NOVA SCOTIA OFFSHORE WIND FARM SITE CONSIDERATIONS - POWER AND ENERGY

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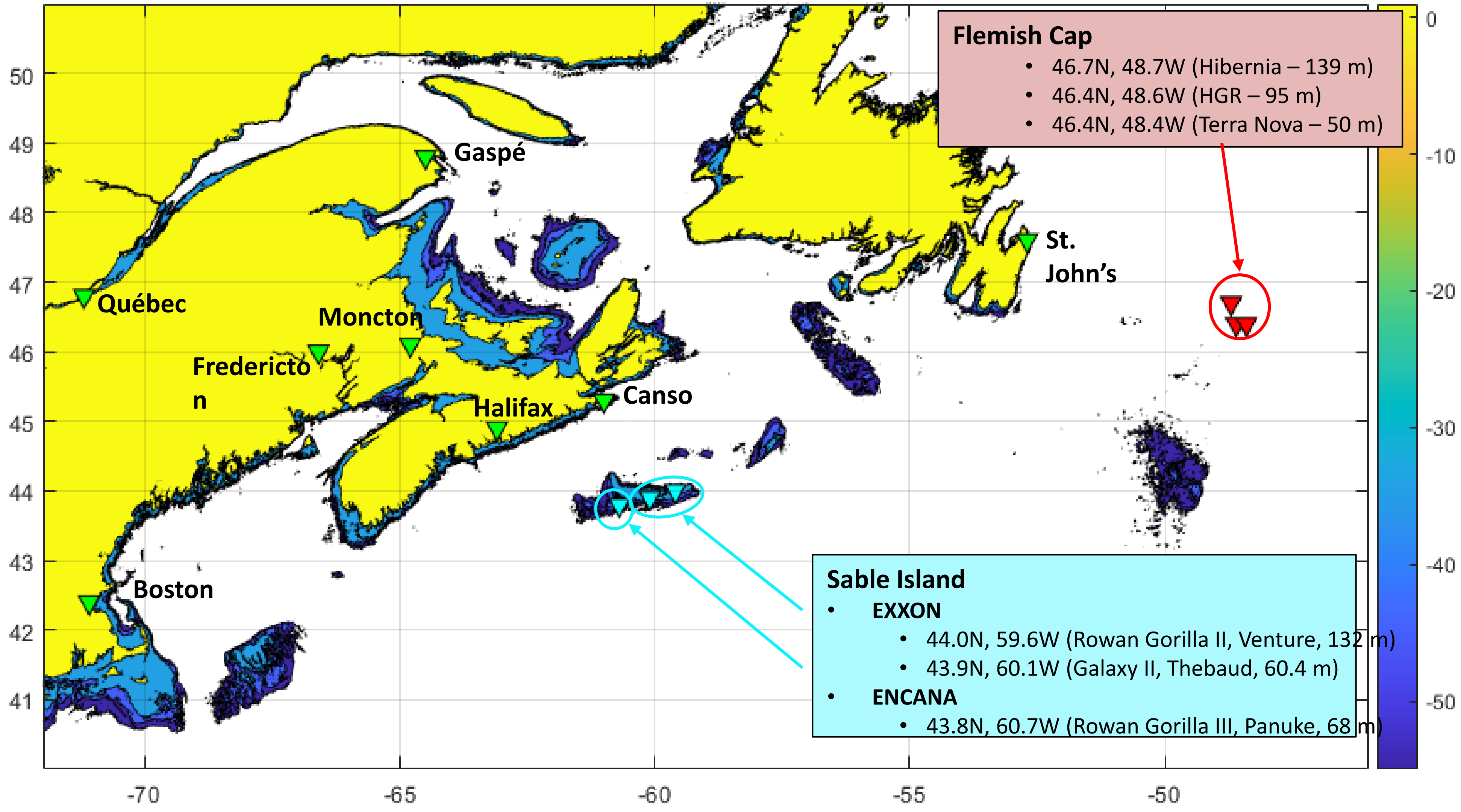
Scope, Method, Objective, and Presentation

- Motivation and Scope
  - **Offshore wind (OSW)** at is a non-emitting energy technology seeing growing interest
  - This project presents work conducted for the Nova Scotia Department of Natural Resources and Renewables (DNRR) to model OSW sites surrounding Nova Scotia
  - For economic reasons, only bottom-mounted turbines are considered, limiting the analysis to areas with **water depth of < 55 m**.
- Section 1: **Wind shear**
  - Use Environment and Climate Change Canada's hourly historical re-analysis weather and seastate database; **MSC50**
  - Use offshore **oil/gas rig anemometer data** to learn about seasonal wind shear, to scale wind speeds up to hub height.
  - Translated to power production (MW) using the **power curves** of a typical modern, large, OSW turbine
- Section 2: Evaluate **performance as a function of locations**
  - The annual average **wind speed** (m/s)
  - The **capacity factor** and potential energy productivity of OSW
  - How does OSW **correlate to existing wind** onshore (of which there will be >950 MW within planning horizons)
  - Evaluate '**reliable' wind capacity** when it's needed most.
  - What are the impacts of **spreading capacity across multiple sites**?
  - What **characteristics of the electrical system** are important to consider?

Part 1: Understanding Wind Shear Offshore

Near hub height wind speed data from oil rigs

- Color gradient is depth in meters
  - White indicates depth greater than 55 m
  - Yellow indicates land
- Offshore oil & gas exploration vessels have environmental monitoring stations onboard.
  - Though gathering data is not their top priority.
- Anemometer data source locations are identified



Near-surface wind speed data: MSC50 Reanalysis Dataset

- MSC50 (Meteorological Service of Canada)
  - Wind & wave time series data from hindcast models produced by Fisheries and Oceans: https://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/MSC50-eng.html
  - MSC50 wind speeds (m/s) are 1-hour averages of wind measured at 10 m above sea level and are distributed by http://oceanweather.net/MSC50WaveAtlas/
- MSC50 Atlantic
  - 1-hour time steps from Jan 1954 to Dec 2018
  - 0.1 ° grid in the Maritimes & 0.5 ° grid in the North Atlantic basin

Anemometer & MSC50 Wind Speed Data Description

Region	Data Set	Location	MSC50	Elevation	Period	*Note
Sable Island	EXXON 1999	44.0N, 59.6W	Same location @10 m	**132 m**	Jan – Dec 1999	Only 1 year of data
	EXXON Aggregate	43.9N, 60.1W	Same location @10 m	60.4 m	Jan – Dec 2008/09/10/12/14/16	Gaps within the data
	ENCANA 1999	43.8N, 60.7W	Same location @10 m	68 m	Jan – Dec 1999	Only 1 year of data
Flemish Cap	Hibernia	46.7N, 48.7W	46.5N, 48.5W @10 m	**139 m**	Avg of 10 years from Jan 1999 – Jul 2009	Data averaged over 10 years
	Henry Goodrich (HGR)	46.4N, 48.6W		95 m	Avg of 10 years from Feb 2000 – Jun 2009	Data averaged over 10 years
	Terra Nova	46.4N, 48.4W		50 m	Avg of 2 years from Aug 2007 – Jul 2009	Data averaged over 2 years

Wind Speed Data

- Anemometer data is only available for certain periods and certain sites
- Reanalysis wind data is available for the period of interest, and at all sites, but reports at 10 m above sea level
  - 10m resource is not the same as hub height resource (~150 m)
- A transfer function is necessary to scale the wind speed up from 10 m to nominal hub height at 150 m
- The transfer function is called the "shear ratio", which is just a ratio of wind speeds.

- Average Monthly Wind Speed (Avg Monthly recorded WS values) are used to assess seasonality

Seasonality of Wind Speed, Anemometer Data

- Average monthly SW at six location
  - 3 at Flemish Cap (red)
  - 3 at Sable Island (blue)

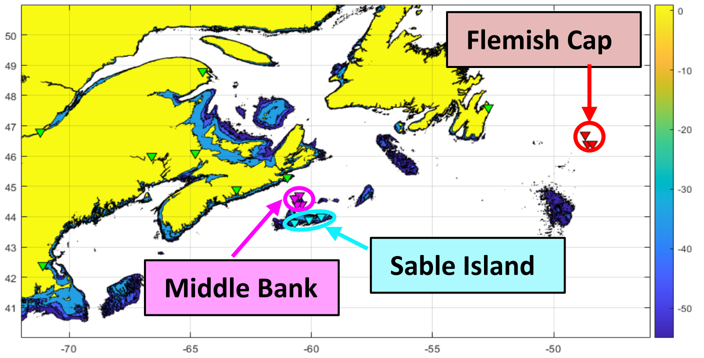
- Flemish Cap data (red) & Exxon Aggregate data (blue diamonds) are relatively smooth curves since they come from averaging multiple years of data

- Some Sable Island sites are based on incomplete months resulting in a possible sampling bias where more samples were taken at higher wind speeds (see next slide)

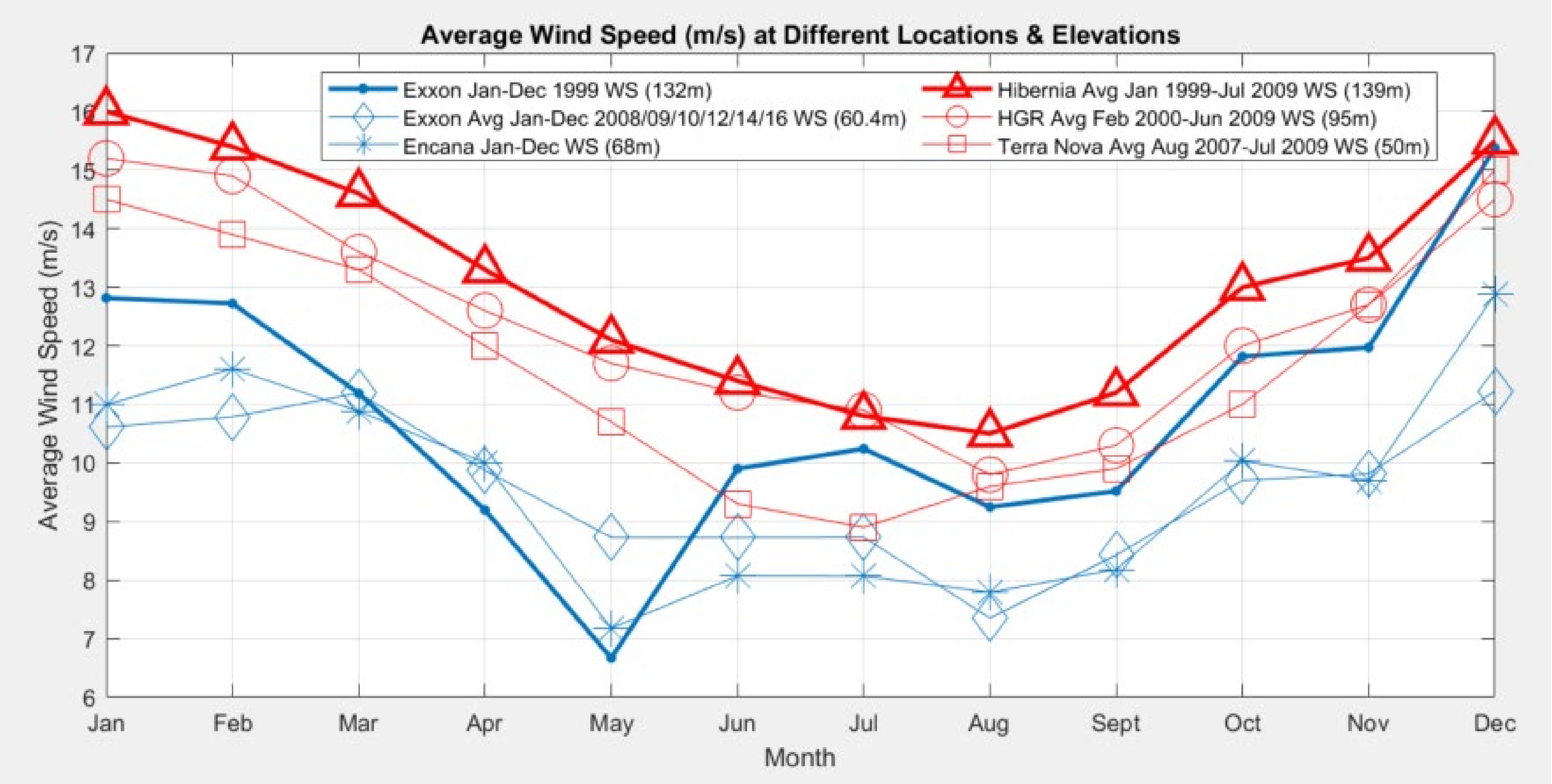
- Exxon 1999 (blue dots) & Encana 1999 (blue stars) values represent one (1) year of data (1 month per point), so are more variable.

- At all measurement locations and in all months, higher elevations have higher wind speeds

- Flemish Cap has higher wind speed in general compared to Sable Island



Near Sable Island
Flemish Cap
Bold Lines – Hub Height



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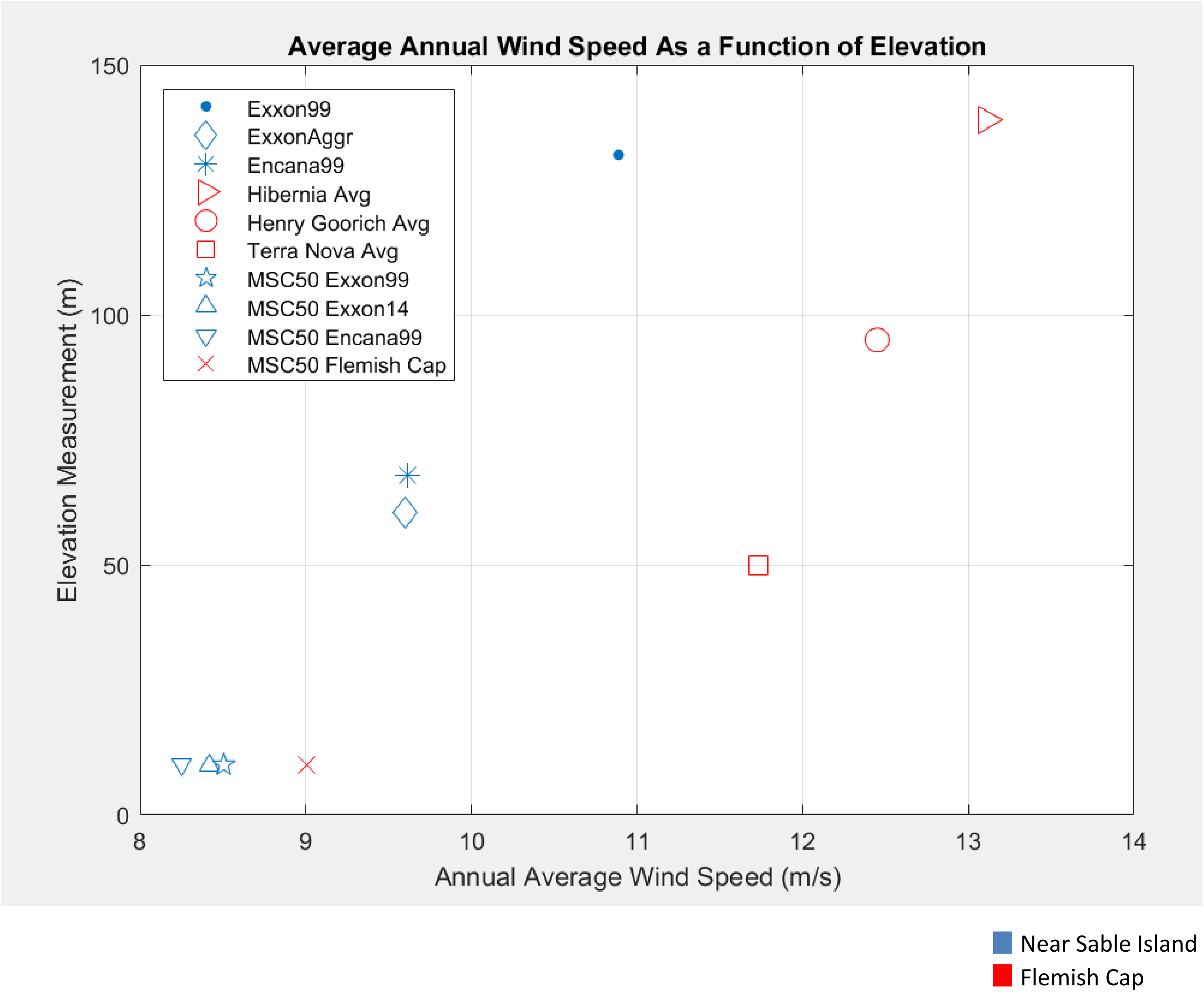
Wind Speed vs Elevation

- Annual average wind speed vs elevation of three (3) sites near Sable Island and three (3) at Flemish Cap with corresponding annual average MSC50 values

- Wind speed increases with elevation
- Similar ratios are seen at Sable Island & Flemish Cap

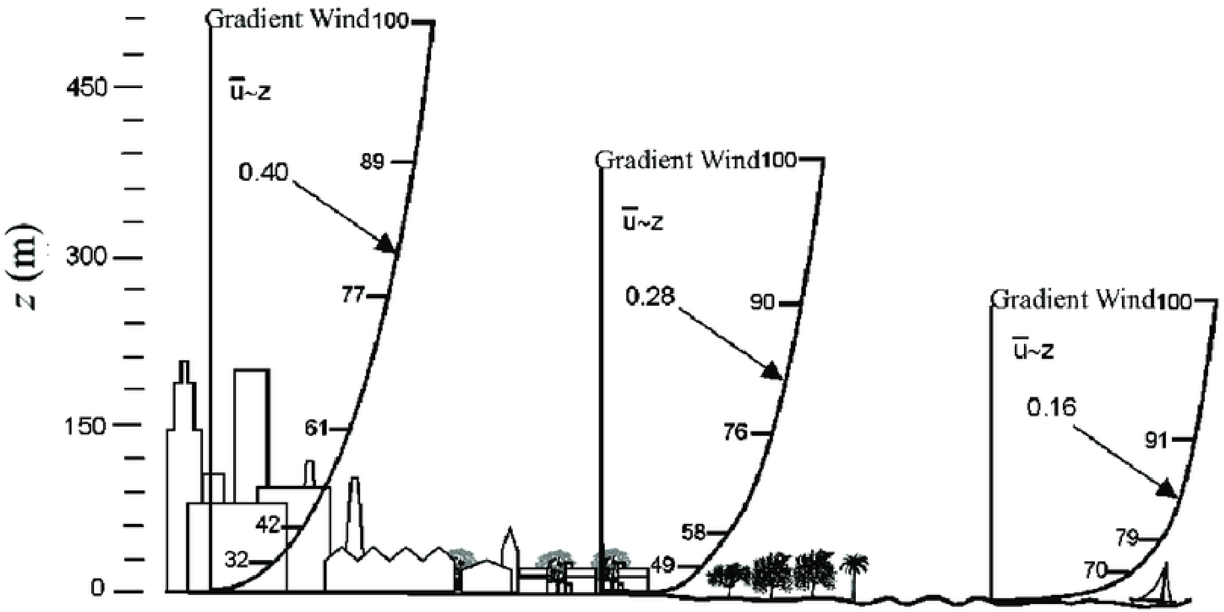
- The slope of the plot approximates wind shear



Intro to Alpha – Wind Shear 'Power Law'

- Shear is often quantified as a power law exponent alpha (α)
  - Equation on right
- Because we have data from a variety of anemometer heights, we use alphas rather than wind speed ratios to remove measurement height from consideration
- In the equation at right, *u* is wind speed, *z* is measurement elevation, and subscript *r* is reference data
  - MSC50 data in this case
- Rougher surfaces produce more vertical mixing which produces lower shear ratios and lower alphas

$$\frac{u}{u_r} = \left(\frac{z}{z_r}\right)^{\alpha}$$



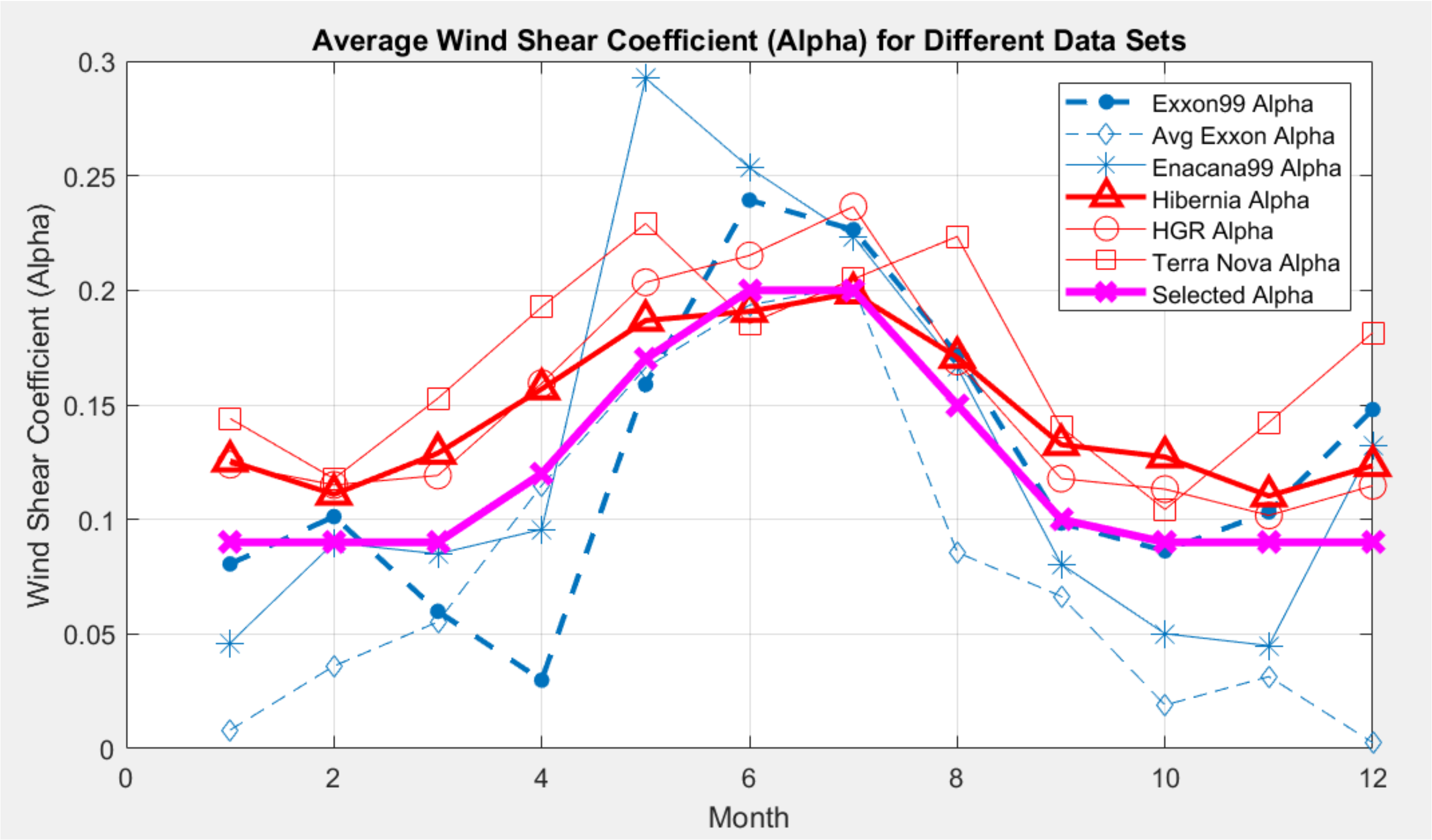
Section Output: Representative Shear Coefficient (α)

- All sites show higher α values in the Spring & Summer than in the Fall & Winter
- Winter values from Flemish Cap (red) are higher than those from Sable (blue)

- Selected α (Magenta)
  - Fall & Winter constant
  - Spring rising, peak in mid-Summer and falling through the end of Summer

- Outcome

  After selecting these alphas, we transfer them back to a shear ratio to represent the difference in wind speed between 10 m MSC50 data and 150 m hub height



Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Selected Alpha	0.09	0.09	0.09	0.12	0.17	0.20	0.20	0.15	0.10	0.09	0.09	0.09
10:150 m Ratio	1.28	1.28	1.28	1.38	1.58	1.72	1.72	1.50	1.31	1.28	1.28	1.28

Part 2: Relating offshore wind to energy needs

Hub height Wind Speed

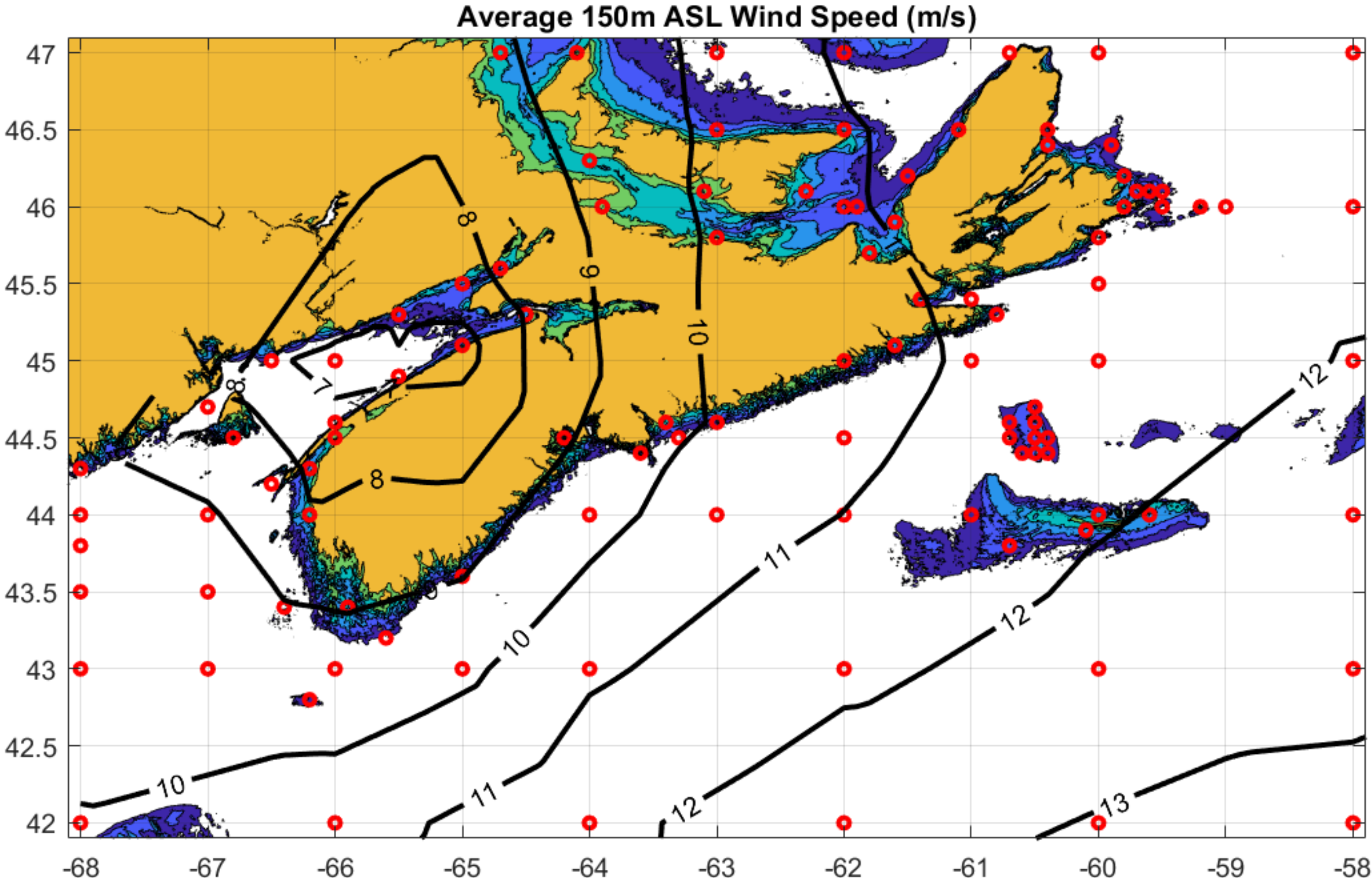
GUIDE

- How does hub height wind speed vary around the region? The unit is meters per second (m/s).
- Annual average wind speed (m/s) at 150m above sea level
- Areas of suitable depth for ground mounting (<55 m) are colored blue
- **Note: disregard values over land**

RESULTS

- Most areas average > 9 m/s
- Many areas average > 11 m/s
- This makes this **an exceptional resource**, beyond "Class 1" in NREL classification scheme (table, bottom)

- Notes
  - there is seasonal variability (winter peaking, as is load load)
  - Uncertainly exists around **geographic variability of vertical wind sheer**. More wind data in diverse areas would improve our understanding.



Fixed-Bottom Offshore Wind Resource Classes

Wind Resource Class	Min. Wind Speed (m/s)	Max. Wind Speed (m/s)	Average Wind Speed (m/s)	Wind Speed Range (m/s)	Percentile Range of Total Resource Potential (%)
1	9.98	10.33	10.24	0.35	<2%
2	9.31	9.98	9.82	0.67	2%–4%
3	9.13	9.31	9.20	0.18	4%–8%

Prologue: turning wind speed into power output via a Turbine Power curve

- Technical Report produced by the International Energy Agency (IEA)
  - https://www.nrel.gov/docs/fy20osti/75698.pdf
  - Defines the IEA 15-MW Offshore Reference Wind Turbine
  - This report was selected to use as a baseline for power output in our offshore energy model
- 15-MW Reference Turbine Characteristics
  - Fixed-bottom monopile support
  - Direct-drive machine (Class IB)
  - Rotor radius of 120 m
  - Hub height of 150 m
  - This machine is based upon European designs and may not be ideally suited to the Nova Scotia offshore wind resource

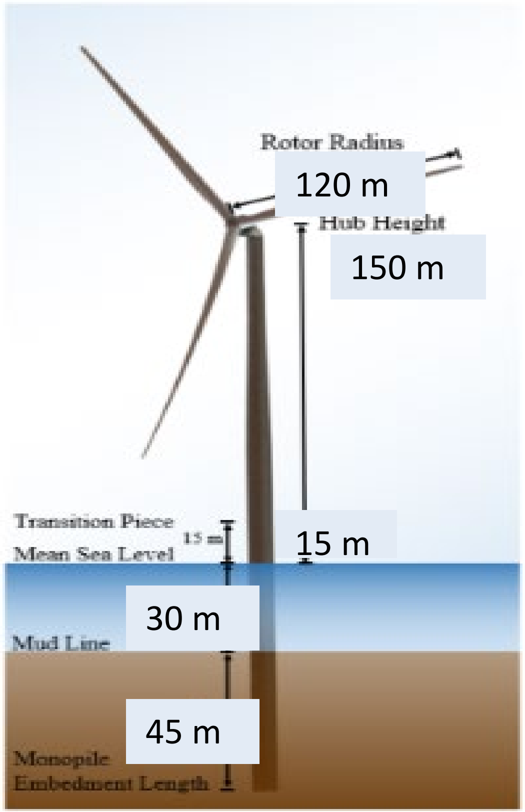
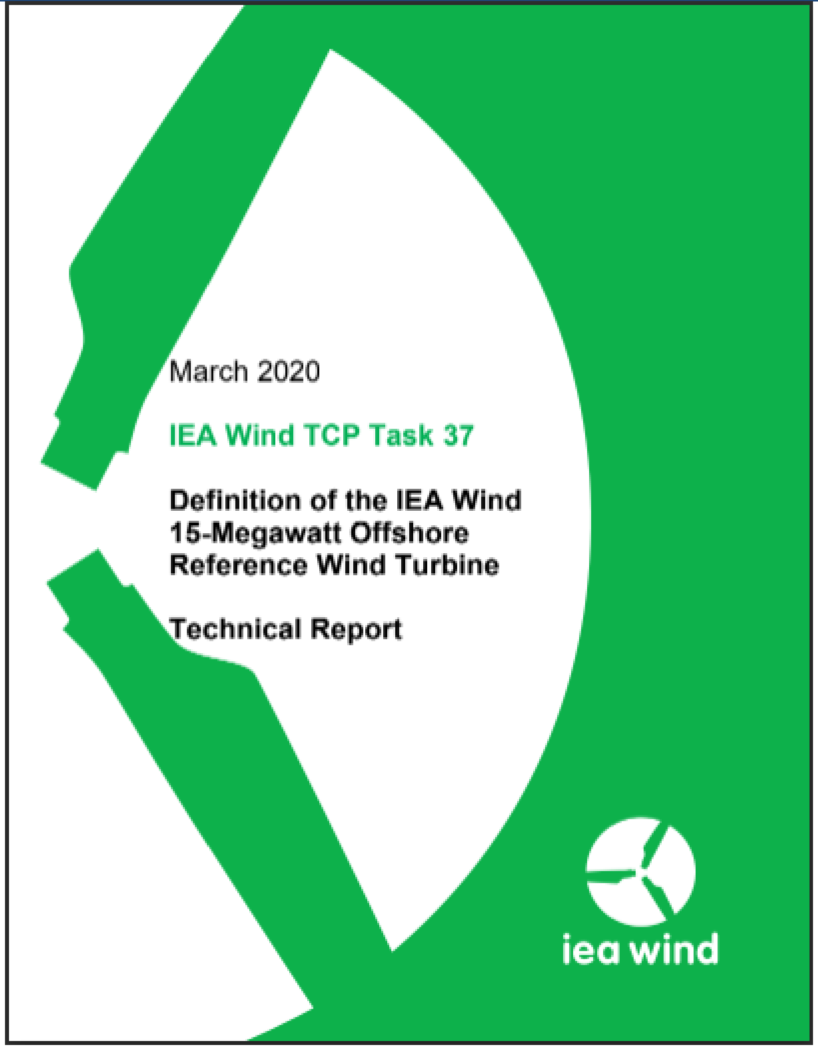


Figure ES-1. The IEA Wind 15-MW reference wind turbine



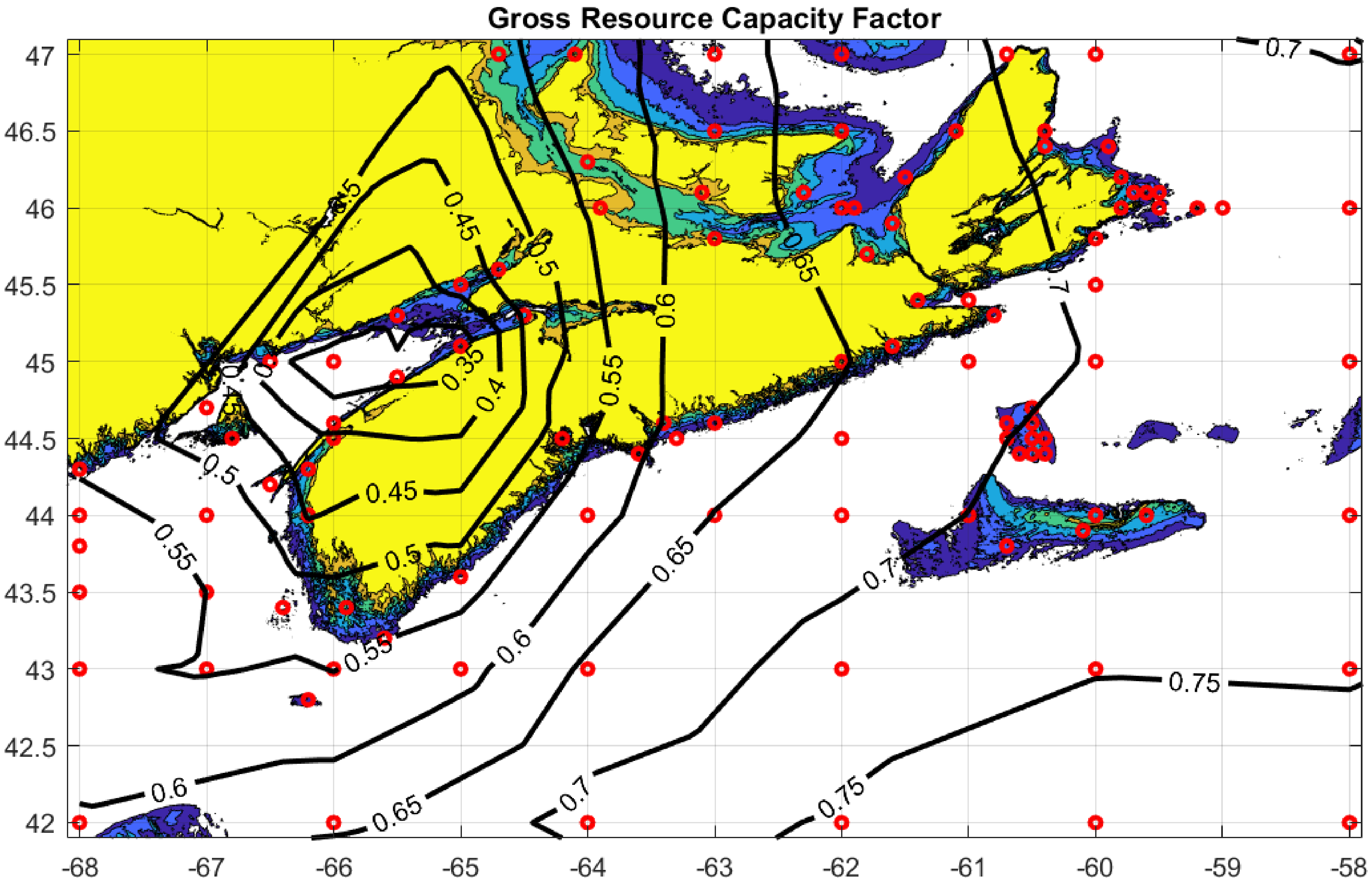
Capacity Factor

How much energy would OSW produce?

- Capacity factor is the annual average power (MW) divided by the nameplate rated capacity (MW). It is unitless and may range from 0 to +1. **Higher capacity value is better and will produce more energy per turbine.**
- Capacity factor is influenced by the **wind speed and the turbine power curve**.
- Gross CF shown here **does not address curtailment**; if generation occurs when it cannot be used, stored, or exported due to load or transmission limitations, functional capacity factor will be reduced.
- **Note: disregard values over land**

<u>RESULTS</u>

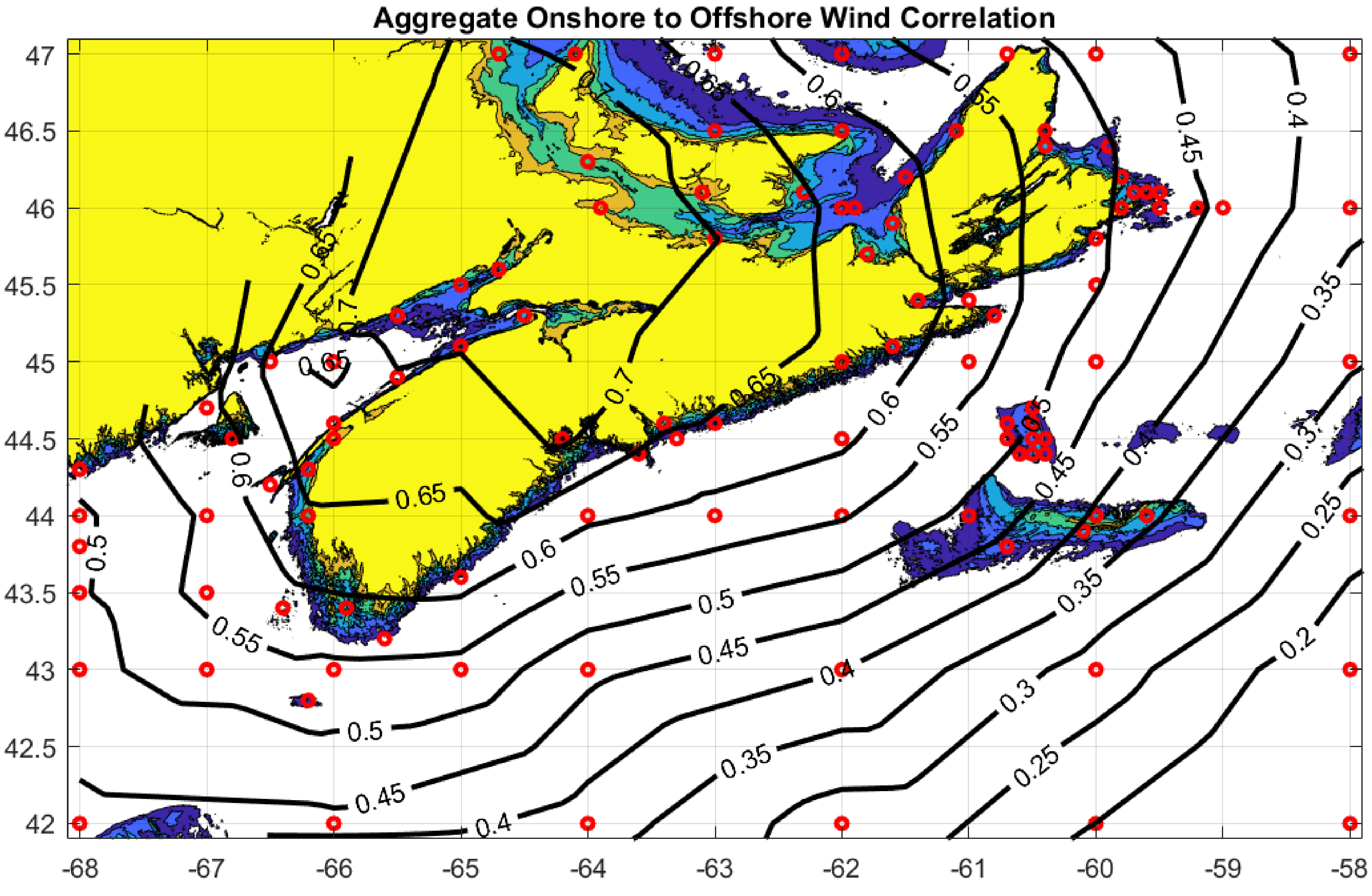
- Capacity factors are higher than those:
  - onshore in NS (up to ~0.45)
  - at existing offshore wind sites (e.g., some in the North Sea reach ~0.60)
- Productivity improves substantially North-East in the province or further offshore
  - Sable Bank
  - Eastern Cape Breton



Correlation between Onshore and Offshore Wind

How similar is the OSW resource to existing onshore wind?

- Correlation is unitless, and ranges from -1 to +1.
- **A lower correlation to existing resources (less similarity) is better.**
- Higher correlation shows the effective centroid of the onshore wind resource.
- Wind event timing varies on the **spatial scales of weather systems**, so correlations do too.
- **Note:**
  - **values over land are probably about right** (though not separately evaluated)



RESULTS

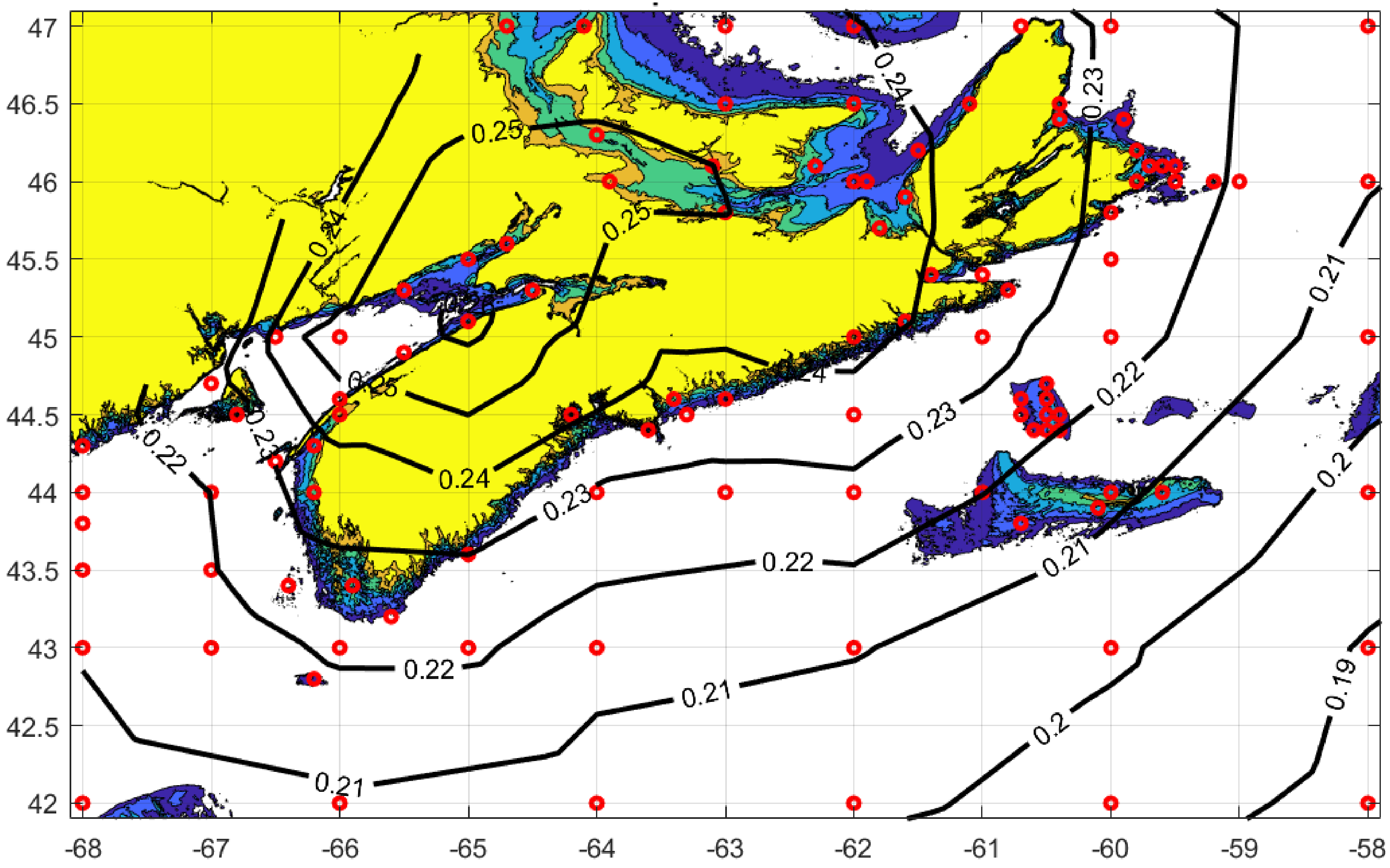
- Offshore banks and eastern Cape Breton offer best resource diversity.
  - Brown's Bank
  - Middle Bank
  - Sable Bank
  - Scatarie Island Shoal

Export/curtailment fraction (when loads are low)

- 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**



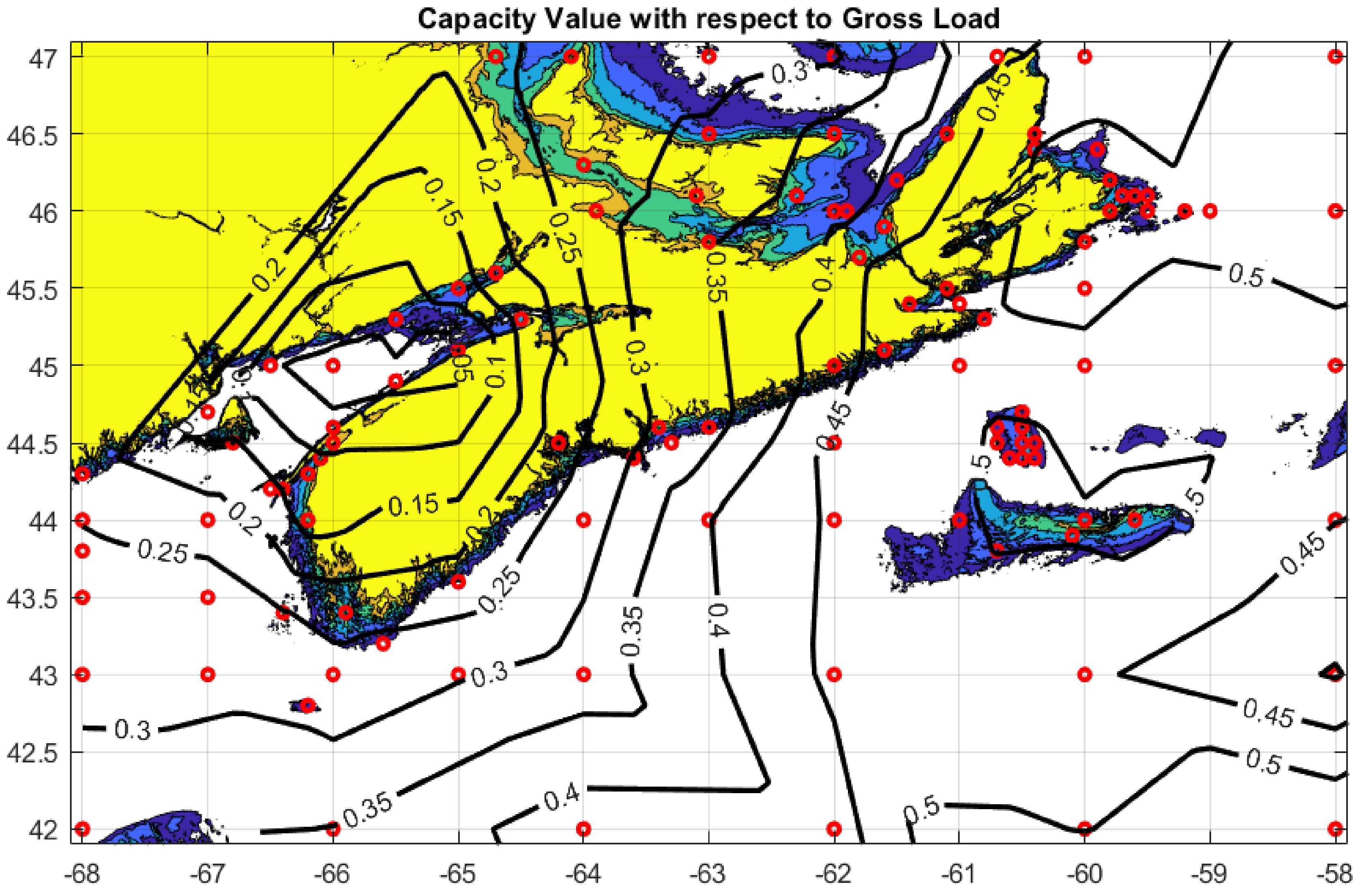
Capacity Value with Respect to Gross Domestic Load (when loads are high)

GUIDE

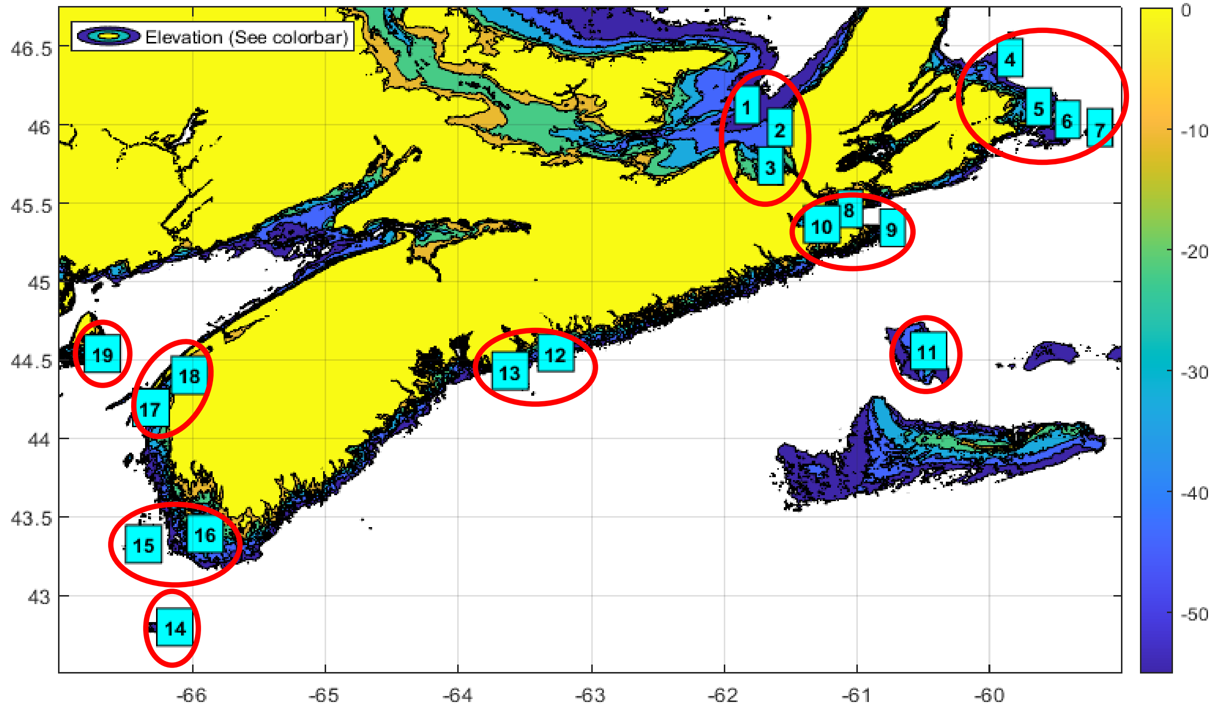
- How much reliable production does each site offer when the grid needs it the most? This is unitless, ranging from 0 to +1. A value of 1 means full power generation occurs when load is high. A value of 0 means no generation occurs when load is high (this is bad).
- Nova Scotia electrical load is winter peaking and occurs during cold, windy periods.
- **Higher values are better.**
- **Note: disregard values over land**

RESULTS

- The values are the 15th percentile wind production during the highest 5% provincial load
  - Values are halved when considering load net of onshore wind and Muskrat Falls
- Values range from near zero in the Bay of Fundy to >25% in eastern Cape Breton and Middle Bank.



Major Finding: Distribute Capacity



GUIDE

- MAP: To assess the regional distribution of OSW farms **we grouped nearby** locations as per the red circles, giving 9 total sites to select from.
- TABLE: Column 1 gives a **metric to be optimized** based on distributing OSW turbines across multiple farms to achieve a total 4.4 GW of installed capacity.
- Row 2 gives the estimated **maximum installable capacity** (MW) at a particular site based on bathymetry and size limitations. Note that each site is limited to 1600 MW because it is unlikely that all OSW would be installed in only one key area.
- Blue cells of the lower 4 rows **give the capacity (MW) allocation** of each wind farm site based on the optimized metric
- The right 4 columns give the performance of that metric to show sensitivity.

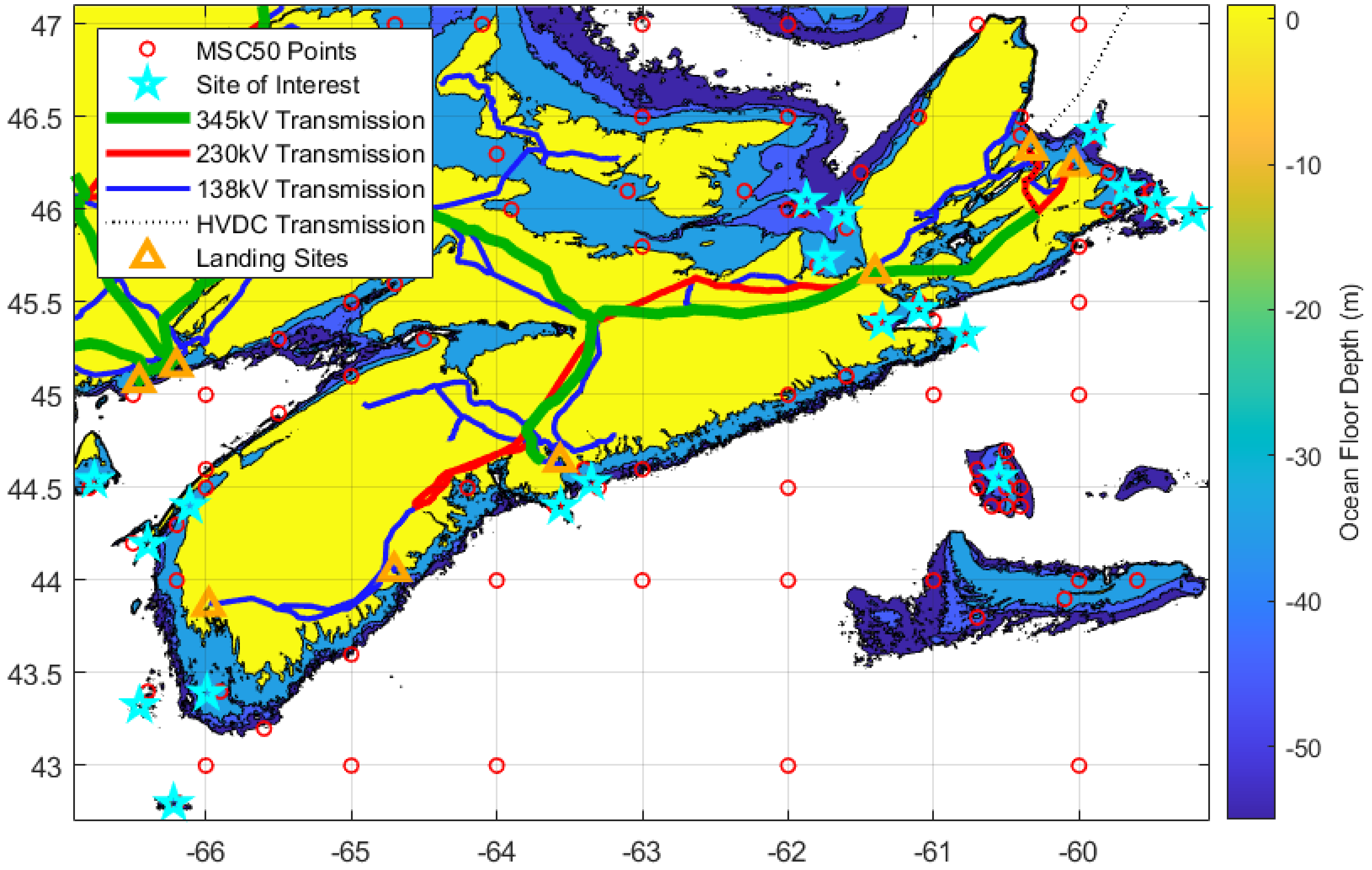
RESULTS

- To **generate the most** electricity (Cap. Fact. row)
  - Maximize East Cape Breton and Middle Bank, and build the rest in Chedabucto Bay
- To **minimize curtailment** (Least Time>90% row)
  - Put smaller projects almost everywhere
- To produce the most **stable output** (Coef. Var. row)
  - Put smaller projects almost everywhere

Criterion to Optimize	StGeorge_Bay	East_CB	Chedabucto_Bay	Middle_Bank	Halifax	Browns_Bank	SW_NS	Digby_Neck	Grand_Manan	TimeAt_0	TimeOver_90	Cap_Fact	Coef_Var
Site Max (MW)	3405	5010	1395	3600	1500	615	1695	1395	660	0	0	0	0
Least Time @ 0	0	1600	400	800	400	400	400	0	400	**0.03**	22.9	64.7	46
Least Time > 90%	0	1200	0	400	800	400	0	1200	400	0.04	**17.4**	58.4	50
Cap. Fact.	0	1600	1200	1600	0	0	0	0	0	0.95	45.2	**70.0**	49
Coef. Var.	0	1600	0	1600	0	400	400	0	400	0.12	23.7	65.8	**45**

Potential Issues

- For more than a couple hundred MW, there are relatively **few potential onshoring locations** (without additional transmission upgrades)
- Orange triangles show locations of
  - Active & inactive coastal power stations
  - Large coastal transmission substations
- For very large projects, subsea **HVDC ties to New England** grid points may be appropriate
- Power generally flows NE to SW, so connecting **further SW** decreases transmission congestion.
- HRM is load center, with onshoring sites.
- Different locations present different benefits; More data on resource variability are needed.
  - SW NS
  - Eastern CB
  - Offshore banks
  - Close to HRM



Summary

- There is a **world class offshore wind resource** around Nova Scotia
- There are abundant areas with ocean depths suitable for ground-mounted turbines. **We group them into 9 different sites**.
  - (floating turbines are being developed, but are not commercially mainstream)
- **Different metrics favor different sites**:
  - Capacity factor, Capacity value etc. favor offshore banks and Eastern CB
  - Transmission congestion (and possible link to New England) favor further Southwest
  - Cost of subsea cables disadvantages offshore banks
- **Distributing** offshore wind capacity across several sites offers multiple benefits:
  - Lower aggregate output variability (i.e., more stable resource)
  - Lower provider risk (multiple vendors / projects)
  - Smaller individual projects may avoid extensive (onshore) transmission upgrades
- More geographically diverse **resource data are needed** to refine our understanding of potentials and interactions with stakeholders.