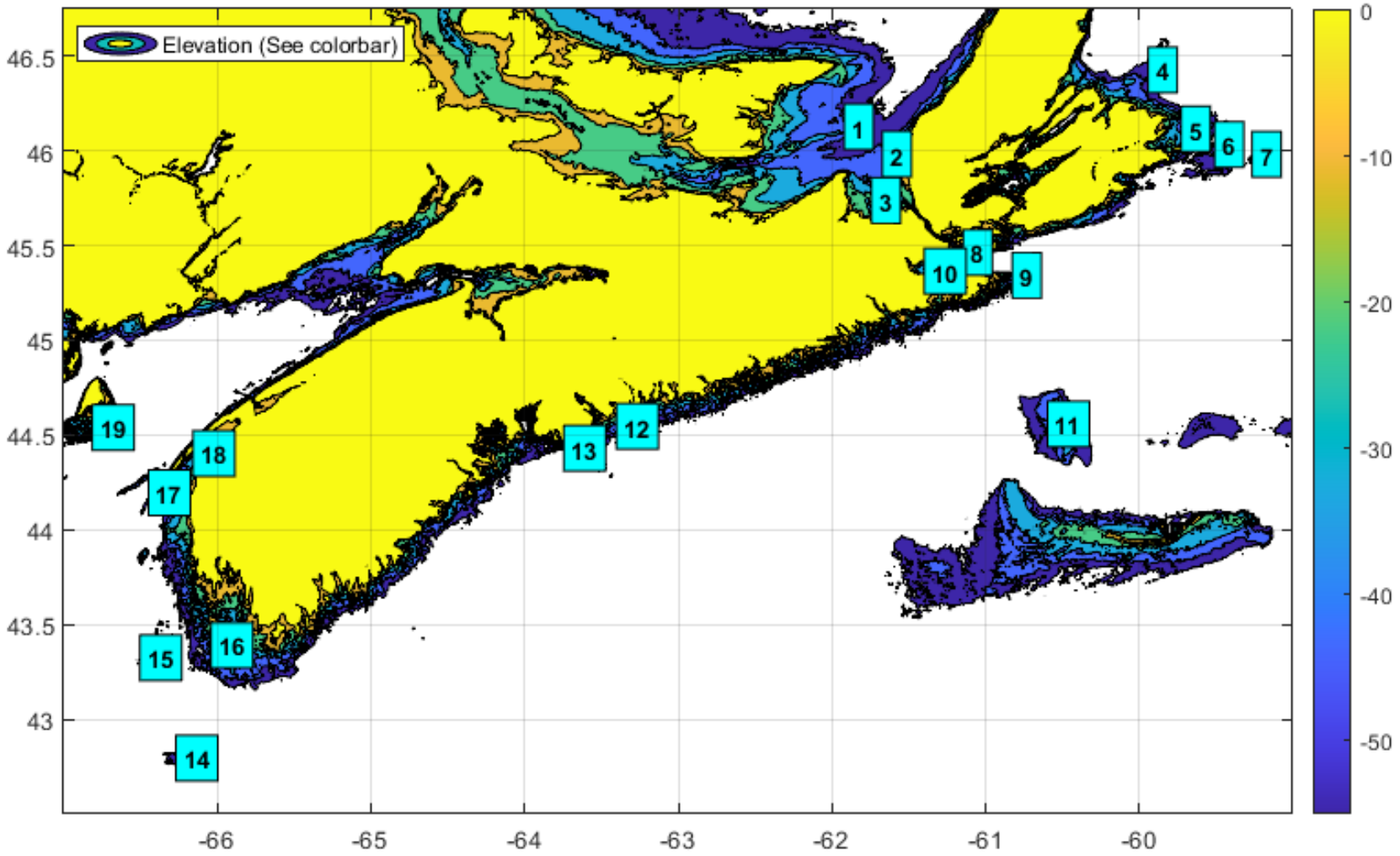
Background, assumptions and considerations

Assumptions

- For simplicity and economics, only **bottom-mounted turbines** are considered;
  - Analysis is limited to areas with water depth of **< 55m**.
- Availability
  - A general 3% farm level derating was applied throughout the year to account for maintenance and availability
  - A further 2% derating was applied in January through March to account for Winter conditions (total 5% derating)
  - This derating is applied to wind farm power output rather than wind speed (so that the power curve is observed) and may be thought of as having 1-2 turbines not operating in the farm.
- Fishing
  - Most fishing technologies can co-exist with wind farms.
    - Bottom trawls must avoid cable routes
    - Drift nets must avoid area
- Setback
  - Onshore wind setback in NS is 4x turbine height, roughly 1 km for ~15 MW OSW turbine (~150m hub height, ~100m blades)
  - Use 2km.
  - Hub height is about the height of your thumb at the end of your outstretched arm.

Locations of Interest based on Bathymetry

- Sites of interest are
  1. Northwestern St Georges Bay
  2. Eastern St Georges Bay
  3. Southern St Georges Bay
  4. Sydney Bight shoal
  5. Sydney South, Inshore
  6. Scatarie Island East, Offshore
  7. Cape Breton East, way offshore
  8. Chedabucto Bay NE
  9. Chedabucto Bay SE
  10. Chedabucto Bay W
  11. Middle Bank
  12. Sambro Ledge NE
  13. Sambro Ledge SW
  14. Brown's Bank
  15. Tusket
  16. Seal Island
  17. Brier Island
  18. St. Mary's Bay
  19. Grand Manan



Approximate minimum distance to shore

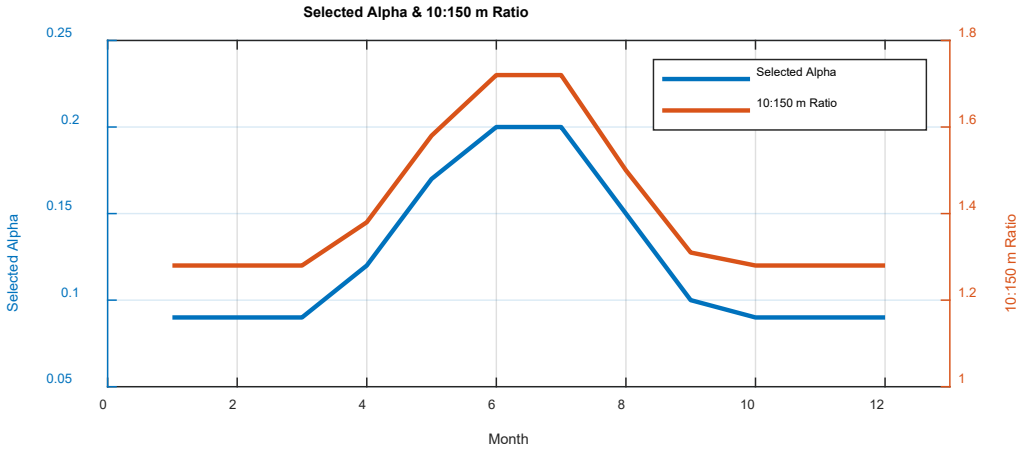
- Distances from shore are approximate
- All ‘near’ sites could be pushed out to some degree, at a cost of site size
- More distant sites are indicated with blue text
  - Less NIMBY / viewshed conflict (?)
- Contiguous or nearly contiguous sites are grouped with red ovals.
- A value of 2 km in effect means that suitable bathymetry runs right to the shoreline.
- Distances to an appropriate power landing site may be significantly greater
- Nova Scotia onshore wind setback is ~1 km.

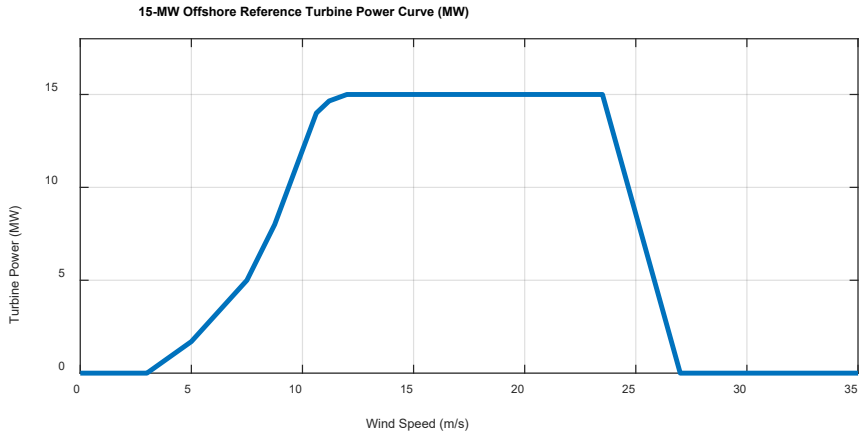
- “The average distance from shore was 47 kilometers (km) for installed projects [in 2019], and project announcements indicate an increase to 70 km by 2025.”
  - https://www.nrel.gov/news/program/2020/2019-offshore-wind-data.html#:~:text=Technological%20advancements%20helped%20offshore%20wind,to%2070%20km%20by%202025.

Number on Map	Site Name	Min Dist from shore
1	Northwestern St Georges Bay	10 km
2	Eastern St Georges Bay	2 km
3	Southern St Georges Bay	2 km
4	Sydney North	10 km
5	Sydney South	2 km
6	Scatarie Island West	20 km
7	Scatarie Island East	40 km
8	Chedabucto Bay NE	2 km
9	Chedabucto Bay SE	2 km
10	Chedabucto Bay W	2 km
11	Middle Bank	60 km
12	Sambro Ledge NE	2 km
13	Sambro Ledge SW	2 km
14	Brown’s Bank	80 km
15	Tusket	35 km
16	Seal Island	25 km
17	Brier Island	2 km
18	St. Mary’s Bay	2 km
19	Grand Manan	2 km

Methodology

- We found higher shear in the summer than in the winter (middle right).
  - *Pearre, N. S., Pimentel, A., & Swan, L. (2025). Seasonality of Vertical Wind Shear in the Northwestern North Atlantic. Wind Energy, 28(9), e70054.*
- The resulting shear profile was applied to each of the model sites (red circles on model map) to scale 10 m wind speeds to 150 m hub heights.
- A prototypical offshore wind turbine power curve produced by IEA (bottom right figure) was used to transform the hub height wind speeds to power output
  - *Gaertner, E., Rinker, J., Sethuraman, L., Zahle, F., Anderson, B., Barter, G., ... & Viselli, A. (2020). Definition of the IEA 15-megawatt offshore reference wind turbine.*
- Power was derated by a factor of 97% to account for maintenance and downtime + additional 2% in Jan, Feb & Mar to account for icing
- Provincial load and renewable generation were adjusted to account for conditions that will be in place in 2030
  - Annual energy demands increased by 6%
  - Peak load increased by 17%
  - Additional 382 MW on onshore wind
  - Maritime Link delivering 153 MW between 8 am & 11 pm daily
- Output parameters were calculated for each location (capacity factor, capacity value, spill fraction, delivered fraction, etc.)
  - Geospatial changes in these parameters were overlayed on maps

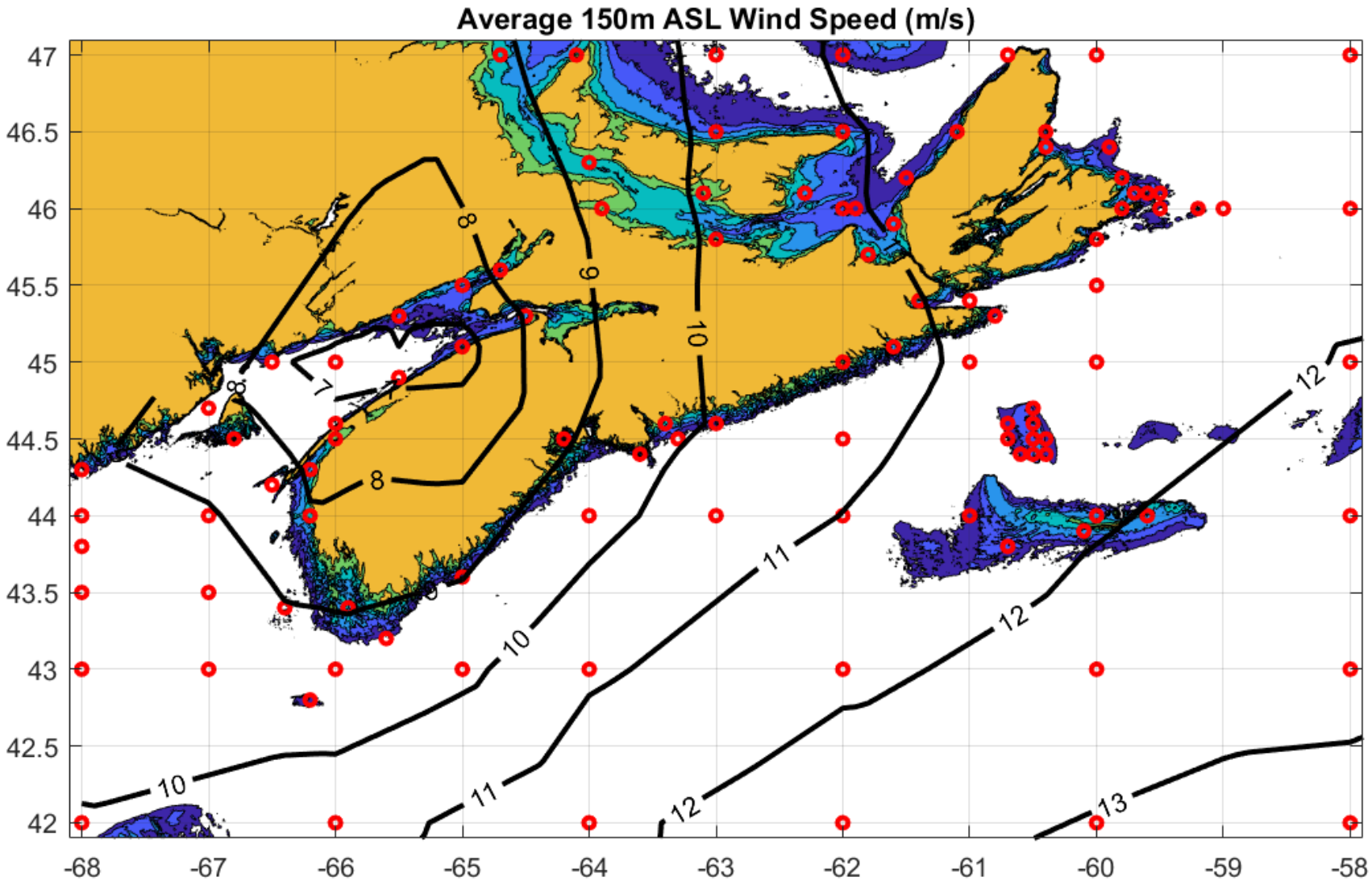




Spatial diversity of the resource

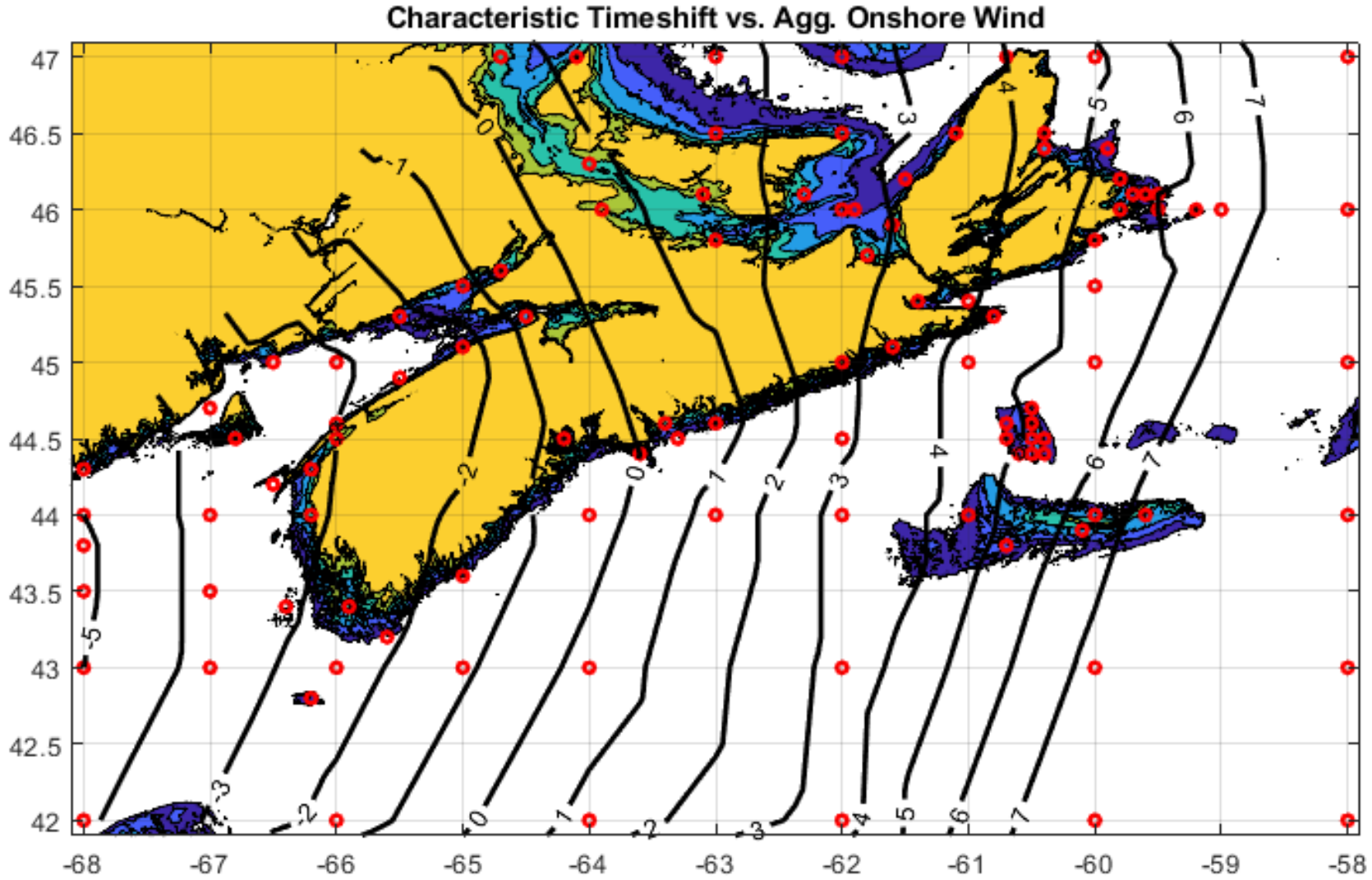
Average 150 m Wind Speed

- Hub height wind speeds are very very high.
- “Class I” offshore wind has ~10m/s annual average wind speed at hub height
- **Note: disregard values over land**



Characteristic Timeshift

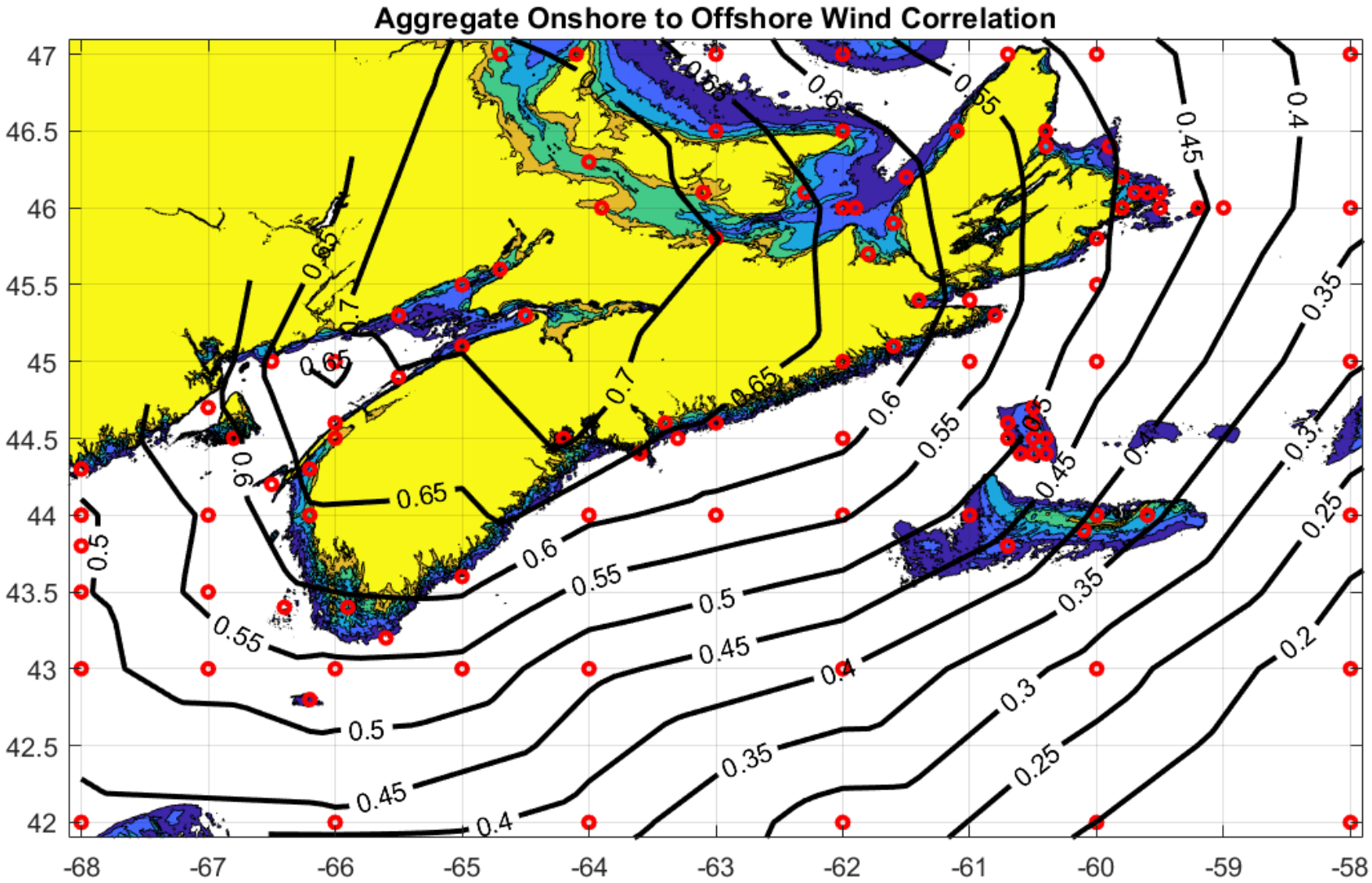
- The average **difference in time** of the arrival of wind events **relative to the average onshore wind generation**.
- Greater timeshift (*higher absolute* values) from existing resources is better.
  - More ‘differentness’ from onshore wind resource
- Wind events (weather systems) blow in **from the west**, so points in the west have negative (leading) values.
- Calculated by finding maximum correlation between two wind energy production timeseries
  - Shifting one forward or backwards in time and re-calculating correlation at each shift.



Correlation vs. Aggregate Onshore Wind

- All other things being equal, a lower correlation (*lower* values) to existing resources is better.
- The correlation between the offshore wind resource and the aggregate provincial onshore wind production shows where the offshore wind resource is similar to the onshore resource
- Values range from >70% in the Bay of Fundy to 50% at Brown's Bank, eastern Cape Breton and Middle Bank.

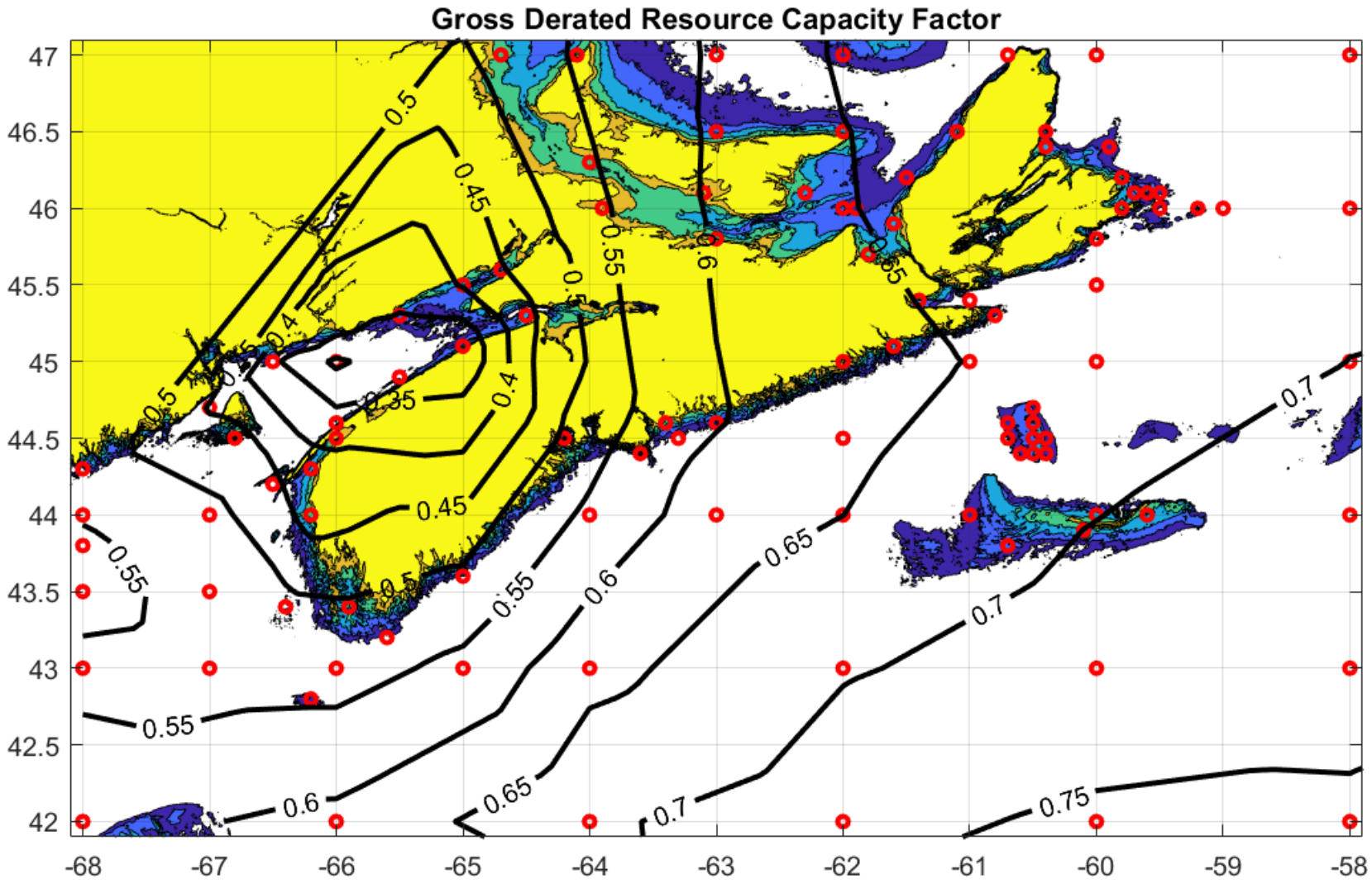
- **Note: disregard values over land**



Gross Derated Capacity Factor

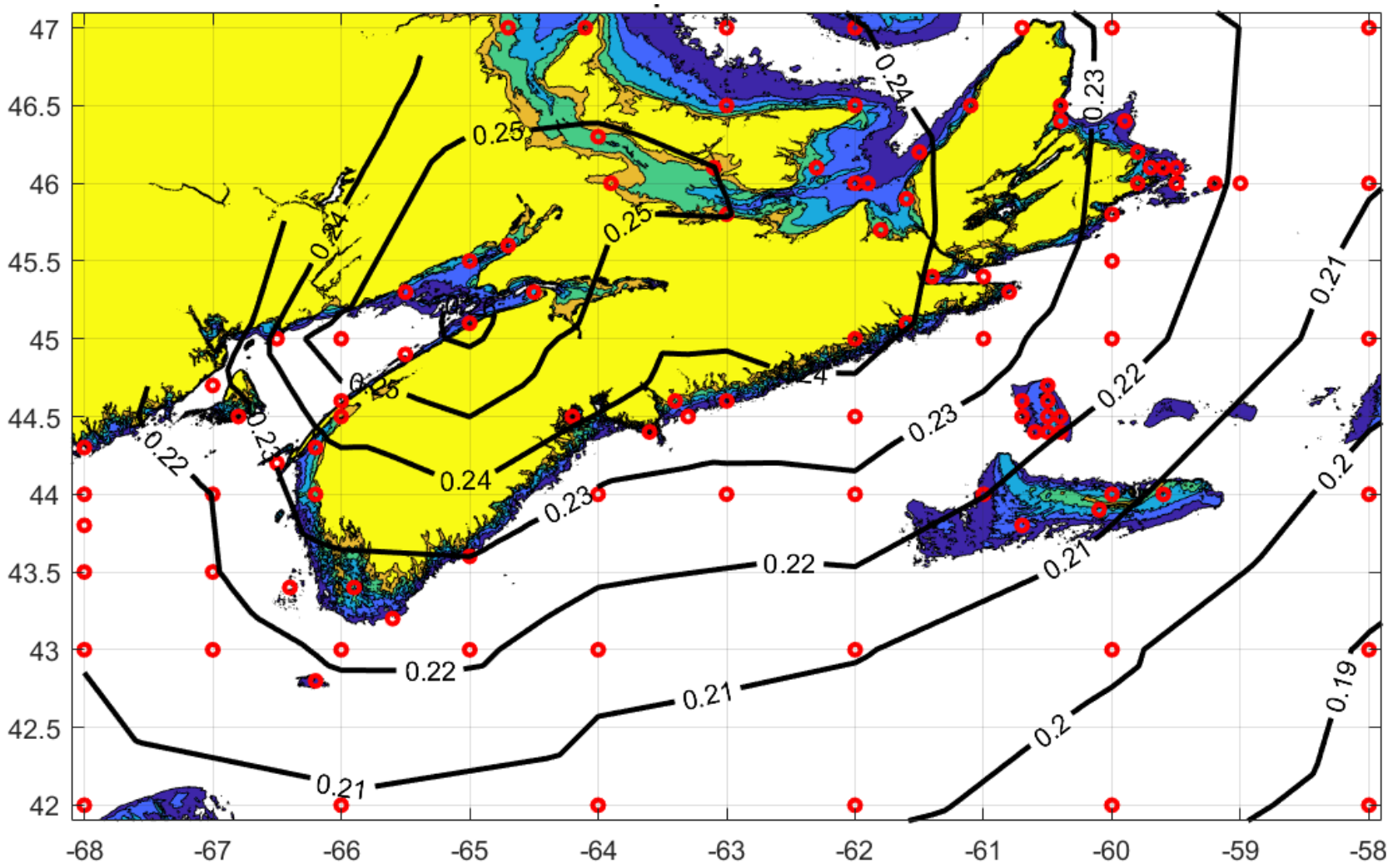
- These values represent a projected available generation once downtime, maintenance, and icing are accounted for
- 95% was used for Jan, Feb, & Mar
- 97% was used for the rest of the year

- **Note: disregard values over land**



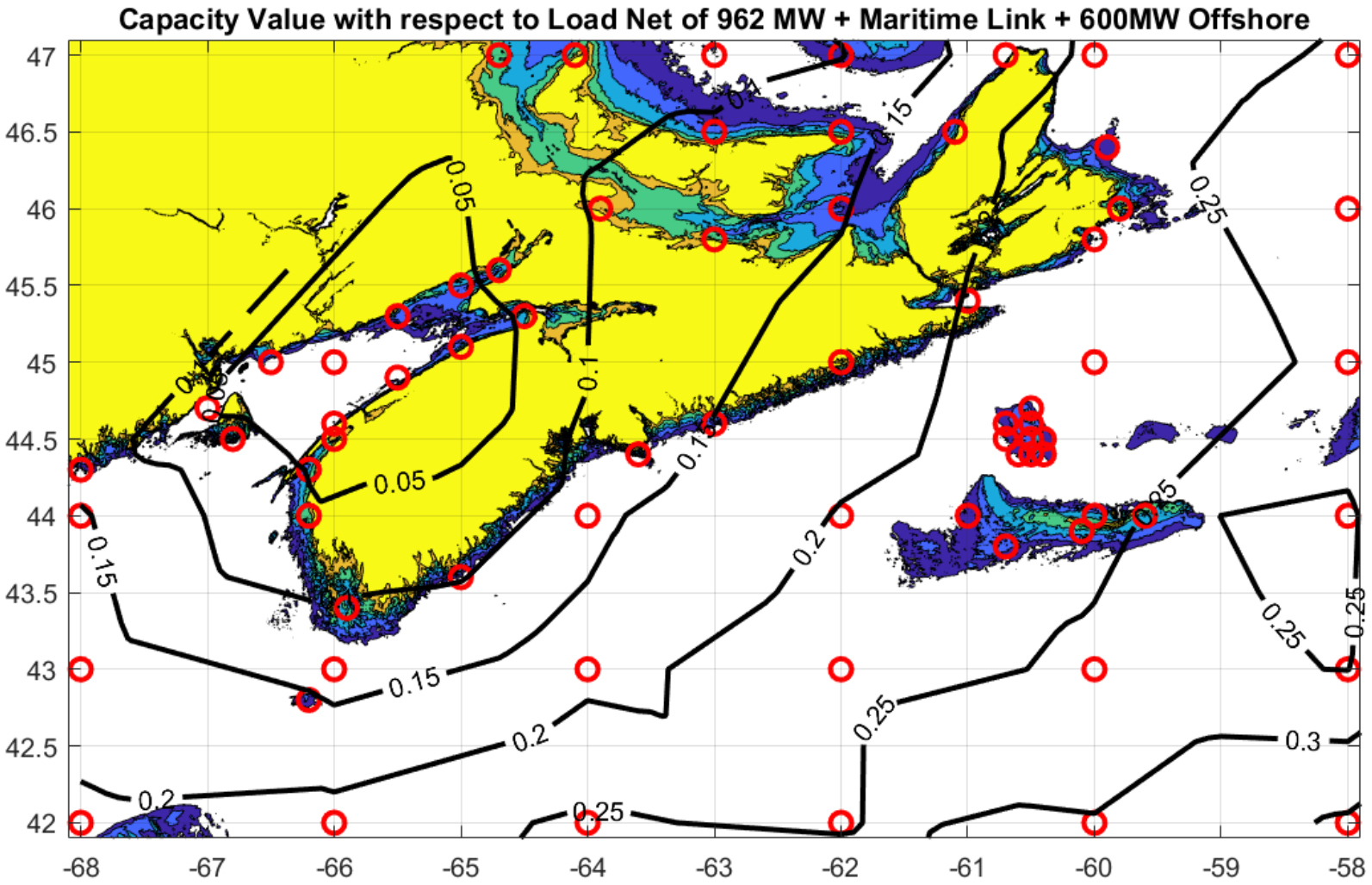
Export/curtailment fraction of 600 MW OSW

- All other things being equal, exporting/curtailing less (*lower* values) is better.
- By the time an offshore wind farm is built, Nova Scotia will have in place
  - 590 MW on onshore wind predating 2022
  - 372 MW of additional onshore wind expected by 2025
  - 153 MW of Maritime Link energy delivered between 8 am & 11 pm daily
- These resources will be used to supply load and will frequently address all of the load, meaning that energy produced from the offshore wind farm will need to be exported or curtailed
- This figure shows the fraction of the (derated) gross resource that would need to be exported or curtailed
- The wind resources in the Bay of Fundy, near the centroid of the province spills the most
  - Locations near much of the existing onshore capacity
  - But the range is not great
  - ~22% - ~26%
- Developers would need to find a second offtaker for approximately one quarter of the generated electricity. Otherwise they would have to curtail it.
- **Note: disregard values over land**



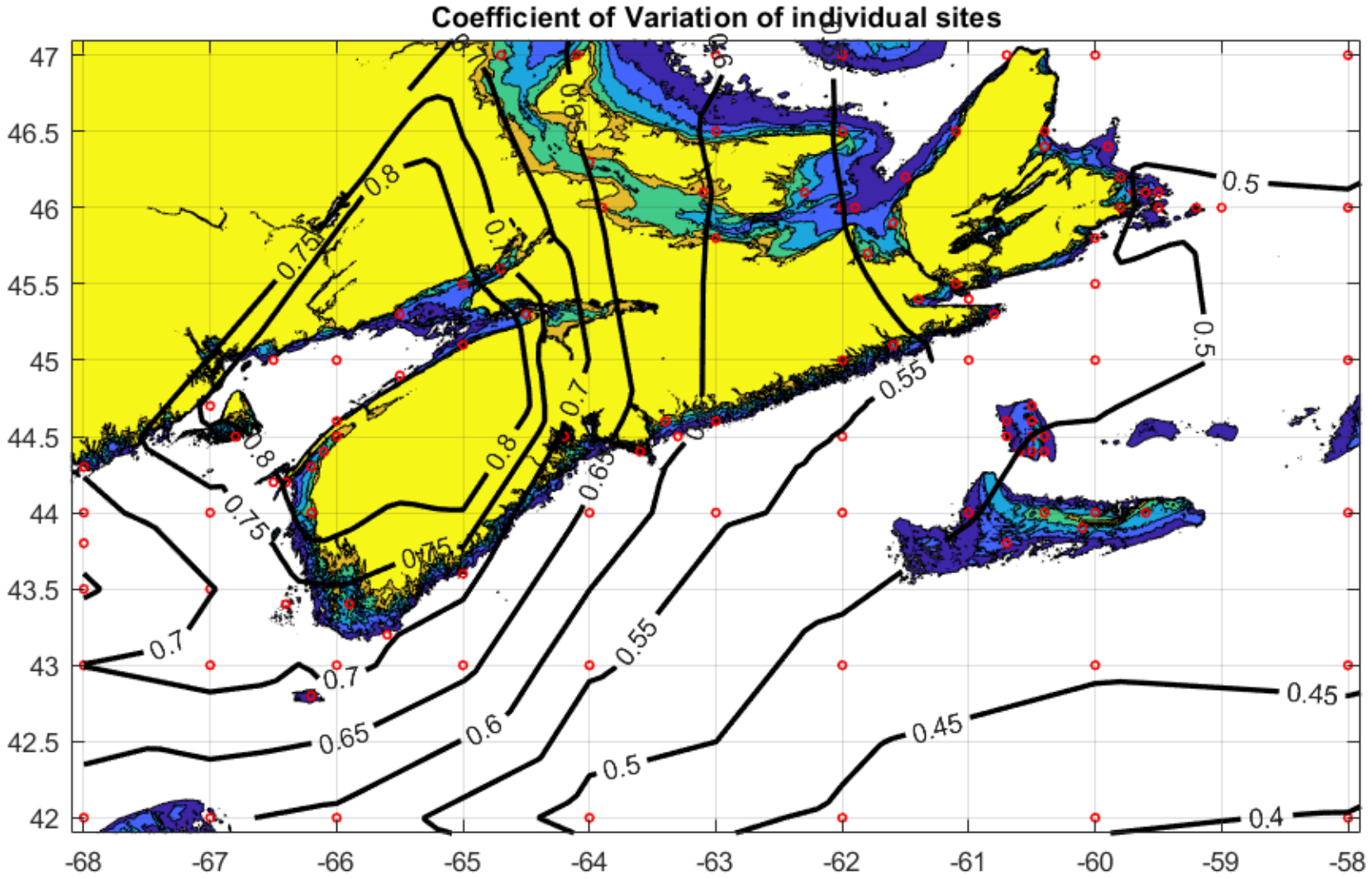
Capacity Value with Respect to Net Load

- Capacity value is effectively the ability of the wind resource to displace and retire other generation.
- Capacity value with respect to other non-dispatchable resources represents the incremental capacity value of new wind capacity
  - After accounting for the impacts of onshore wind and Maritime Link



Coefficient of variation of individual sites

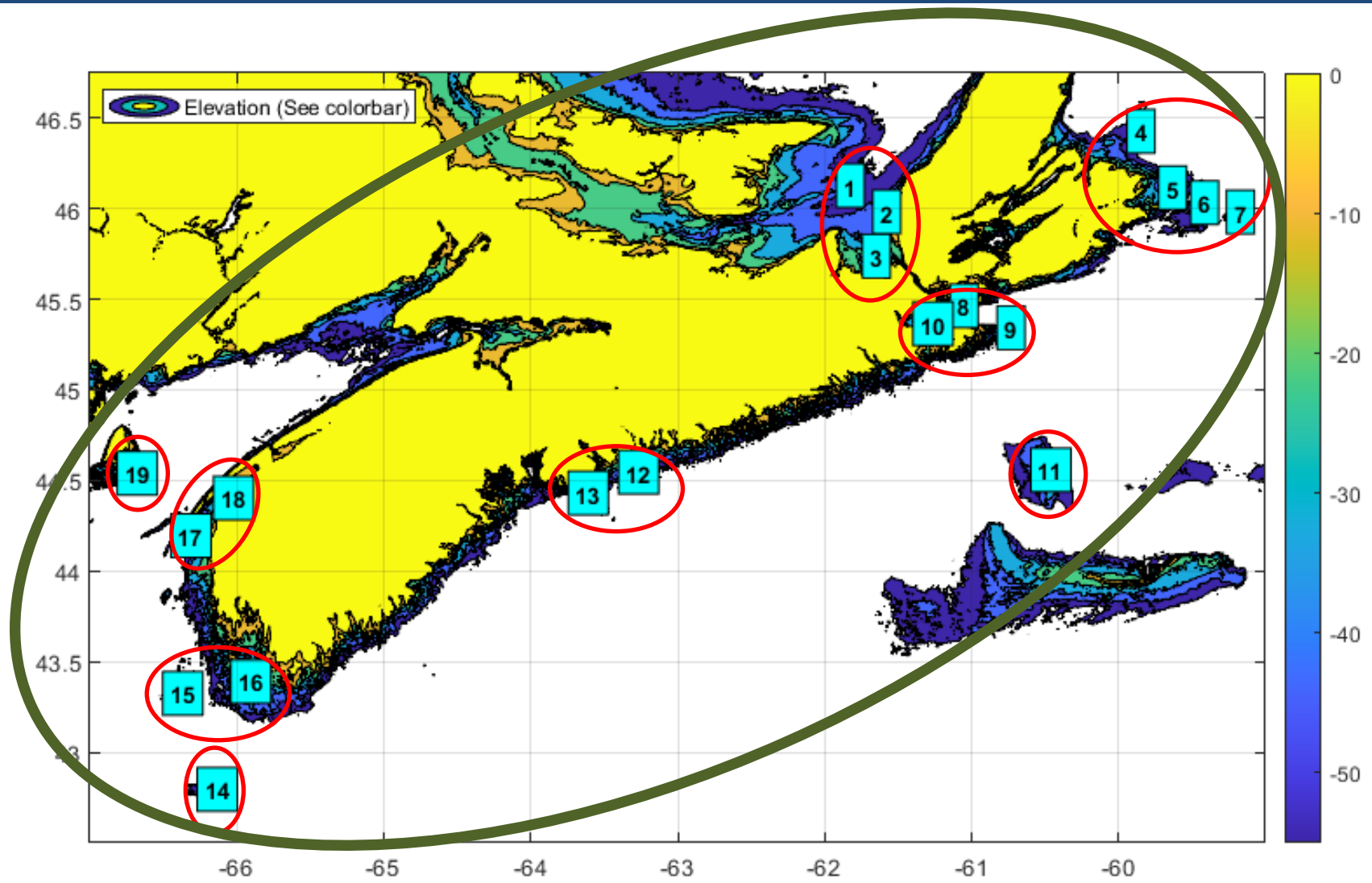
- Coefficient of variation is the standard deviation [of power output] divided by the mean.
  - A quantitative answer to the question “How variable is the resource?”
- Lower values are better, especially in the context of
  - energy export plans.
  - Green hydrogen/ammonia production



Benefit of multiple sites

Total province (+ Grand Manan) optimization

- How best to install 4.4 GW across the whole province
- 19 sites are down selected and aggregated into 9 meta-sites.
- The **dark green oval** shows the physical scope of the analysis
- The **red ovals** show the ‘units of analysis’



Province-wide capacity allocation optimization

- Sites are grouped into eight meta-sites
- Where multiple different configurations resulted in the same value for a metric, the ‘best’ of those was chosen based on capacity factor.
- Site capacity options are [0, 400, 800, 1200, 1600] MW
- This analysis envisions 4400MW total capacity

Site	StGeorge_Bay	East_CB	Chedabucto_Bay	Middle_Bank	Halifax	Browns_Bank	SW_NS	Fundy_Bay	TimeAt_0	TimeUnder_10	TimeUnder_25	TimeUnder_50	TimeOver_90	Cap_Fact	Coef_Var
Criterion/Units	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*
Site Max MW	*3405*	*5010*	*1335*	*3600*	*915*	*615*	*1695*	*2055*							
Least Time @ 0	0	1600	400	800	400	400	400	400	**0.03**	5.1	14.9	33.2	22.6	64.4	46.1
Least Time < 10%	0	1600	0	1200	800	400	400	0	0.07	**4.8**	14.6	32.2	25.9	65.9	45.7
Least Time < 25%	0	1600	0	1600	0	400	800	0	0.19	5.0	**14.4**	32.1	26.0	66.1	45.6
Least Time < 50%	800	1600	0	1600	0	400	0	0	0.19	5.6	15.4	**31.2**	35.4	68.8	46.5
Least Time > 90%	0	1200	0	400	800	400	0	1600	0.04	5.4	17.3	42.6	**17.4**	58.5	50.0
Cap. Fact.	0	1600	1200	1600	0	0	0	0	0.95	7.0	16.8	31.5	45.2	**70.0**	48.5
Coef. Var.	0	1600	0	1600	400	400	400	0	0.07	4.9	14.6	31.9	26.8	66.8	**45.6**

Discussion and Conclusions

- The difference in capacity factor between the Western and Eastern NS is dramatic
  - Western ~53% vs. Eastern 71%
  - This would have a dramatic impact on LCOE

- A more rigorous shoreline setback (currently ~2 km) quickly diminishes maximum allowable capacities at 11 of the 19 sites and constrain the solution space.
  - A 2 km setback means the turbine will appear about as large as your thumb at the end of your outstretched arm to the nearest observer on land.

- The site selections do not substantial change the values of low power time.
- The impactful performance trade off is to optimize either capacity factor or time spent below 90% power.
  - If capacity factor is optimized it leads to site selection in Eastern NS
  - If minimized maximum power to avoid export/curtailment is optimized it leads to diverse site selection across NS

- In all optimizations, development in eastern Cape Breton is specified.