Mapping O&M Strategy for US offshore wind farms

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2nd US Offshore Wind Conference & Expo

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Overview

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Reference O&M Concepts for Near and Far Offshore Wind Farms

- Understand impacts of metocean conditions on O&M costs
- O&M study of 5 offshore wind plants in the North Sea
- Tool: ECN O&M Access Tool
- December 2016

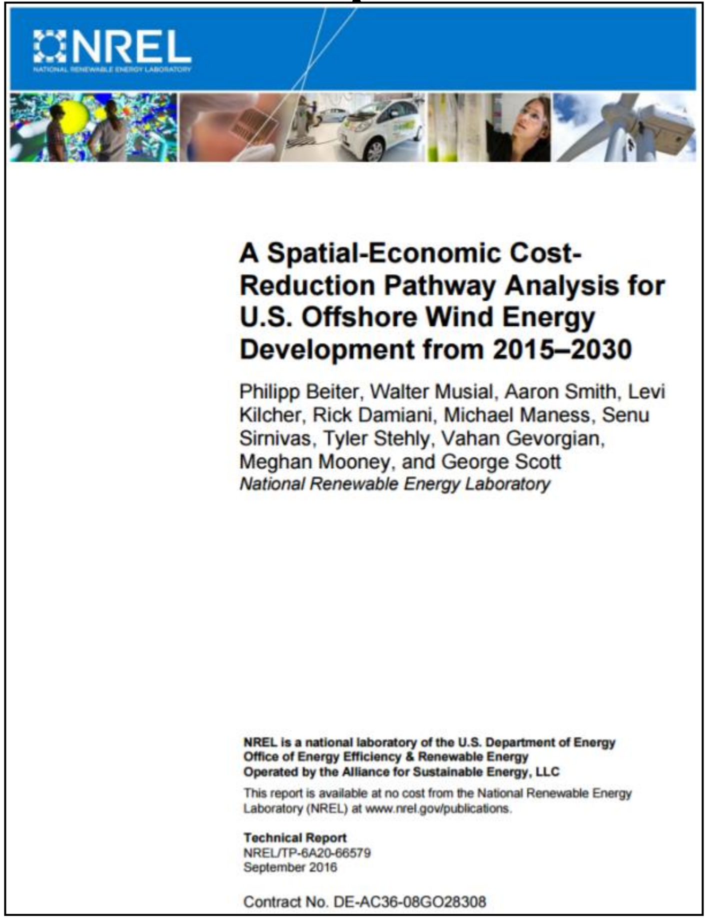
A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015-2030

- Quantify the impact of spatial characteristics of the U.S. offshore wind resource area on LCOE
- O&M specific tool: ECN O&M Tool
- September 2016

Mapping O&M Strategy for U.S. Offshore Wind Farms

- Collaboration between ECN and NREL
- O&M study of 6 offshore wind plants in the U.S.
- Tool: ECN O&M Calculator
- Anticipated joint publication 2017

NREL's Spatial-Economic Analysis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A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015–2030

Philipp Beiter, Walter Musial, Aaron Smith, Levi Kilcher, Rick Damiani, Michael Maness, Senu Sirnivas, Tyler Stehly, Vahan Gevorgian, Meghan Mooney, and George Scott
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Technical Report
NREL/TP-6A20-66579
September 2016

Contract No. DE-AC36-08GO28308

The analysis considers:

- 4 access strategies
  - Close to shore
  - Advanced close to shore
  - Medium distance
  - Far shore

Key variables:

1. Distance from O&M port
2. Metocean conditions

- 3 types of large maintenance strategies
  - In situ
  - Tow to port
  - Tow to assembly area

Distance from O&M Port

ECN

Distance to O&M Port (km)	Metocean Conditions "Mild" Site Mean Hs = 0.88 m Mean Wind Speed = 6.12 m/s[a]			"Moderate" Site Mean Hs = 1.39 m Mean Wind Speed = 7.32 m/s[a]			"Severe" Site Mean Hs = 2.50 m Mean Wind Speed = 6.61 m/s[a]		
10	CS[a]	MD[b]	FS[c]	CS+[d]	MD	FS	CS+	MD	FS
30	CS	MD	FS	CS+	MD	FS	CS+	MD	FS
50	CS	MD	FS	CS+	MD	FS	CS+	MD	FS
70	CS	MD	FS	CS+	MD	FS	CS+	MD	FS
90	***	MD	FS	***	MD	FS	***	MD	FS
110	***	MD	FS	***	MD	FS	***	MD	FS
150	***	MD	FS	***	MD	FS	***	MD	FS
200	***	***	FS	***	***	FS	***	***	FS
300	***	***	FS	***	***	FS	***	***	FS
400	***	***	FS	***	***	FS	***	***	FS
500	***	***	FS	***	***	FS	***	***	FS

[a] Mean wind speed at 10 m above mean sea level

[a] Close to shore

[b] Medium distance

[c] Far shore

[d] Advanced close to shore

*** Distance exceeds the 2-hour limit for transporting technicians between the O&M port and the project

Photo courtesy of Atlantic Wind Transfers

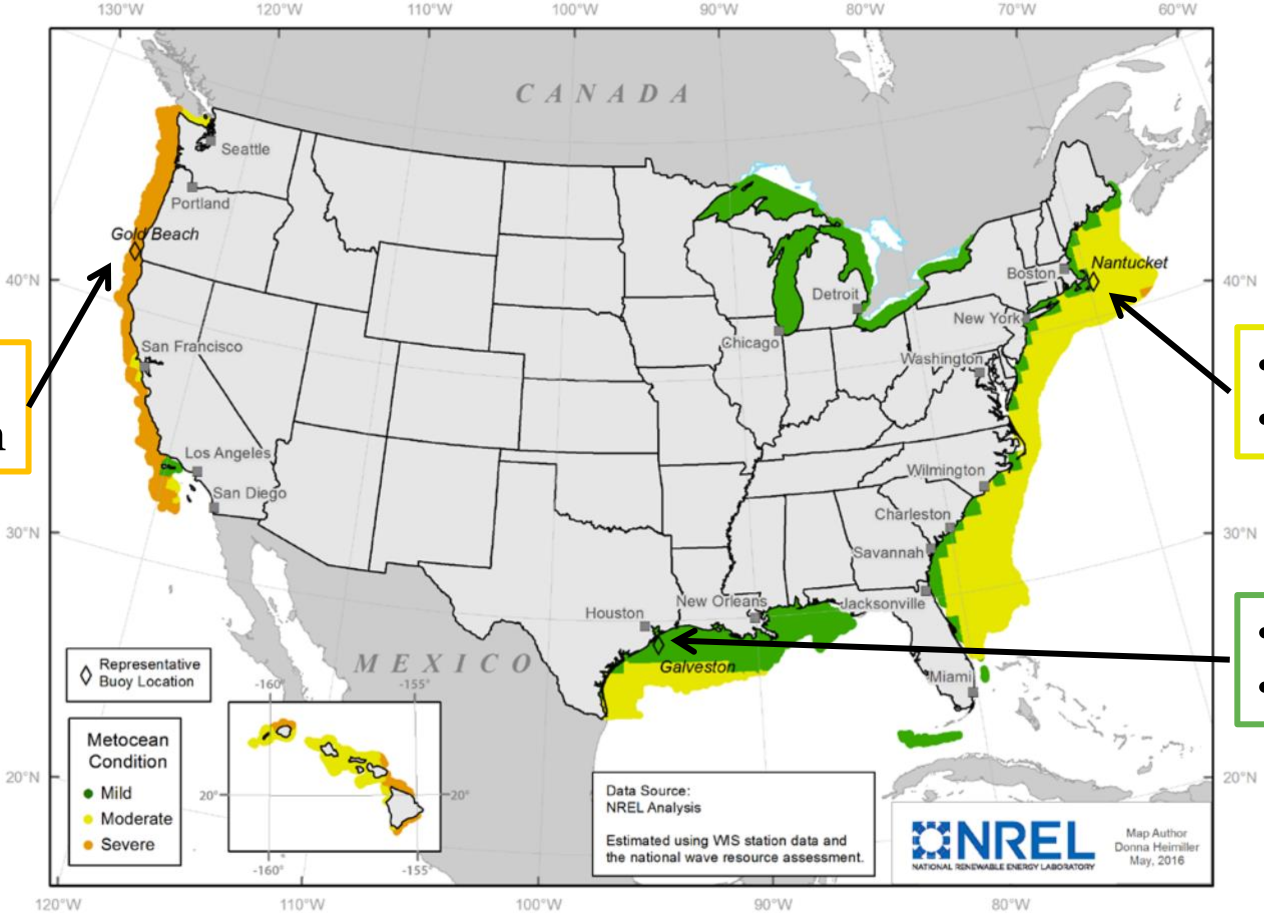
Image copyright © Mercator Media 2017

Source: http://www.esvagt.com

Representative Metocean Conditions

ECN

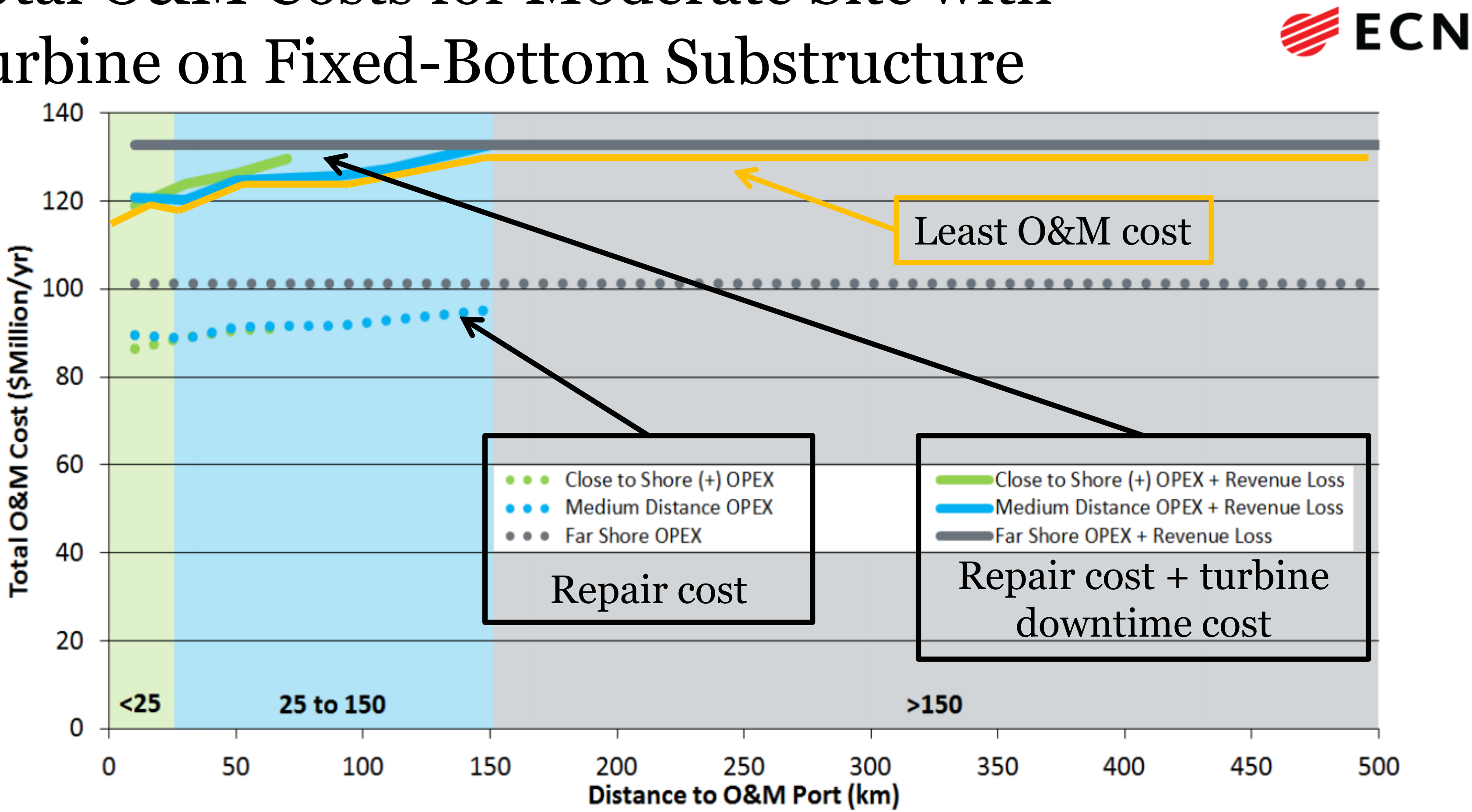
- Severe
- Hs ~2.5 m



- Moderate
- Hs ~1.39 m

- Mild
- Hs ~0.88 m

Total O&M Costs for Moderate Site with Turbine on Fixed-Bottom Substructure



Identifies least cost choice among the 4 access strategies


45°N
40°N
35°N
30°N
25°N
0 1000 2000 3000 km
Lake Erie
(Ohio)
New York
(New York)
Kitty Hawk
(North Carolina)
Channel Islands North
(California)
Corpus Christi
(Texas)
160°W
30°N
0 250 500 km
20°N
Oahu South
(Hawaii)
150°W
160°W

Wind Farm Capacity

345 MW (100 x 3.45 MW)

Mono-bucket (ice breaker) foundations

600 MW (100 x 6MW)

Fixed bottom foundations

600 MW (100 x 6MW)

Fixed bottom foundations

600 MW (75 x 8MW)

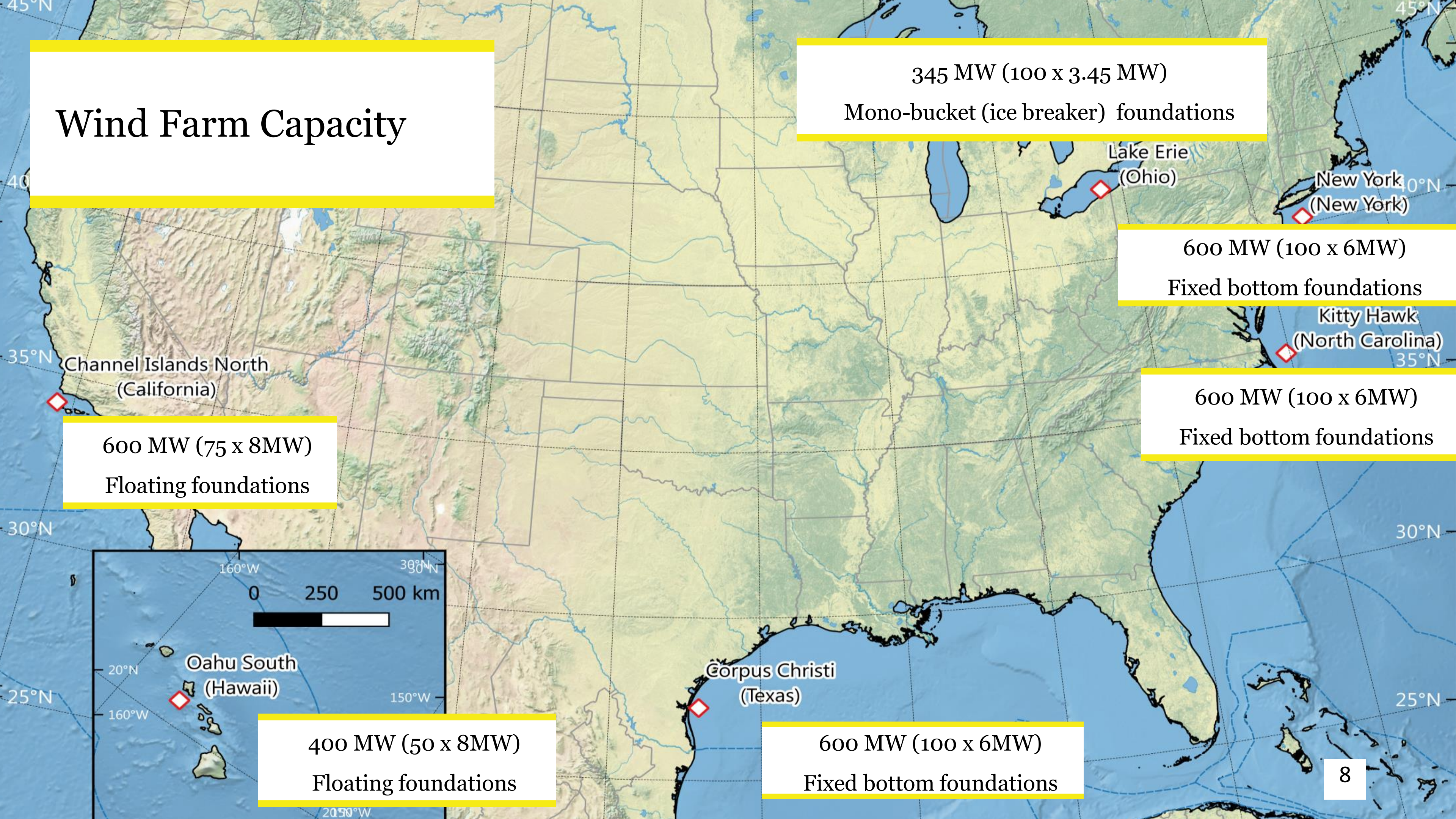
Floating foundations

400 MW (50 x 8MW)

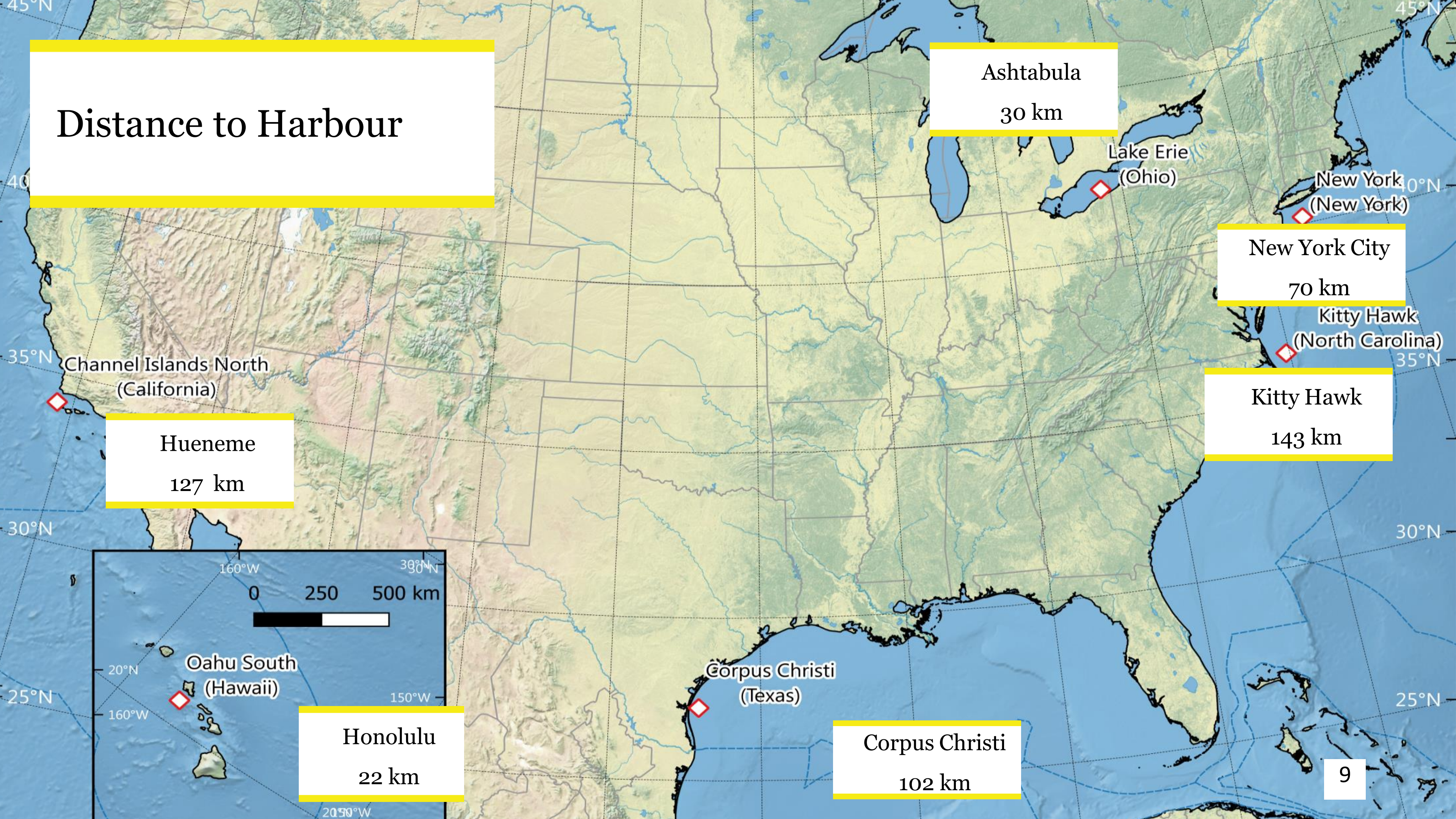
Floating foundations

600 MW (100 x 6MW)

Fixed bottom foundations



Distance to Harbour



Ashtabula
30 km

New York City
70 km

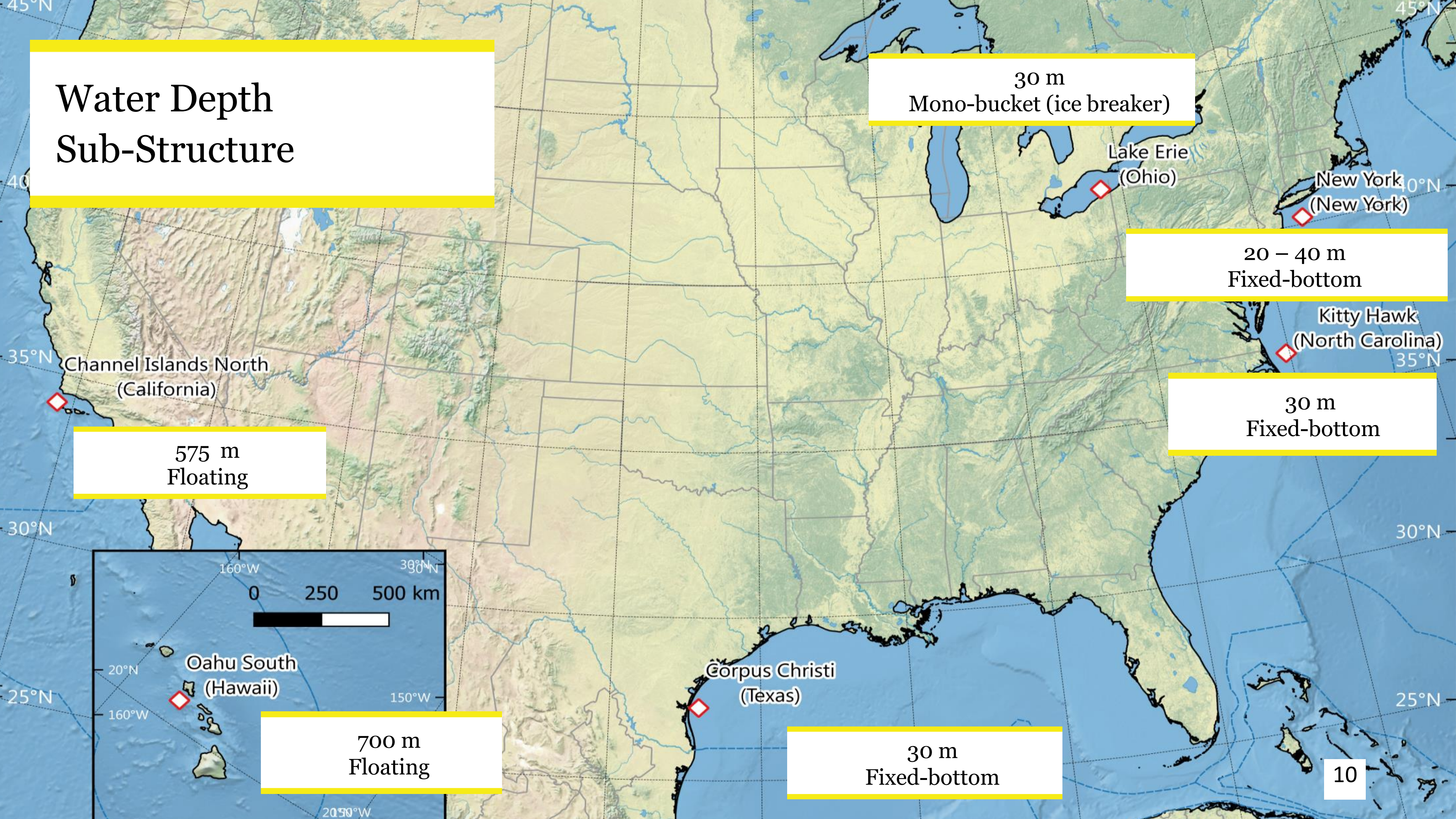
Kitty Hawk
143 km

Hueneme
127 km

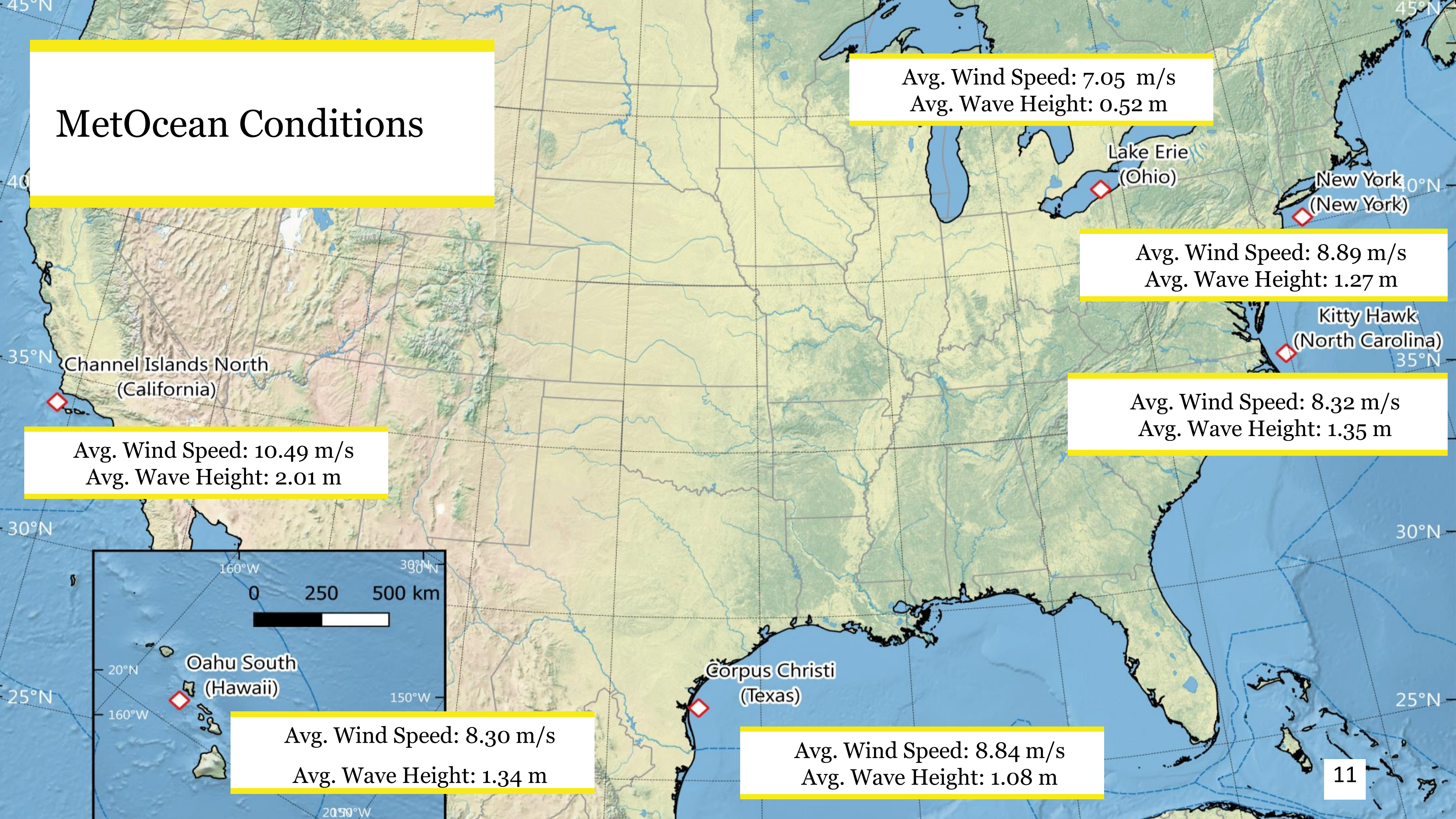
Honolulu
22 km

Corpus Christi
102 km

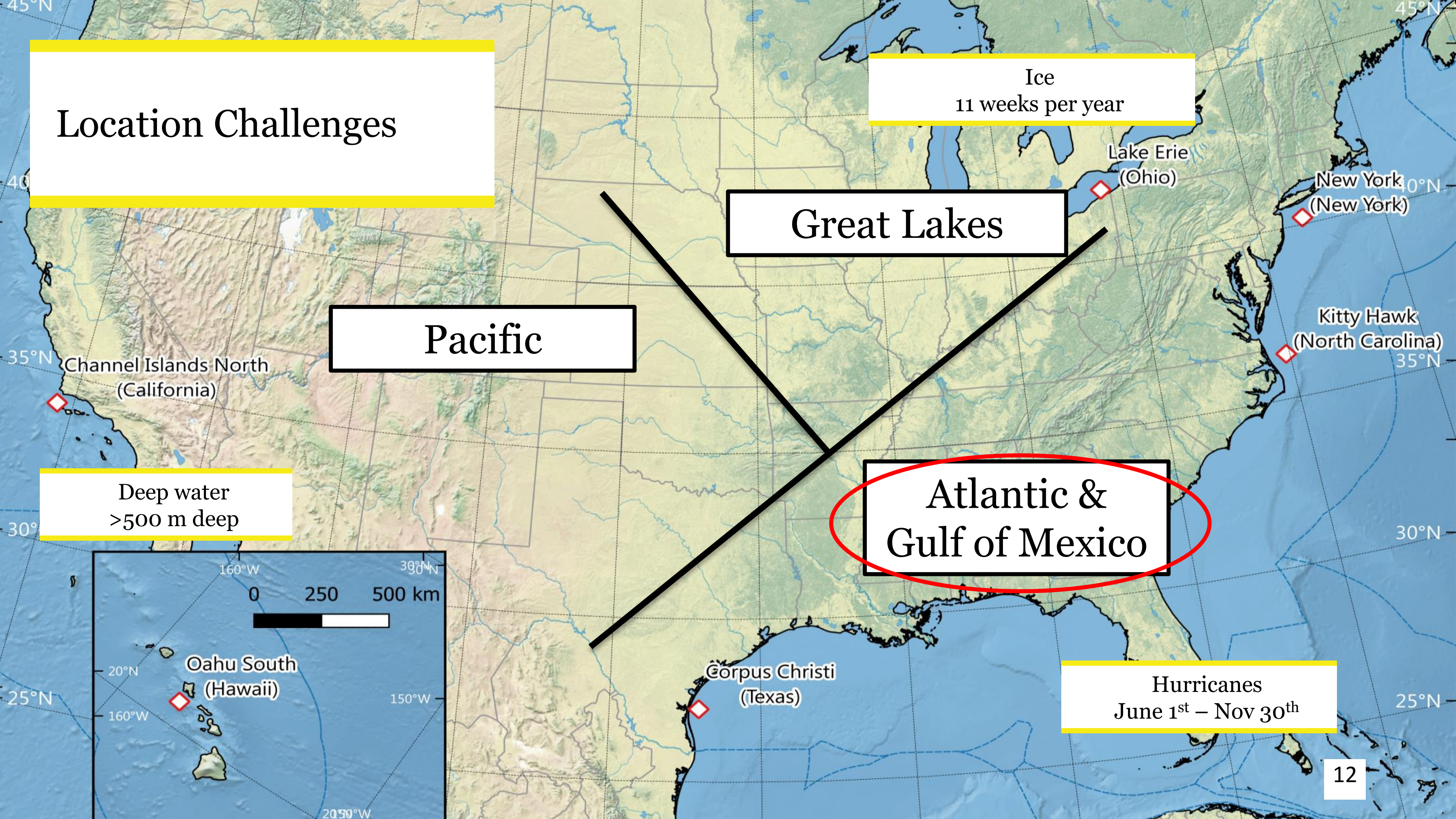
Water Depth
Sub-Structure



MetOcean Conditions



Location Challenges



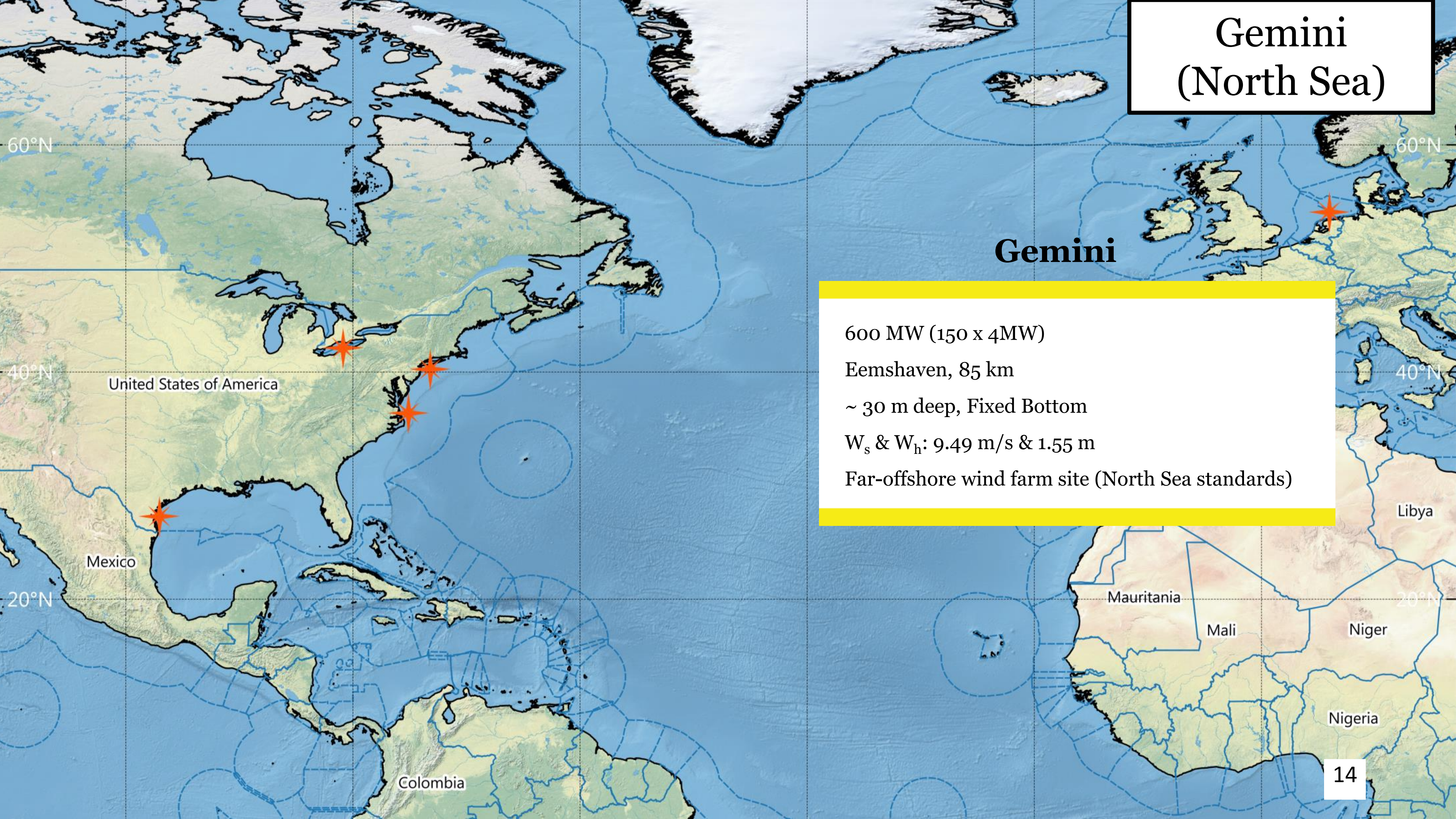
Ice
11 weeks per year

Deep water
>500 m deep

Hurricanes
June 1st – Nov 30th

Atlantic & Gulf of Mexico; Gemini (North Sea)

Gemini (North Sea)



Gemini

600 MW (150 x 4MW)

Eemshaven, 85 km

~ 30 m deep, Fixed Bottom

W_s & W_h: 9.49 m/s & 1.55 m

Far-offshore wind farm site (North Sea standards)

Atlantic & Gulf of Mexico; Gemini (North Sea)

600 MW (150 x 4MW)

85 km

~ 30 m deep, Fixed Bottom

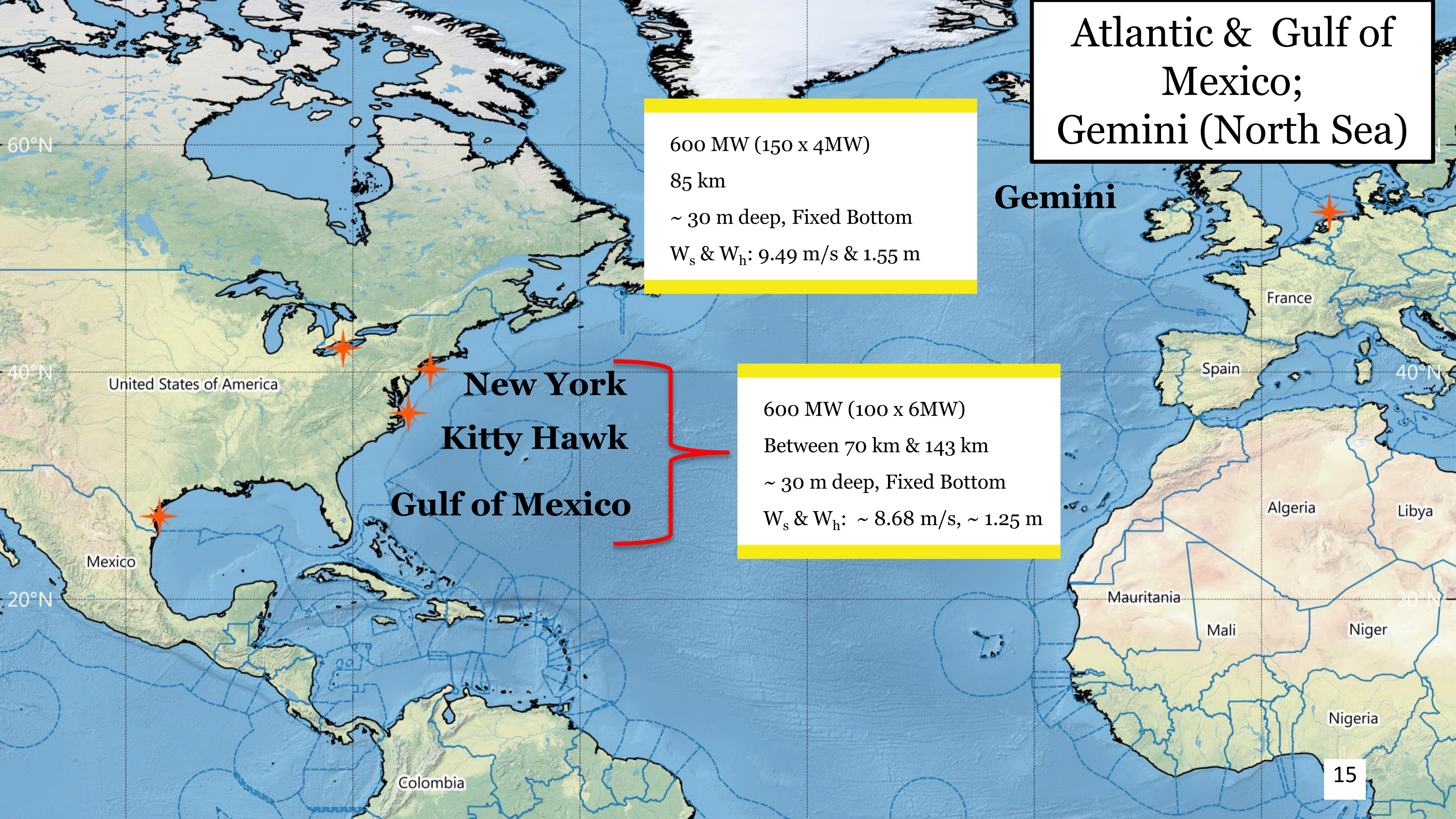
W_s & W_h: 9.49 m/s & 1.55 m

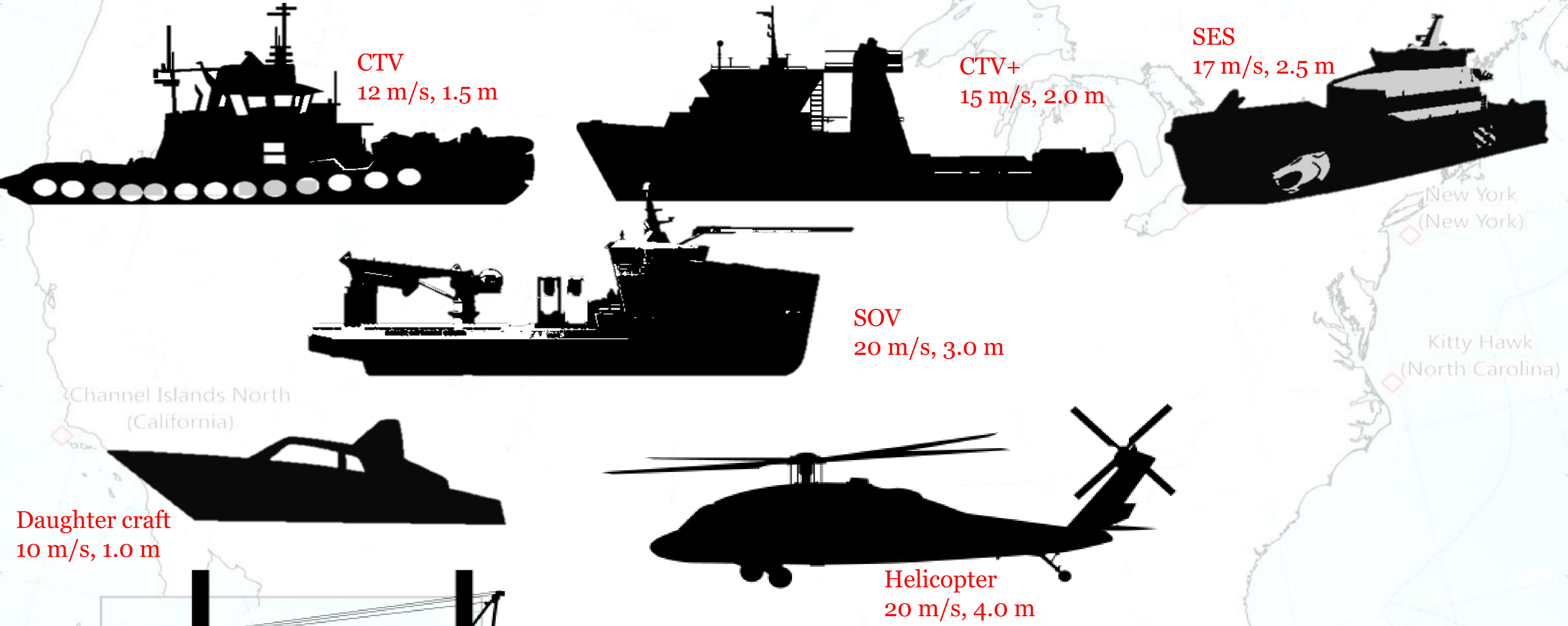
600 MW (100 x 6MW)

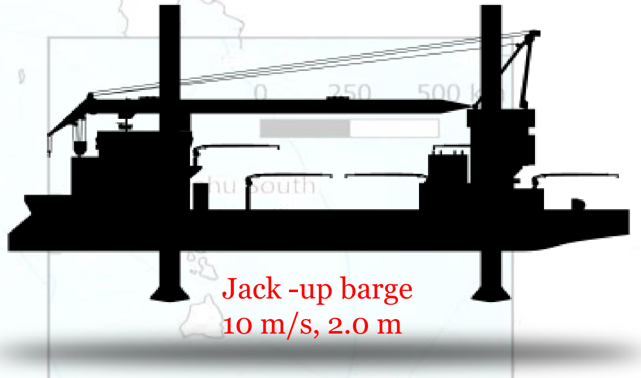
Between 70 km & 143 km

~ 30 m deep, Fixed Bottom

W_s & W_h: ~ 8.68 m/s, ~ 1.25 m







Vessels for replacement

O&M Strategy: Selection of the logistic solution for Gemini

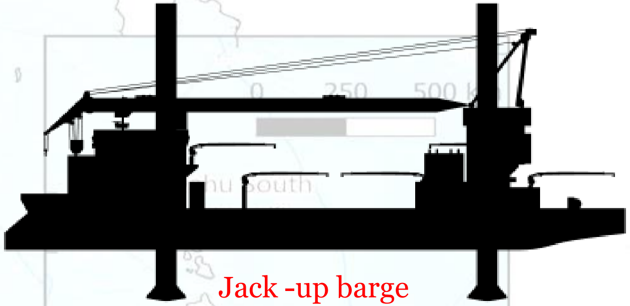
SOV
20 m/s, 3.0 m

Primary access Vessel

Daughter craft
10 m/s, 1.0 m

Secondary access Vessel

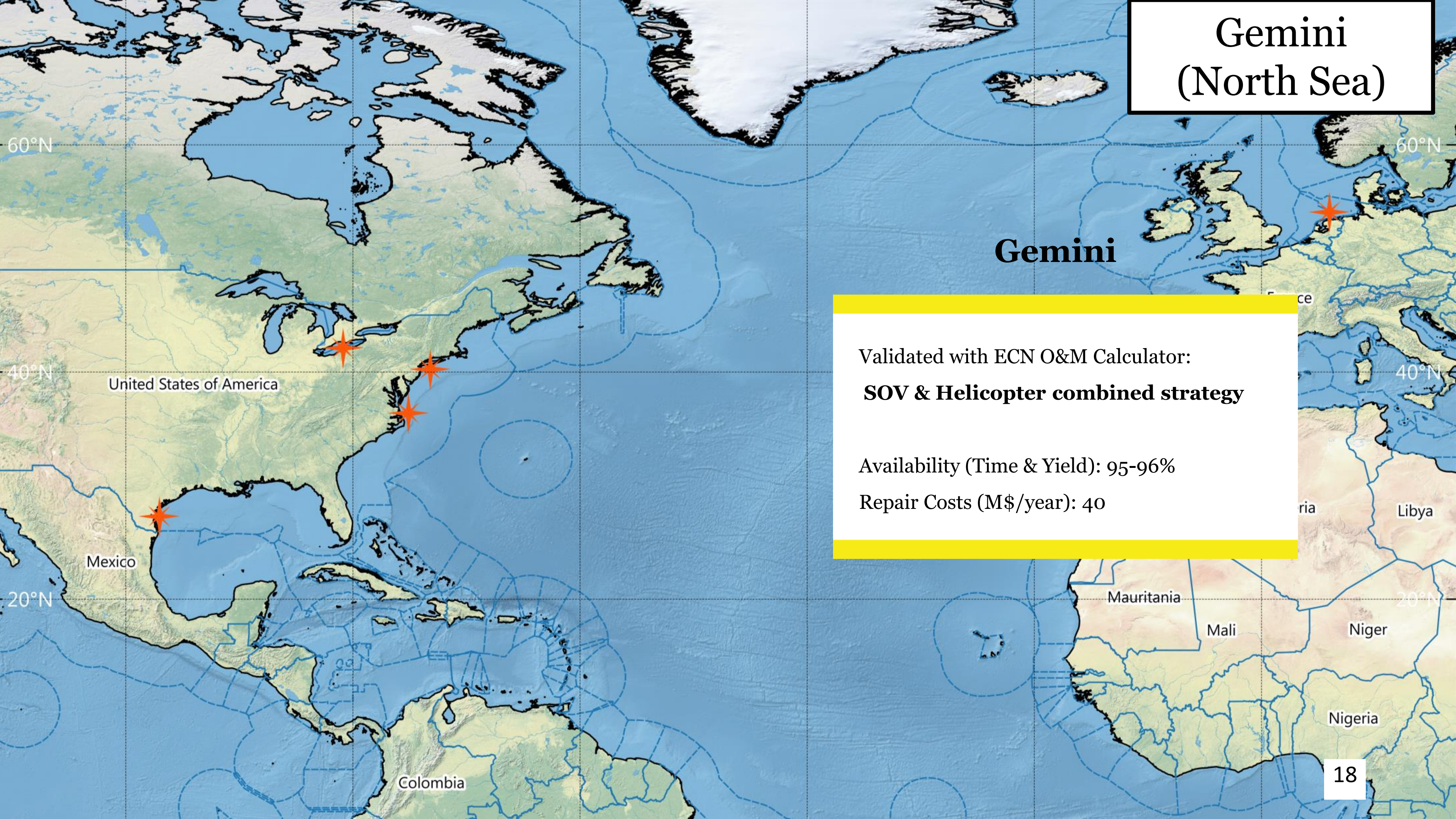
Helicopter
20 m/s, 4.0 m



Vessel for Replacement

Jack -up barge
10 m/s, 2.0 m

Gemini (North Sea)

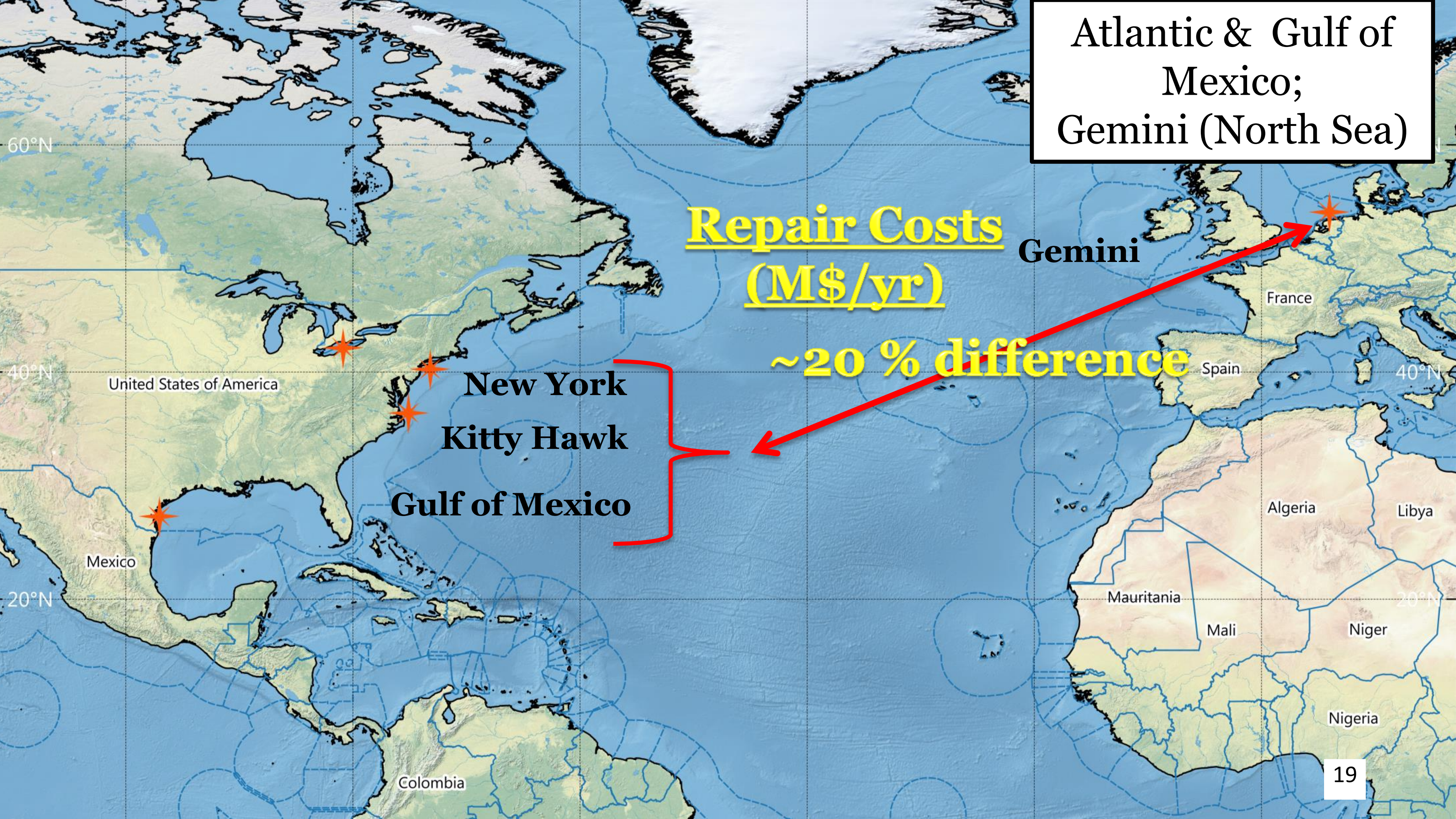


Validated with ECN O&M Calculator:

SOV & Helicopter combined strategy

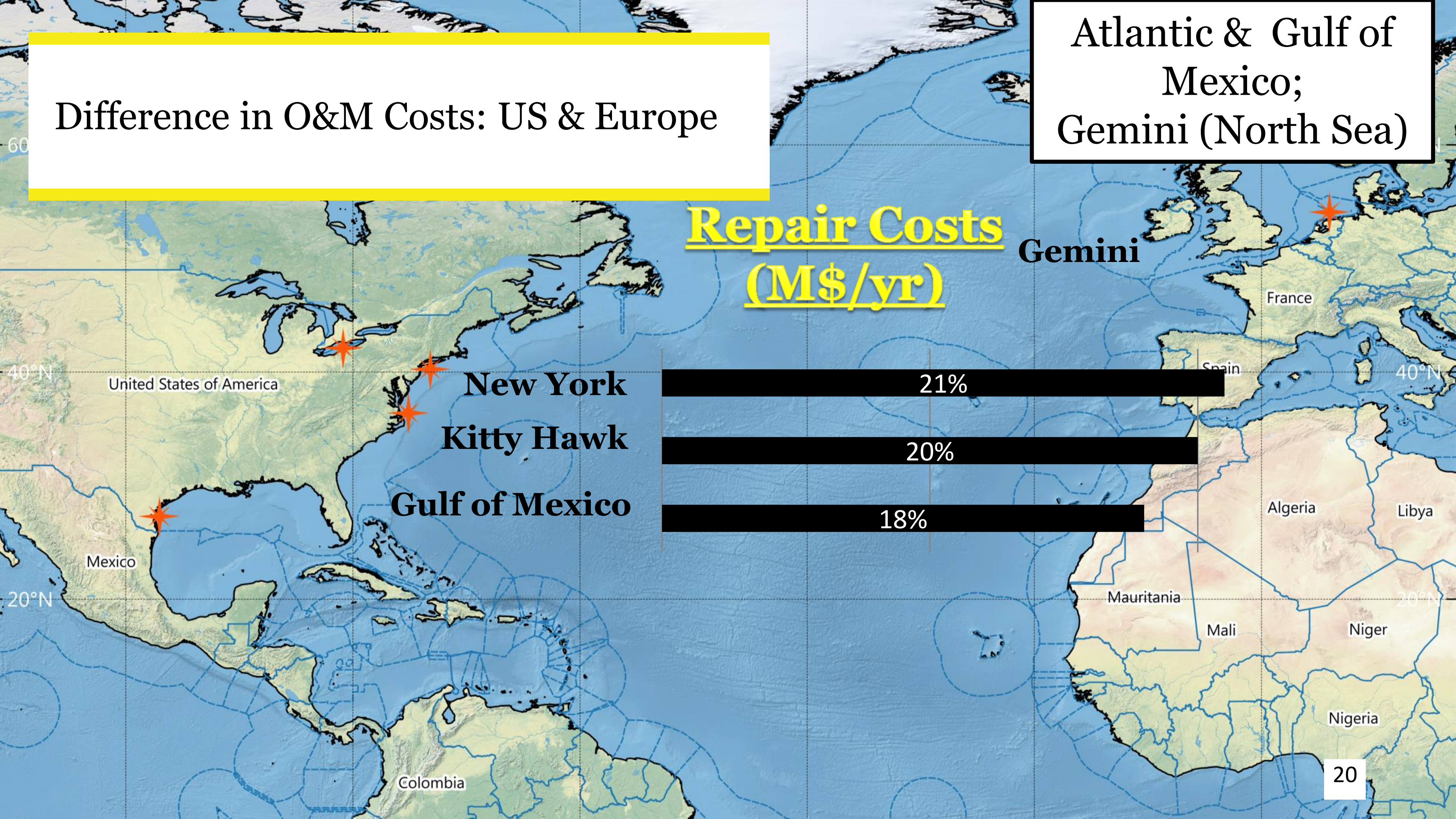
Availability (Time & Yield): 95-96%

Repair Costs (M$/year): 40


Atlantic & Gulf of Mexico;
Gemini (North Sea)
Repair Costs
(M$/yr)
Gemini
~20 % difference
New York
Kitty Hawk
Gulf of Mexico
60°N
40°N
20°N
United States of America
Mexico
Colombia
France
Spain
Algeria
Libya
Mauritania
Mali
Niger
Nigeria

Difference in O&M Costs: US & Europe

Atlantic & Gulf of Mexico;
Gemini (North Sea)



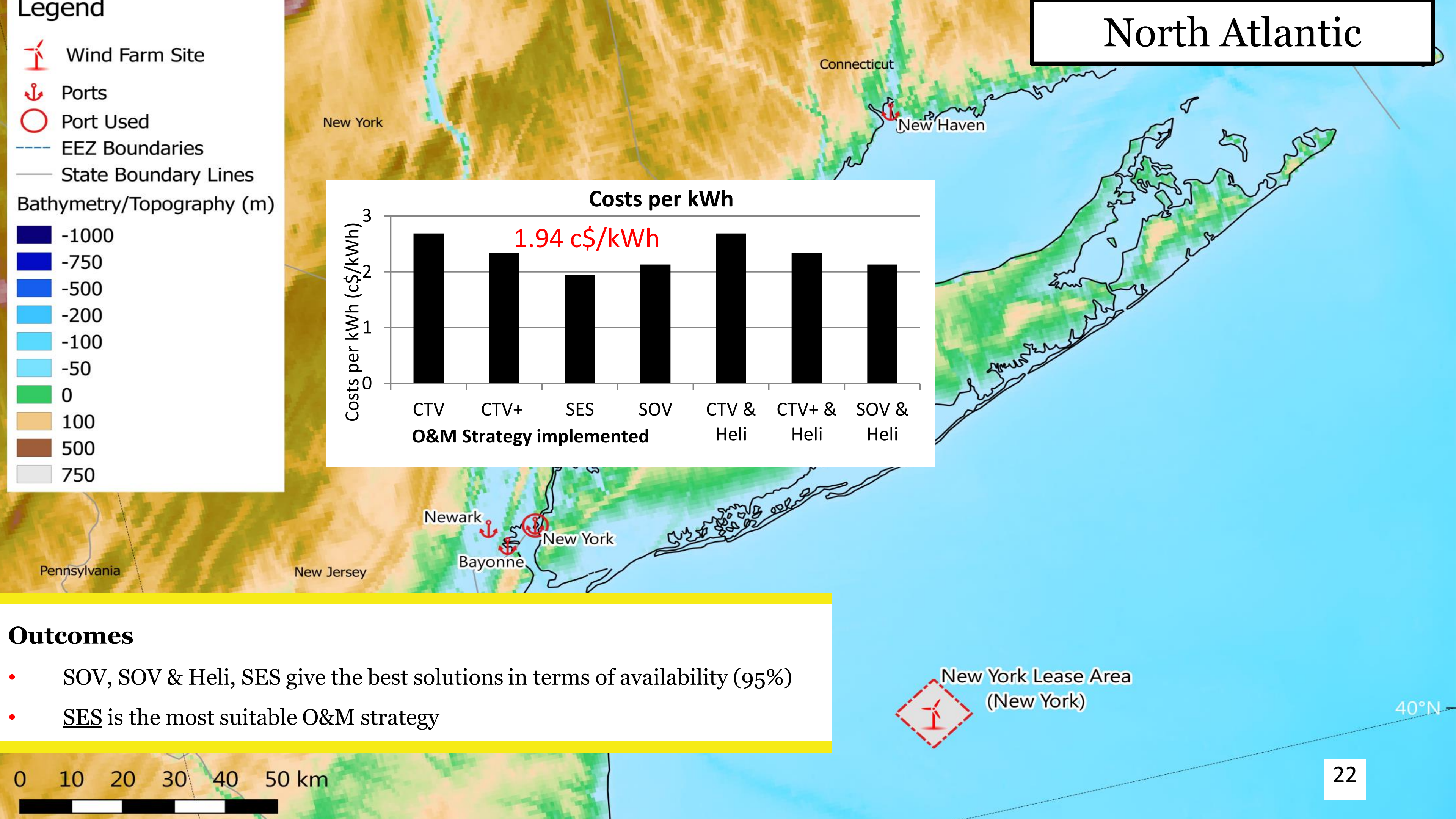
How to reduce the difference in repair costs?

**Atlantic & Gulf of Mexico;
Gemini (North Sea)**

Optimisation and Selection of the "<u>most suitable O&M Strategy</u>" with ECN O&M Calculator

- Criterion of min 95% availability (time and yield)
- Highest availability with a cost-effective solution

North Atlantic



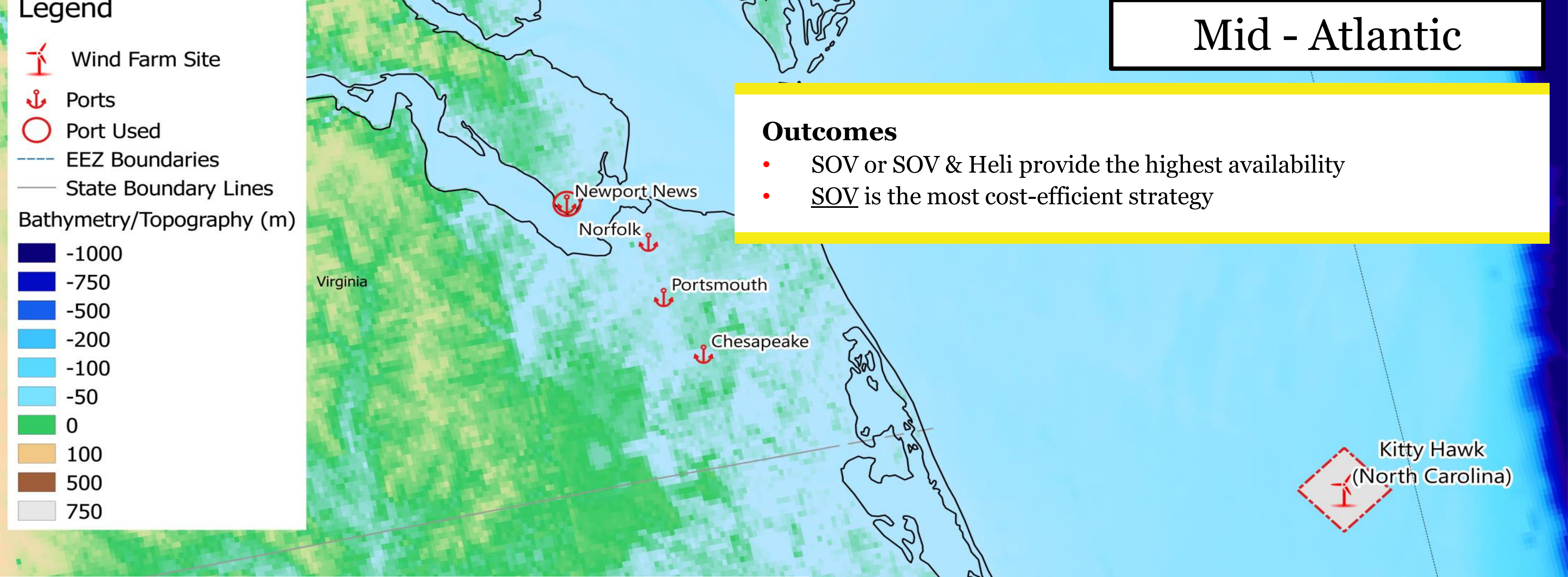
Outcomes

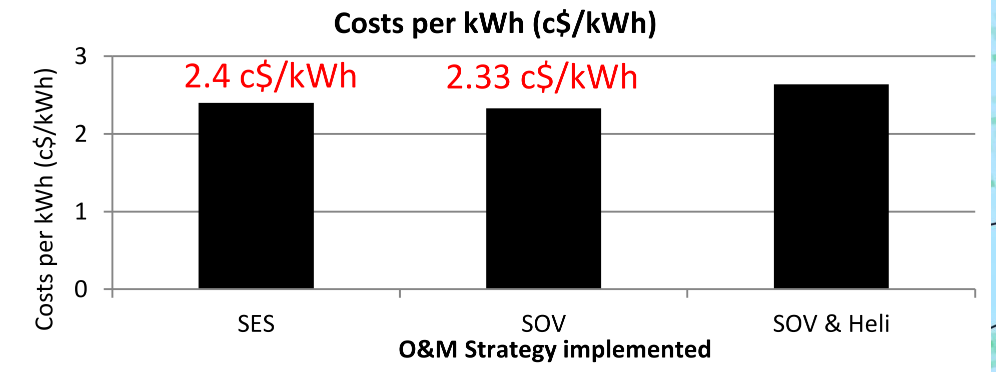
- SOV, SOV & Heli, SES give the best solutions in terms of availability (95%)
- <u>SES</u> is the most suitable O&M strategy

Mid - Atlantic

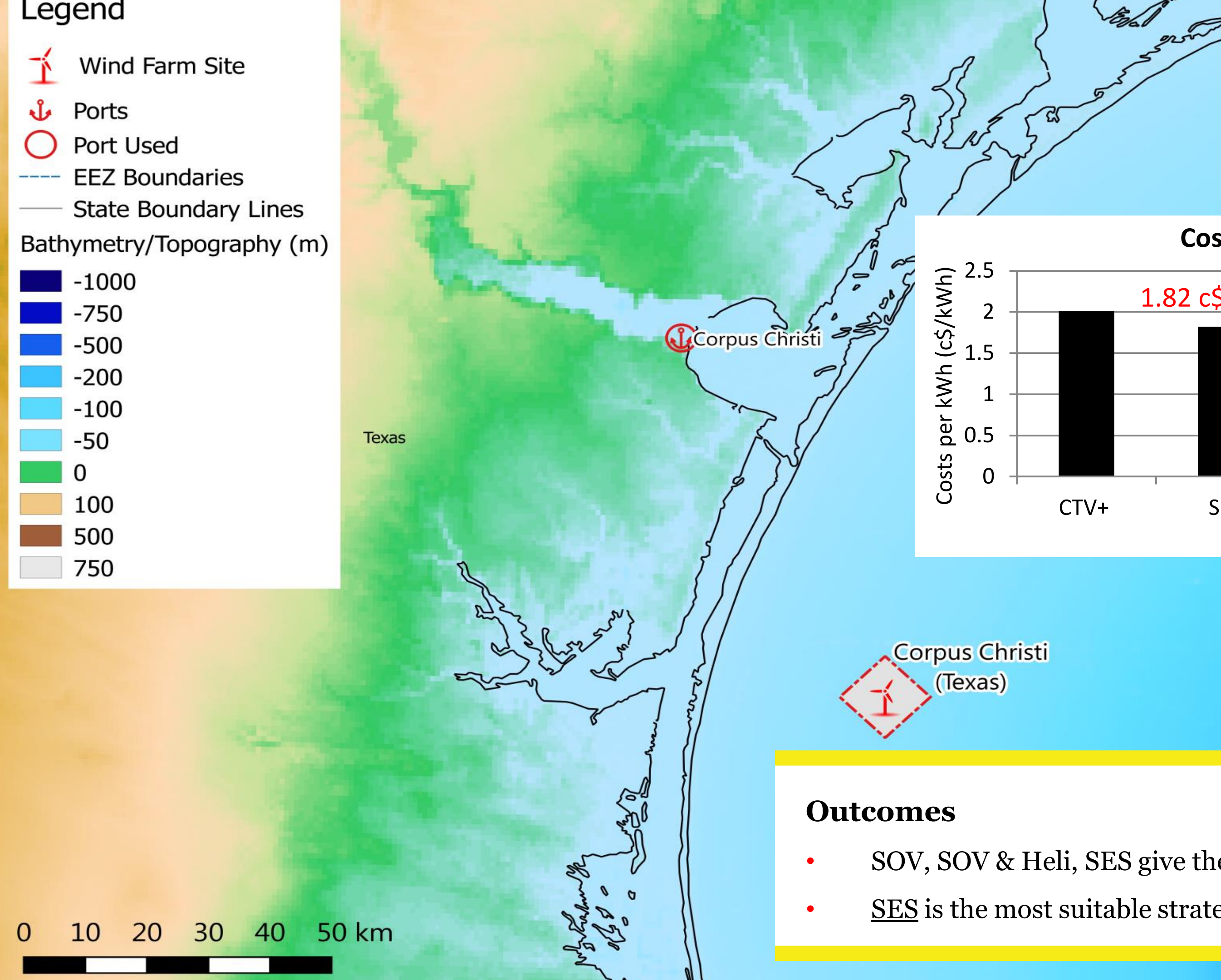
Outcomes

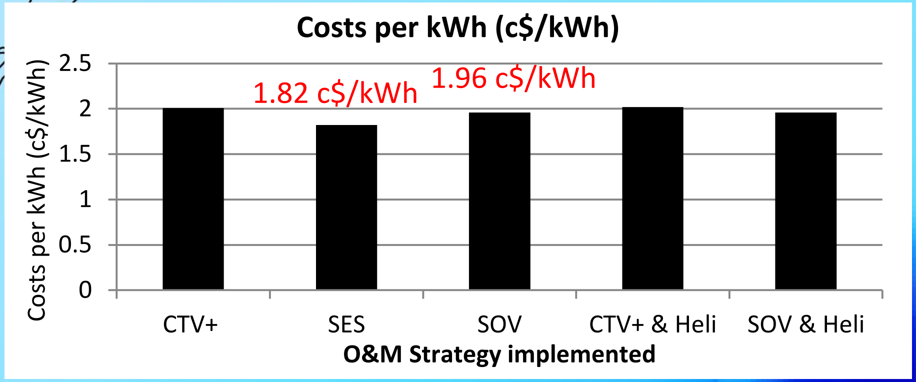
- SOV or SOV & Heli provide the highest availability
- <u>SOV</u> is the most cost-efficient strategy





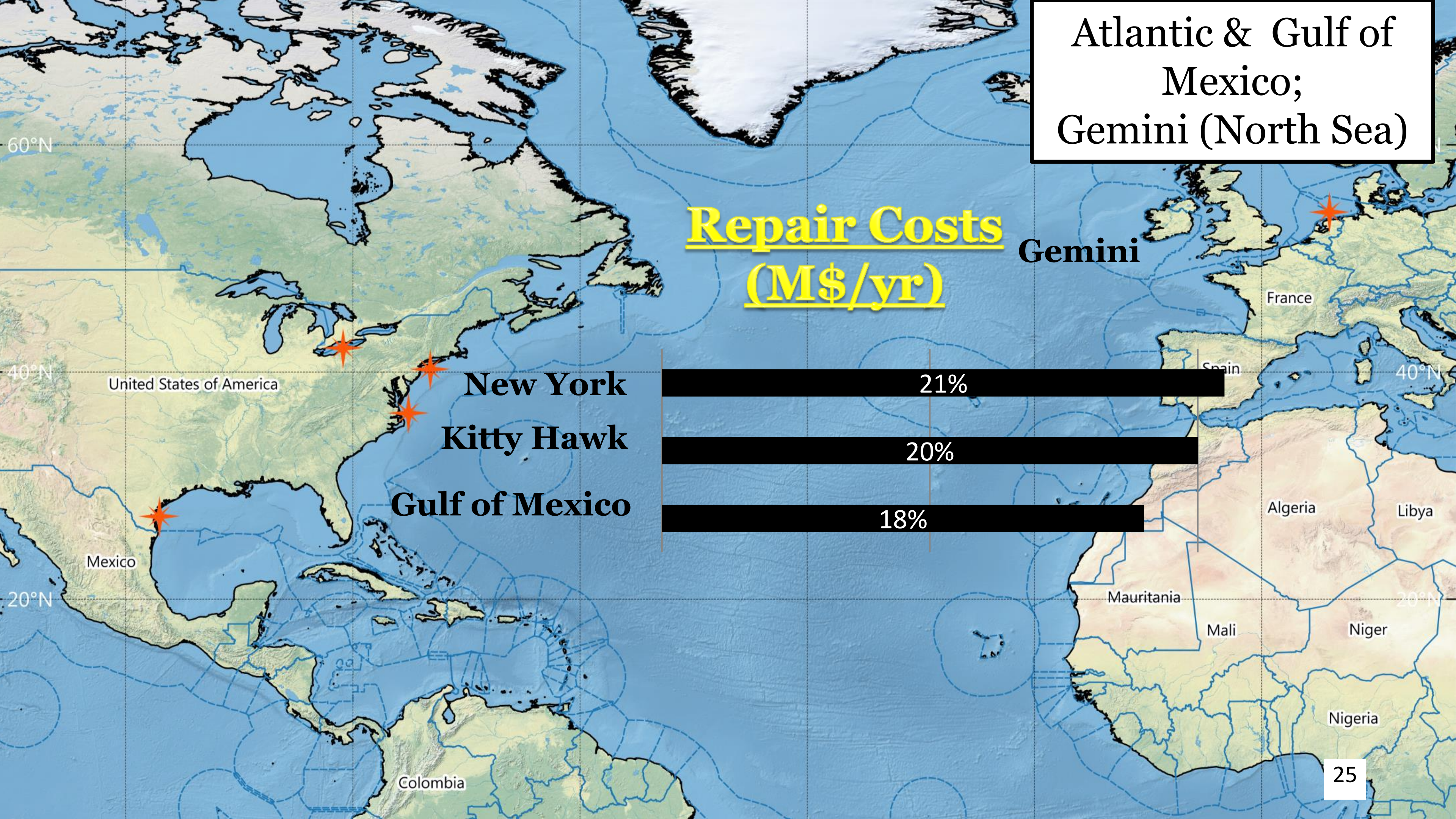
Gulf of Mexico





Outcomes

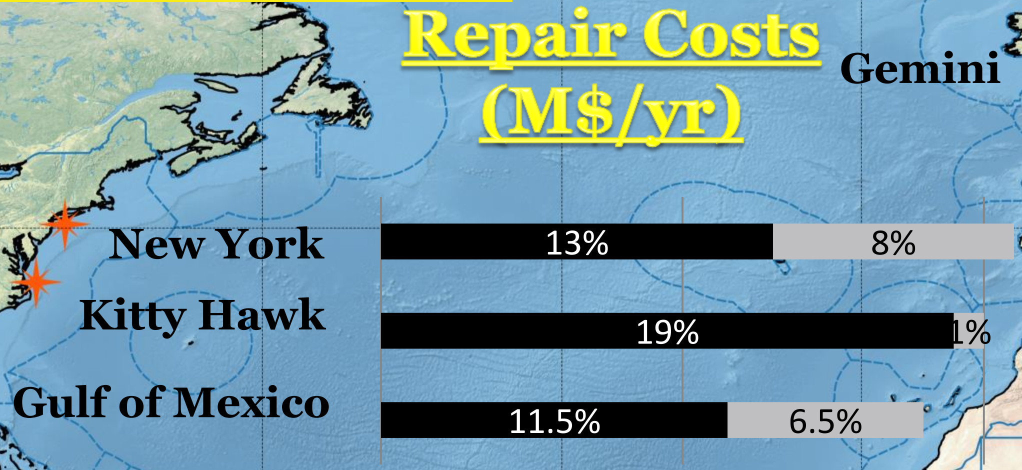
- SOV, SOV & Heli, SES give the best solutions in terms of availability
- <u>SES</u> is the most suitable strategy



Atlantic & Gulf of Mexico;
Gemini (North Sea)
Repair Costs (M$/yr)
Gemini
New York
21%
Kitty Hawk
20%
Gulf of Mexico
18%
60°N
40°N
20°N
United States of America
Mexico
Colombia
France
Spain
Algeria
Libya
Mauritania
Mali
Niger
Nigeria

Choice of the “most suitable” O&M Strategy

Atlantic & Gulf of Mexico; Gemini (North Sea)

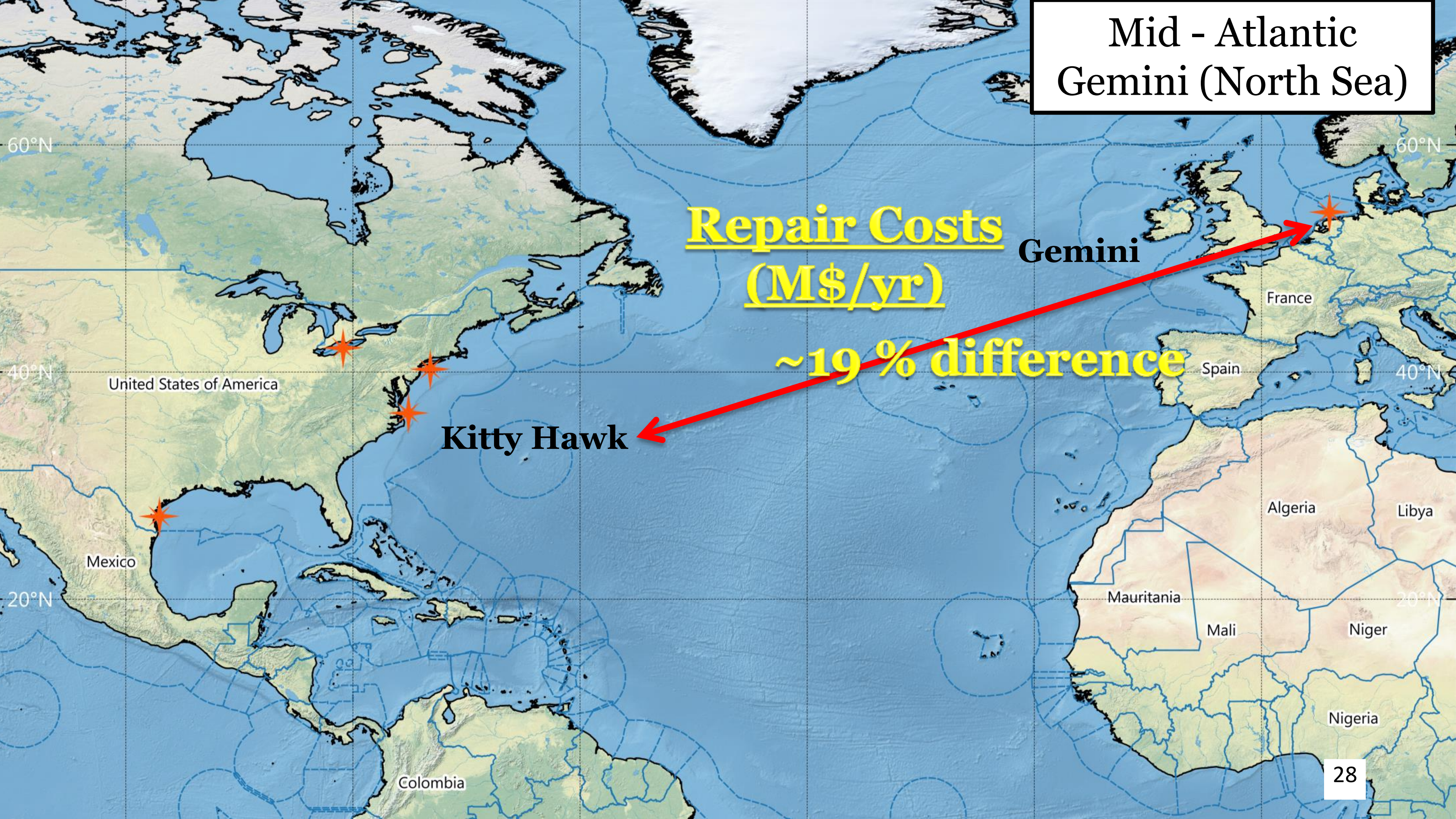


How to reduce the difference in repair costs?

Mid - Atlantic
Gemini (North Sea)

In-house manufacturing of vessels

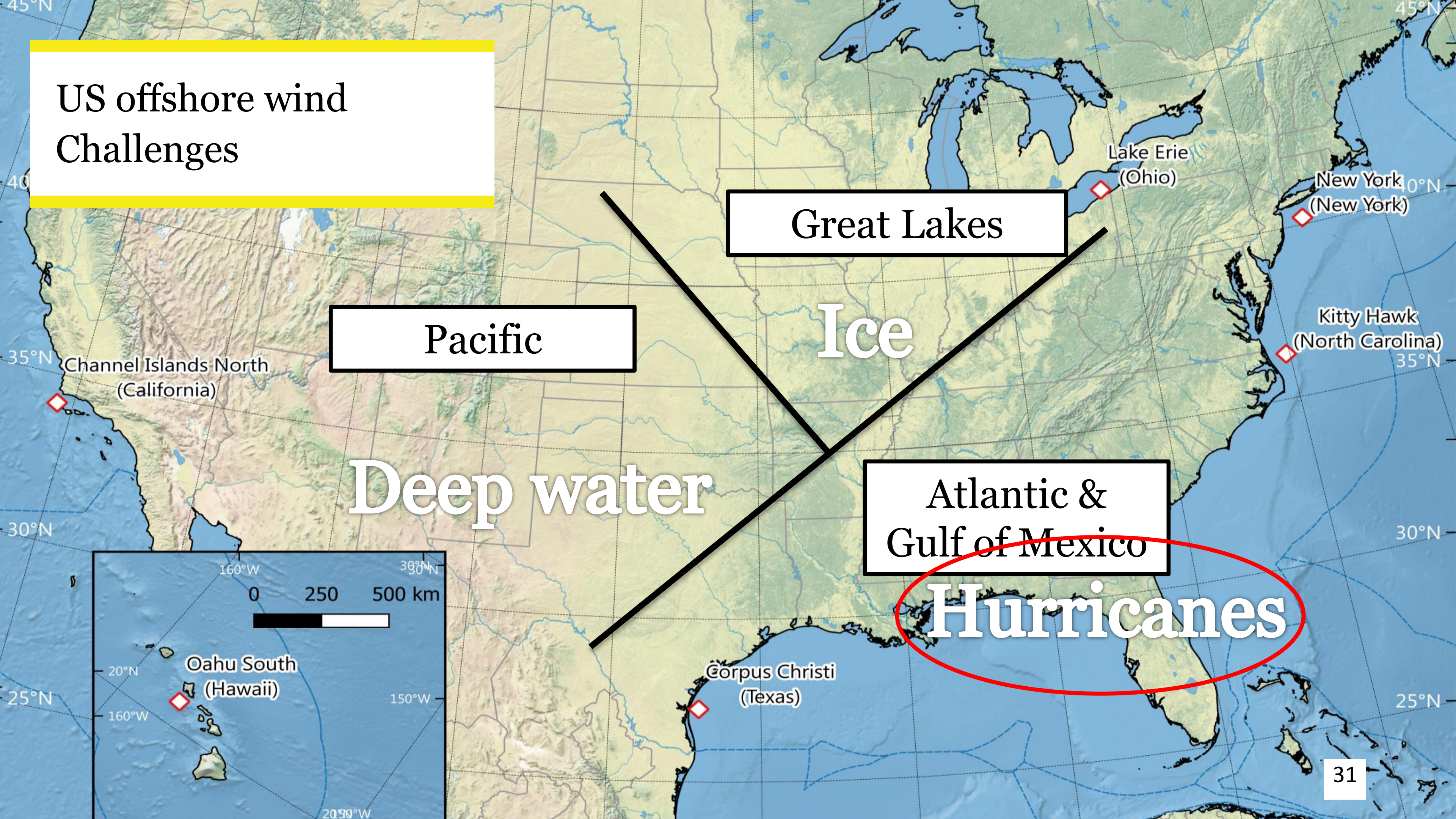
- Alternative to current strategy of chartering vessels from Europe
- No additional support vessel requirement to comply with Jones Act
- Overall lower vessel price and less mobilization time


Mid - Atlantic
Gemini (North Sea)
Repair Costs
(M$/yr)
Gemini
~19 % difference
Kitty Hawk
60°N
40°N
20°N
United States of America
Mexico
Colombia
France
Spain
Algeria
Libya
Mauritania
Mali
Niger
Nigeria

Mid - Atlantic; Gemini (North Sea)

Atlantic & Gulf of Mexico; Gemini (North Sea)

US offshore wind Challenges



Gulf of Mexico

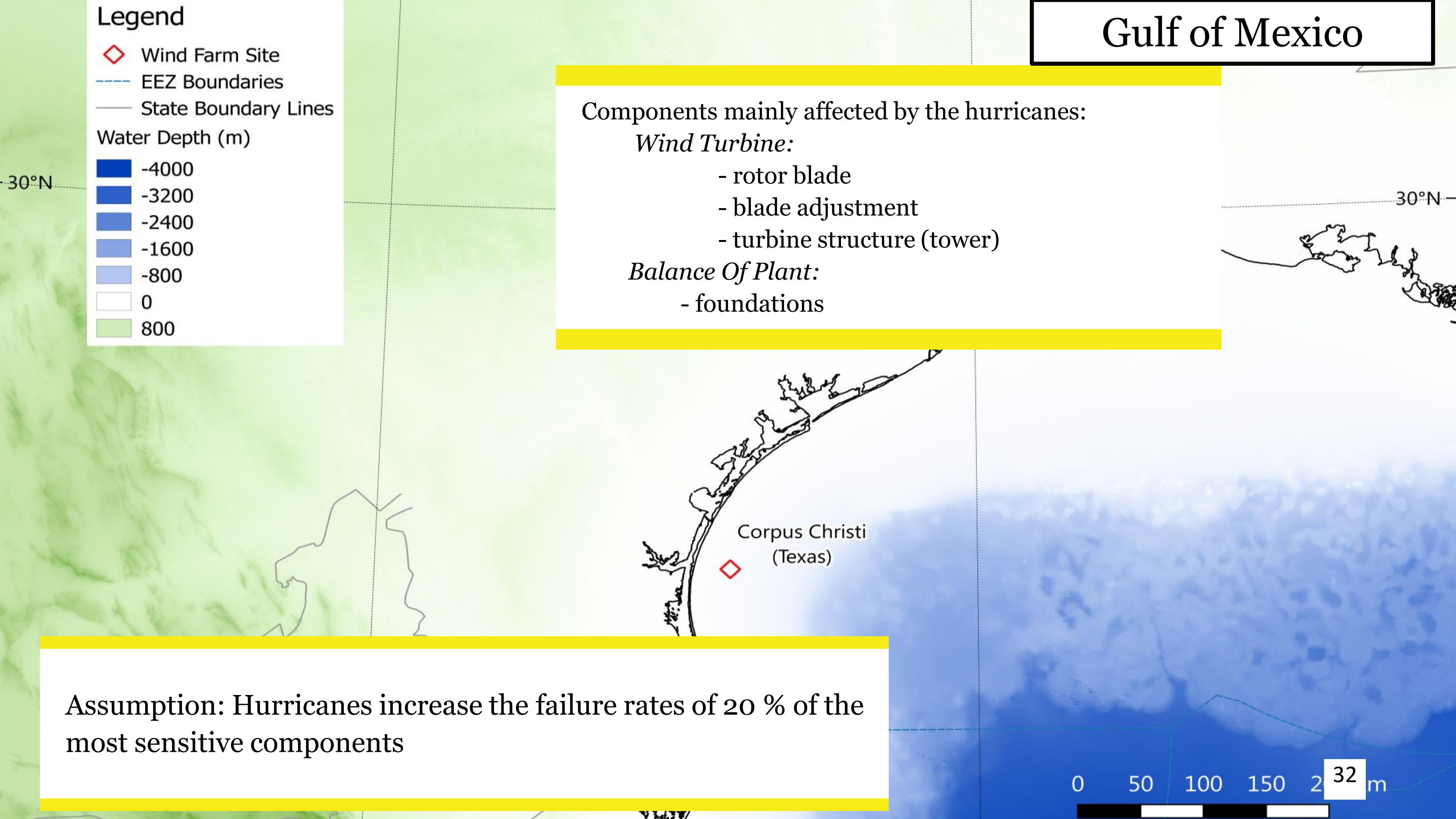
Components mainly affected by the hurricanes:

Wind Turbine:

- rotor blade
- blade adjustment
- turbine structure (tower)

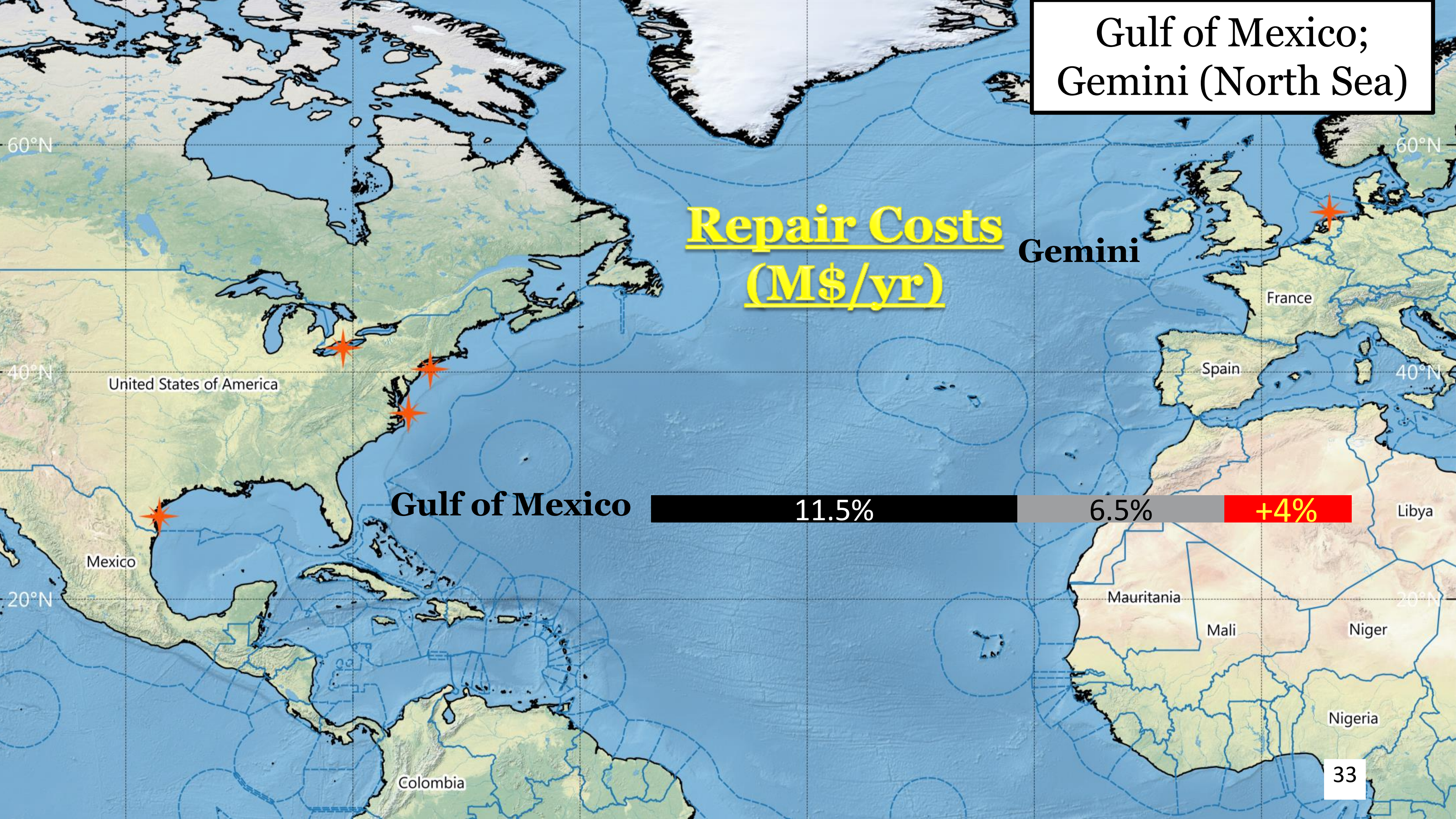
Balance Of Plant:

- foundations

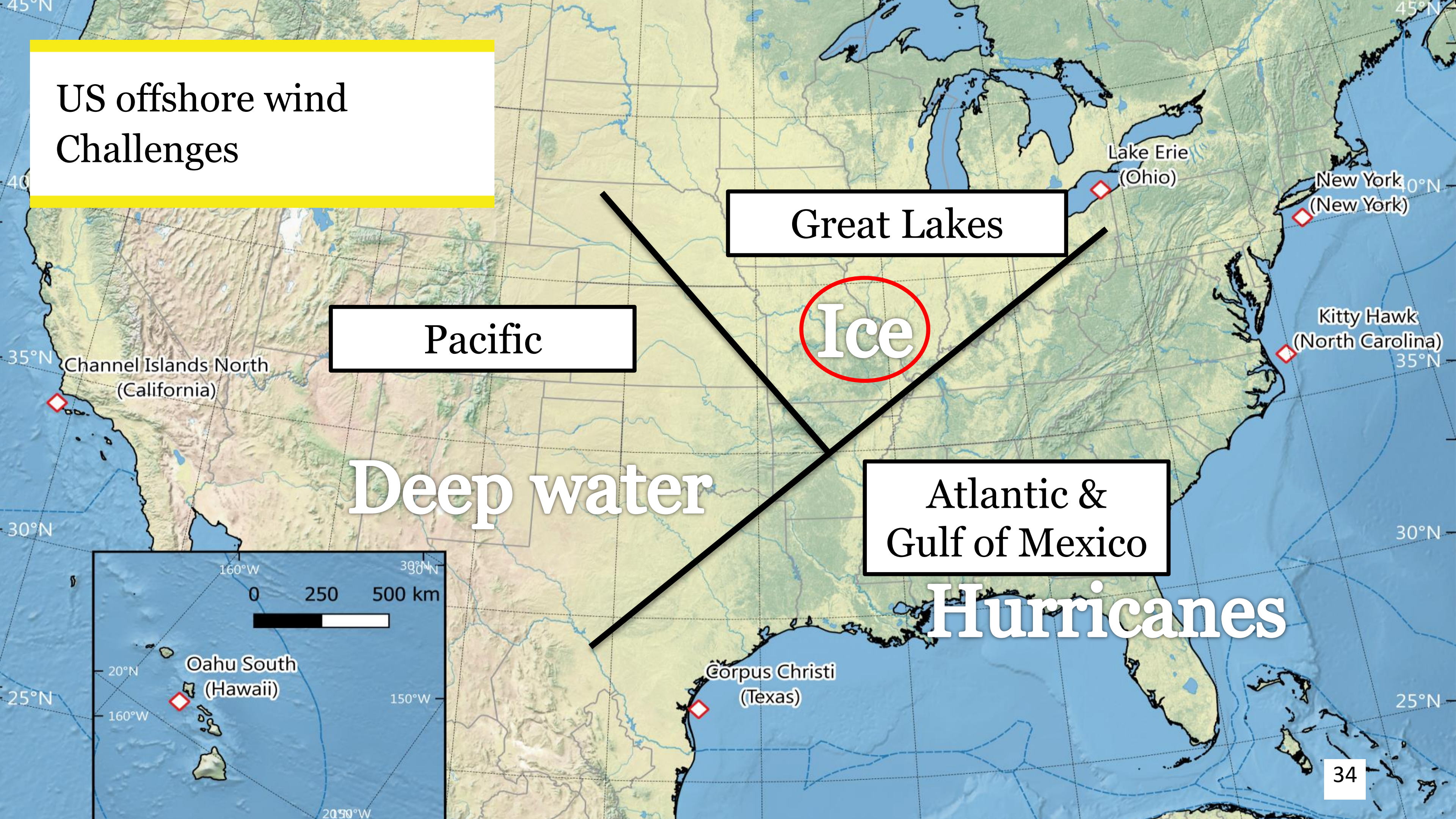


Assumption: Hurricanes increase the failure rates of 20 % of the most sensitive components

Gulf of Mexico; Gemini (North Sea)



US offshore wind Challenges



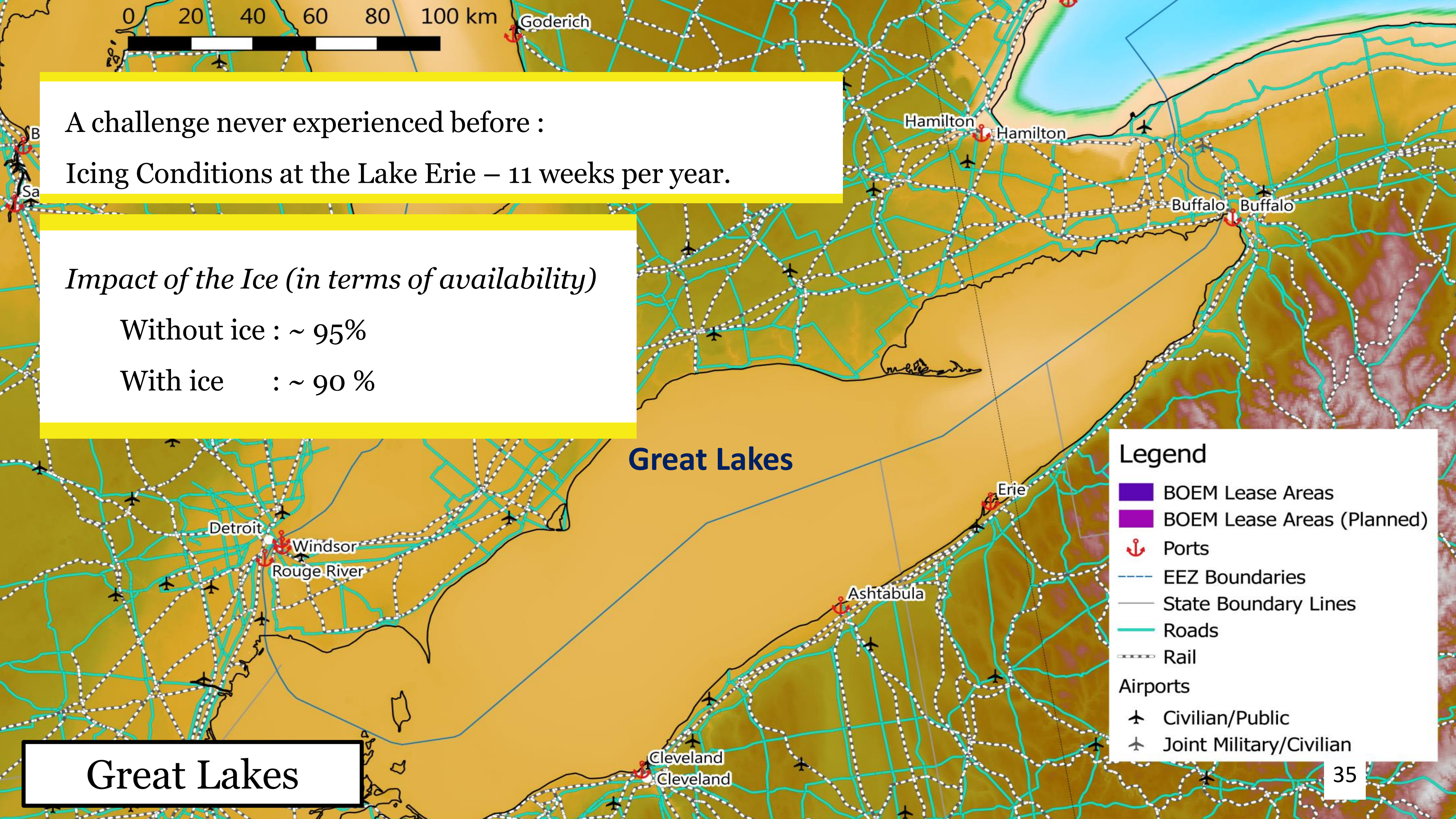
A challenge never experienced before :

Icing Conditions at the Lake Erie – 11 weeks per year.

Impact of the Ice (in terms of availability)

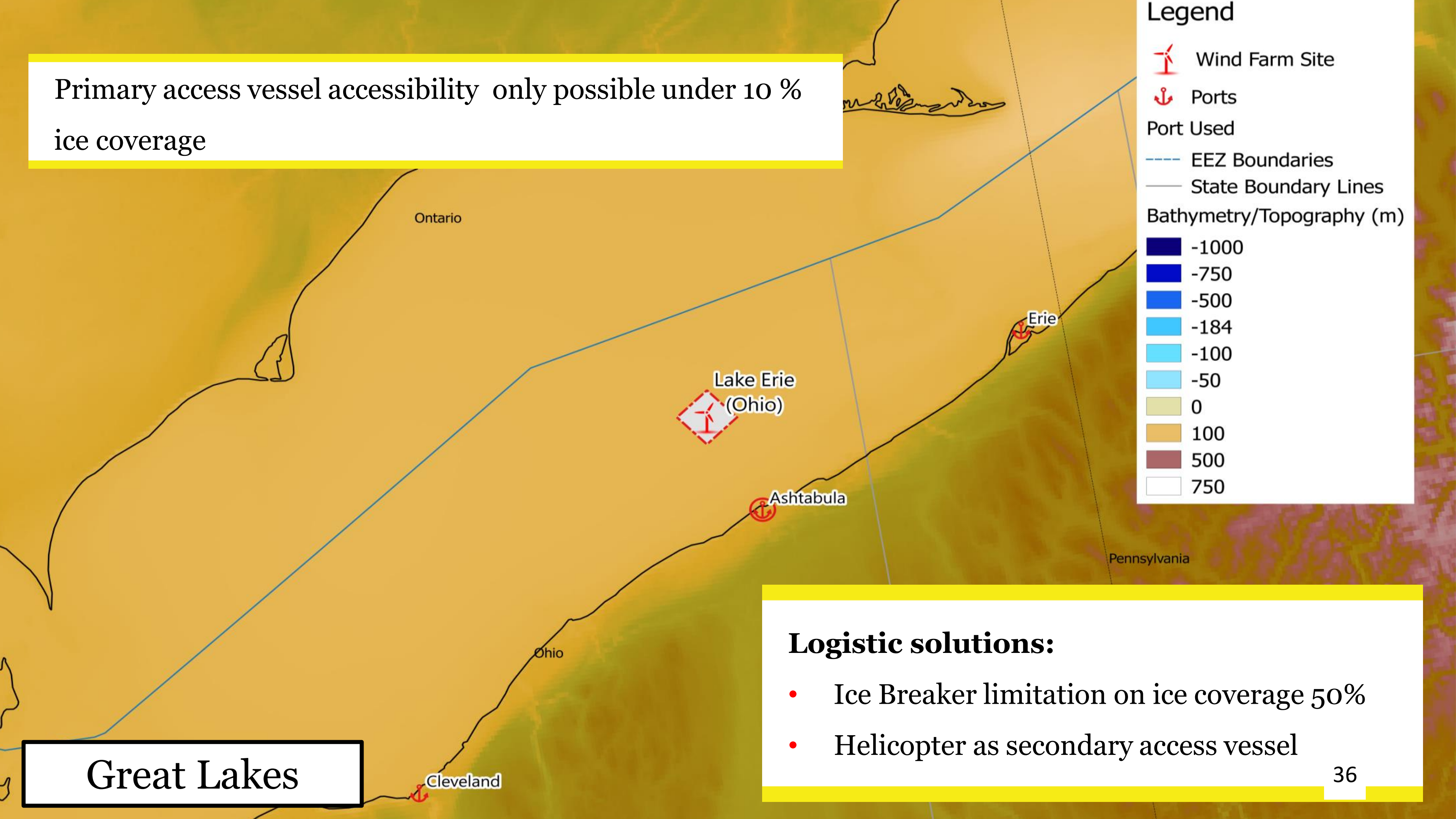
Without ice : ~ 95%

With ice : ~ 90 %



Great Lakes

Primary access vessel accessibility only possible under 10 % ice coverage



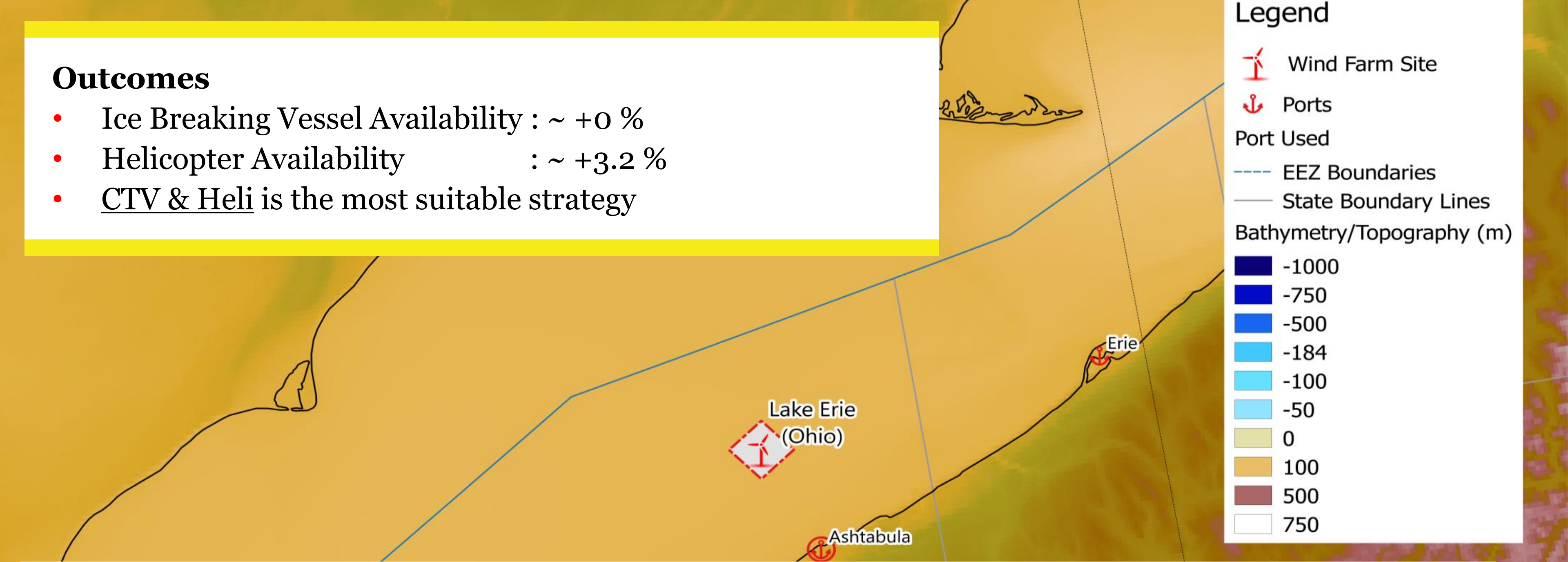
Great Lakes

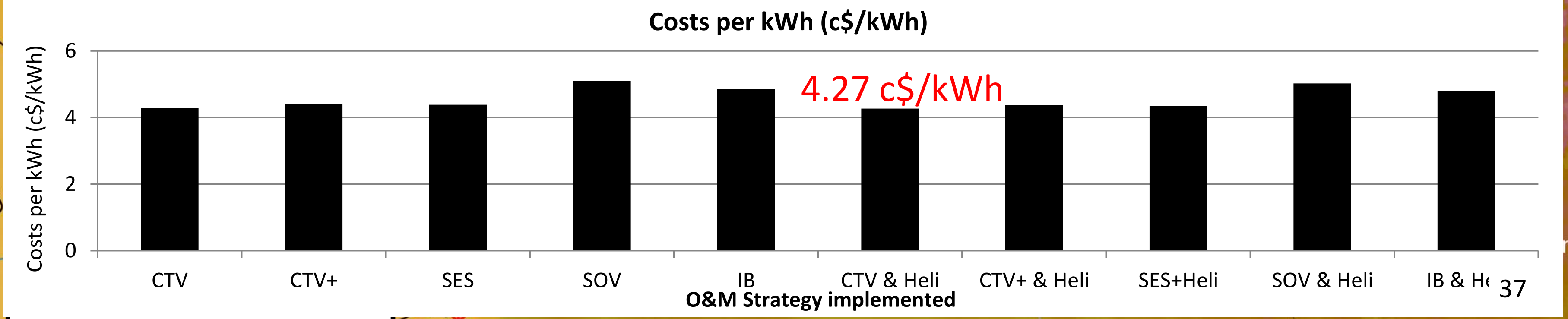
Logistic solutions:

- Ice Breaker limitation on ice coverage 50%
- Helicopter as secondary access vessel

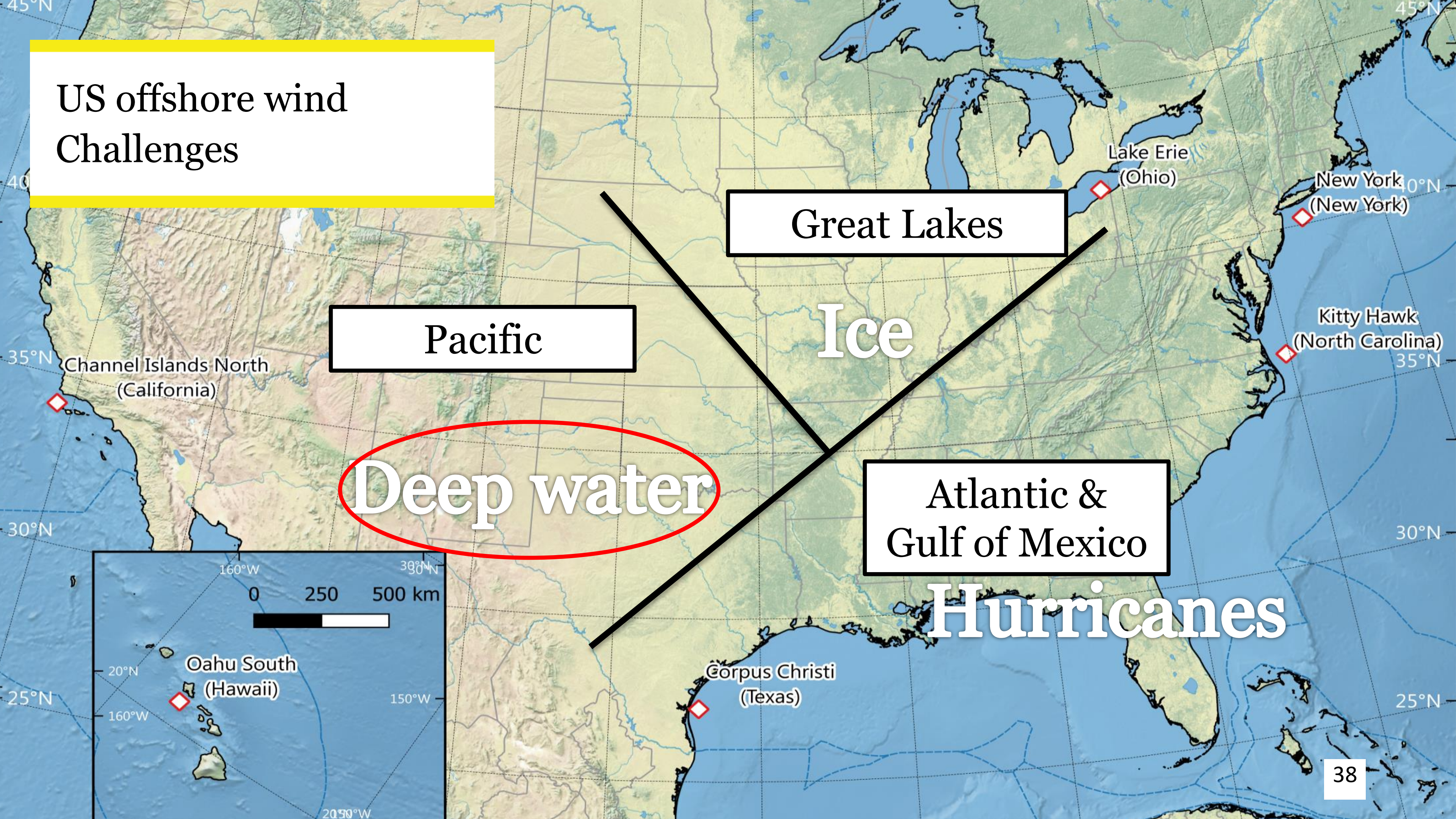
Outcomes

- Ice Breaking Vessel Availability : ~ +0 %
- Helicopter Availability : ~ +3.2 %
- CTV & Heli is the most suitable strategy

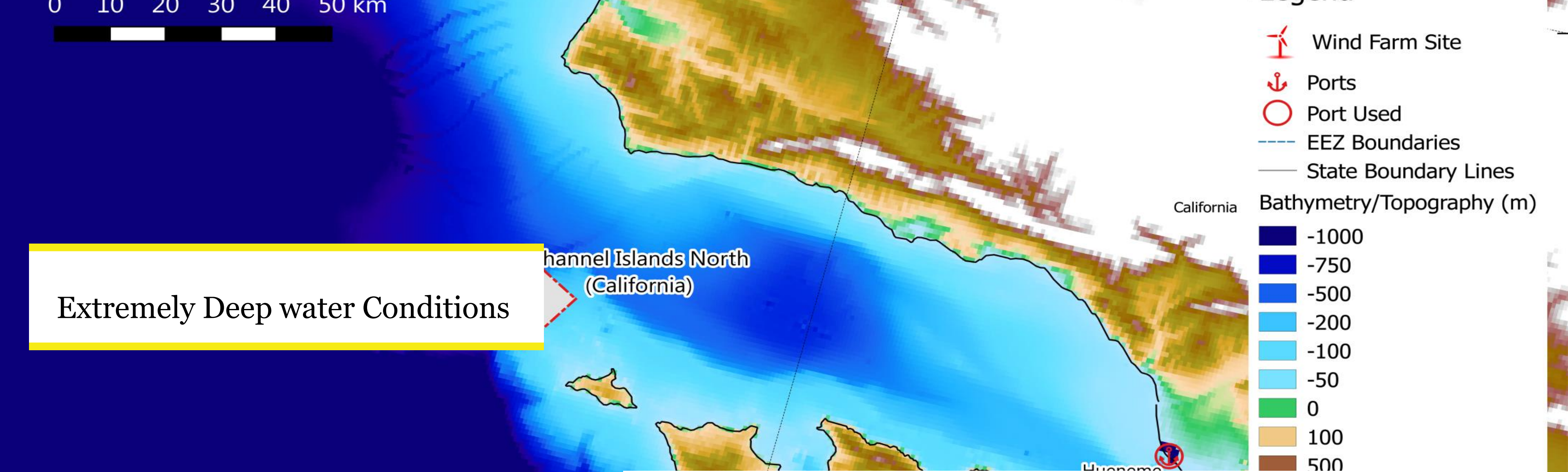


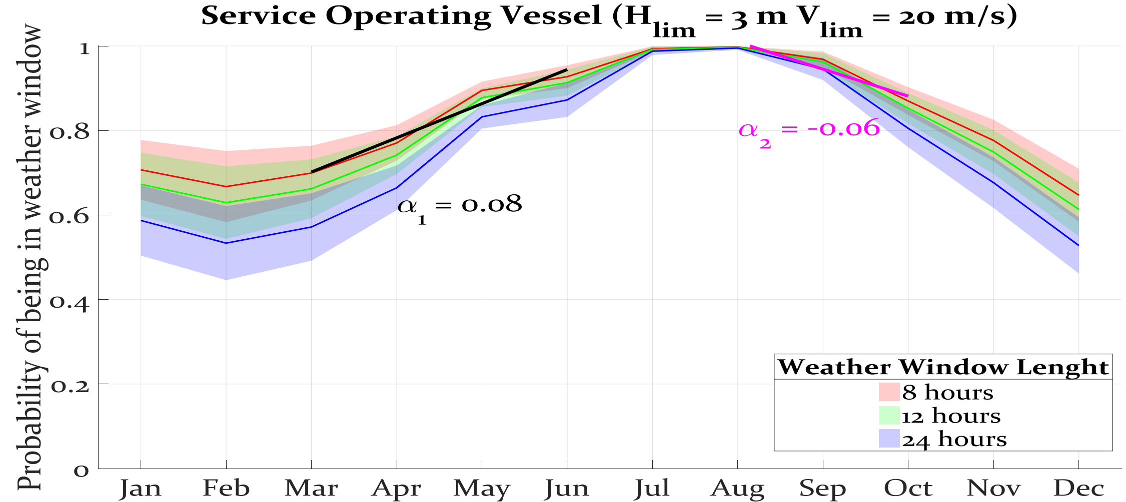


US offshore wind Challenges

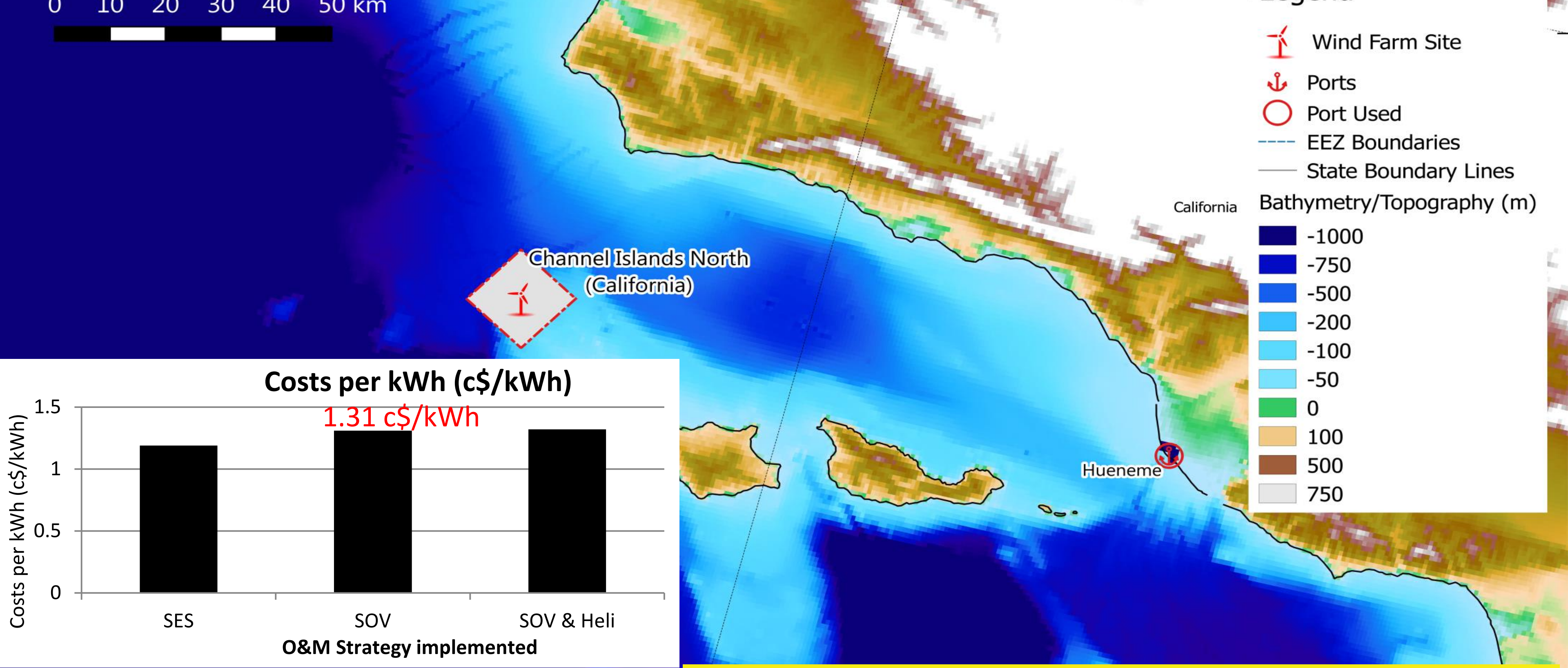


Extremely Deep water Conditions





North Pacific

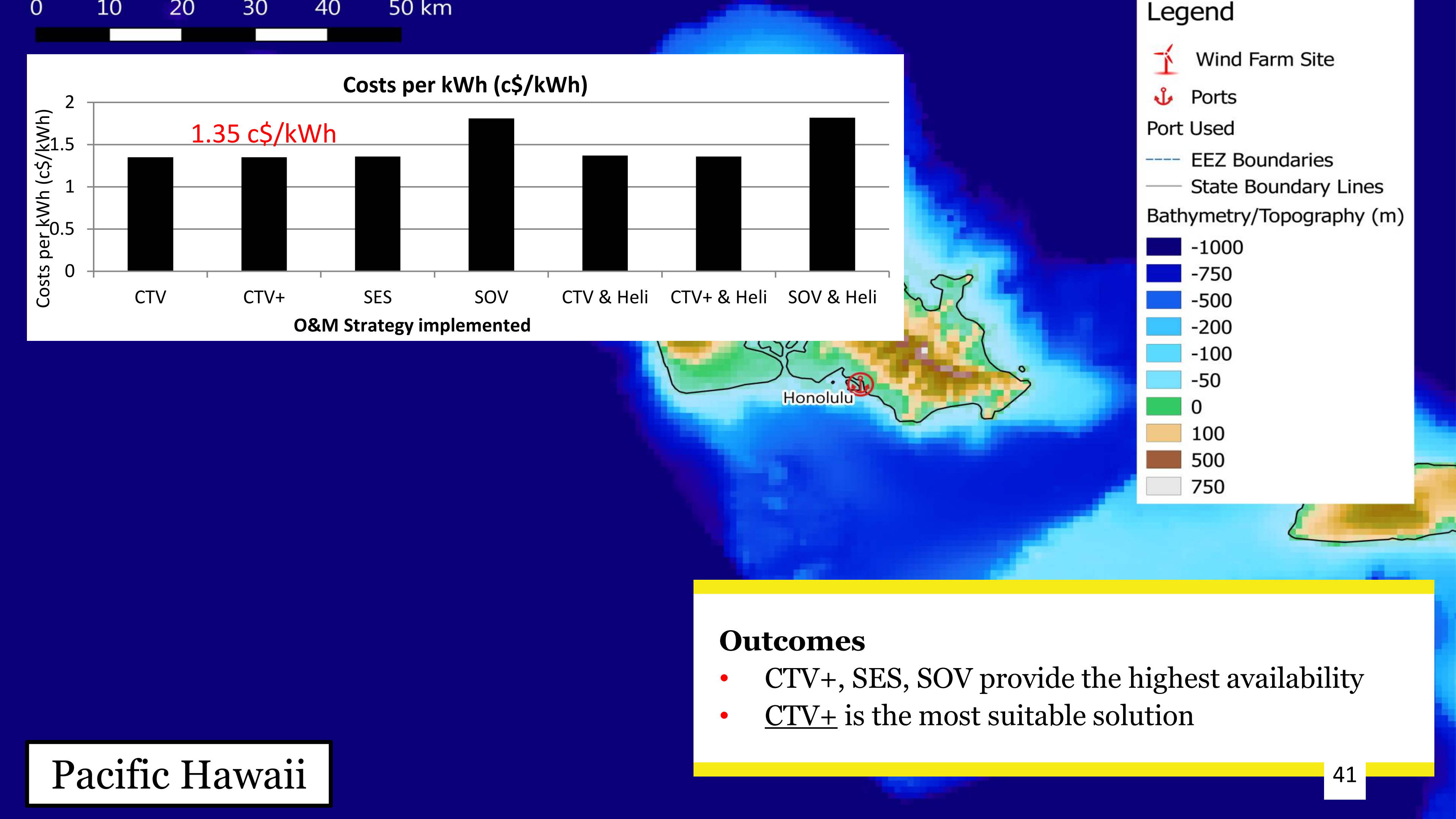


Outcomes

- O&M Strategy with only SES and SOV possible
- SES gives lower availability (~ 93%)
- <u>SOV</u> is the most suitable strategy

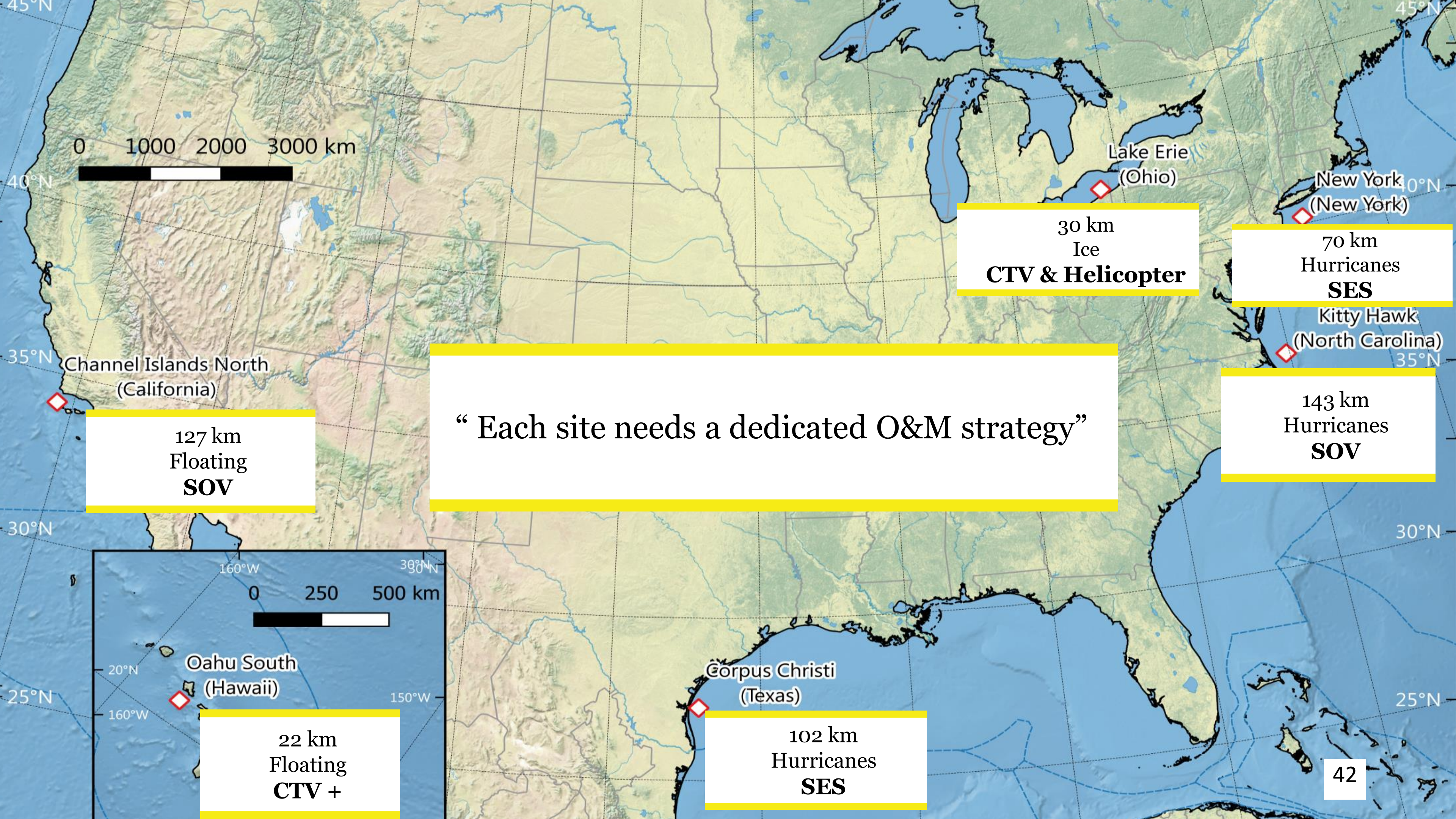
North Pacific

Pacific Hawaii



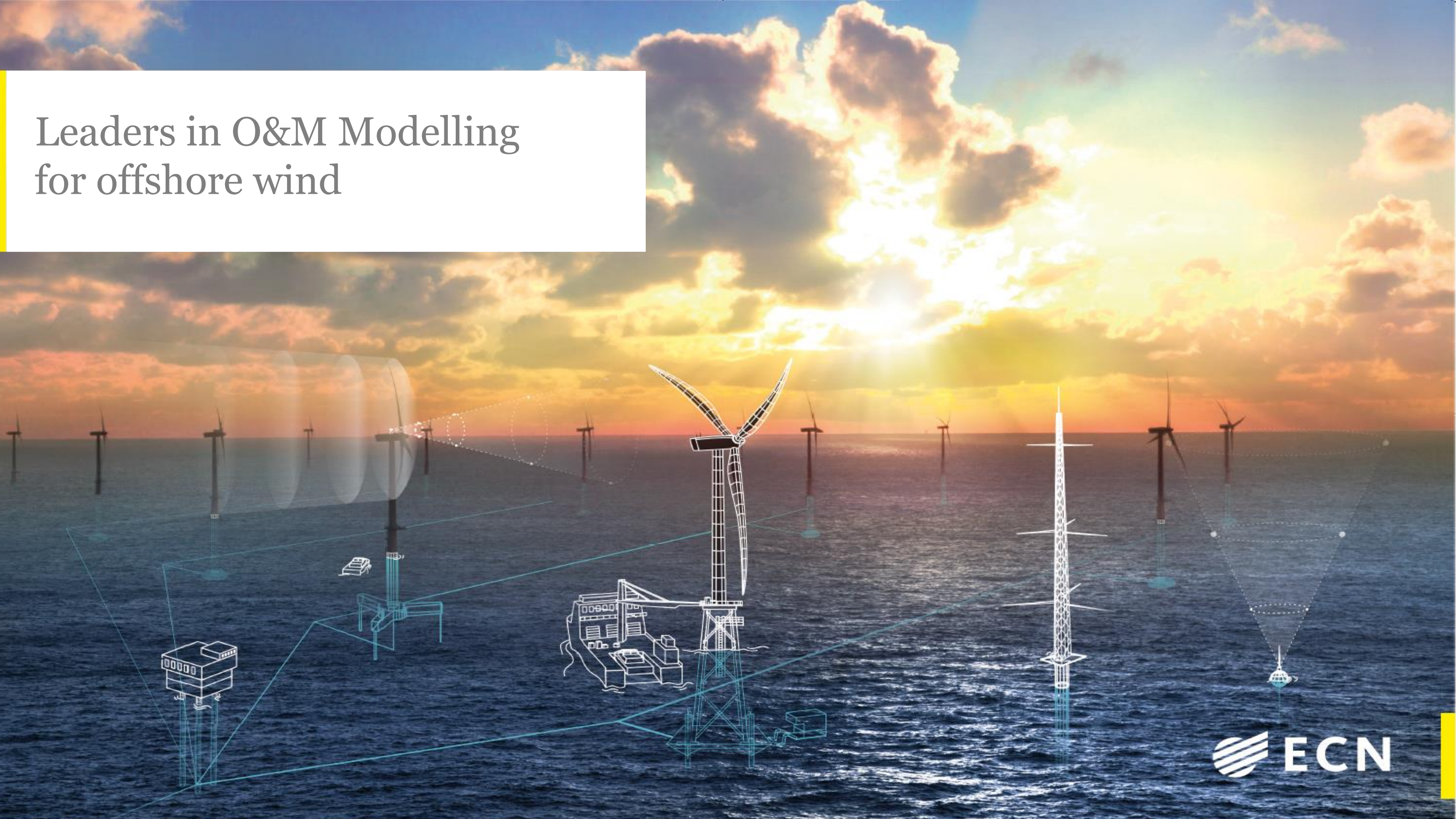
Outcomes

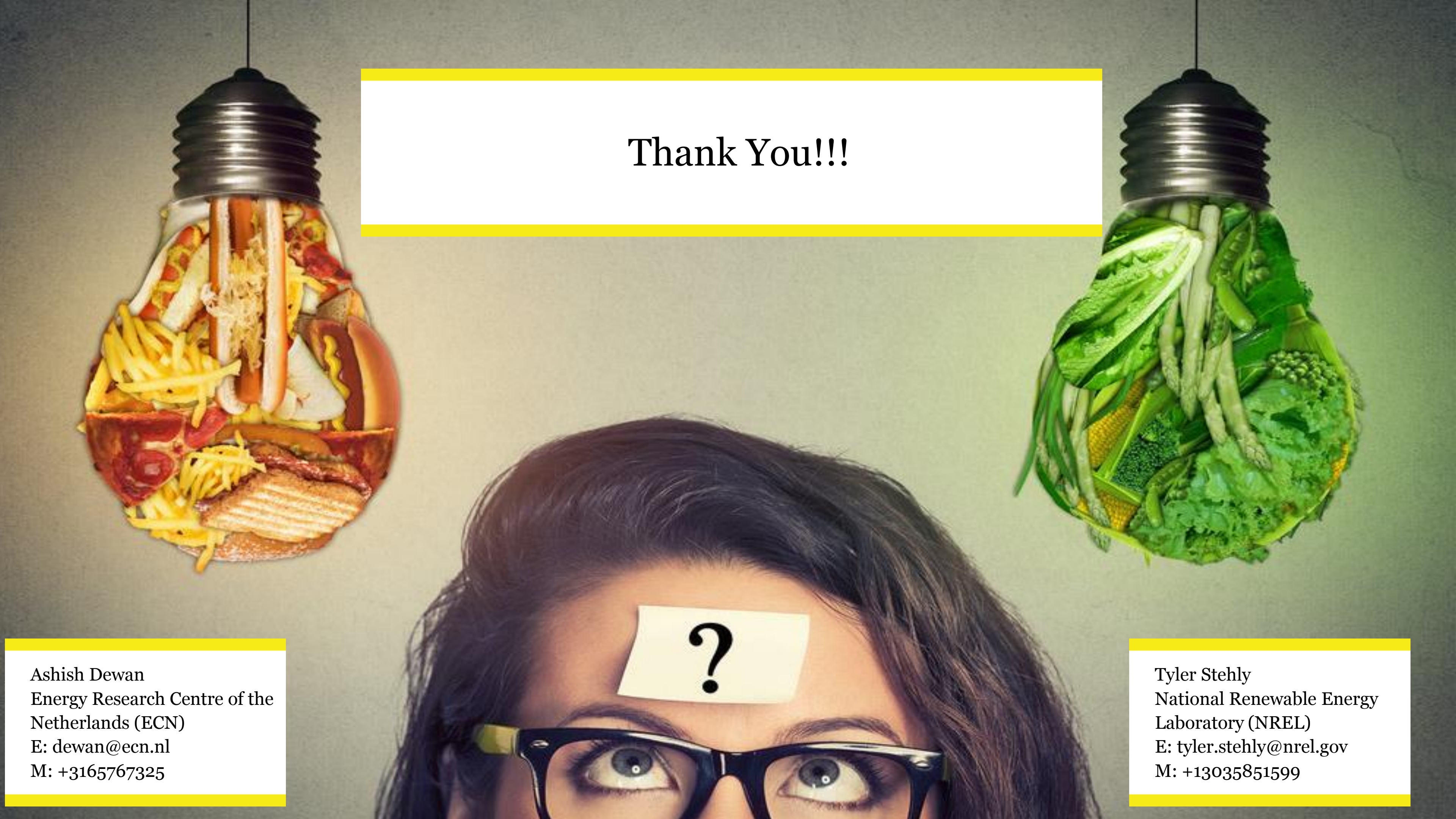
- CTV+, SES, SOV provide the highest availability
- CTV+ is the most suitable solution



0 1000 2000 3000 km
45°N
40°N
35°N
30°N
25°N
Channel Islands North
(California)
127 km
Floating
SOV
Lake Erie
(Ohio)
30 km
Ice
CTV & Helicopter
New York
(New York)
70 km
Hurricanes
SES
Kitty Hawk
(North Carolina)
143 km
Hurricanes
SOV
“ Each site needs a dedicated O&M strategy”
160°W
30°N
0 250 500 km
20°N
150°W
Oahu South
(Hawaii)
22 km
Floating
CTV +
Corpus Christi
(Texas)
102 km
Hurricanes
SES

Leaders in O&M Modelling for offshore wind





Thank You!!!

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Backup Slides

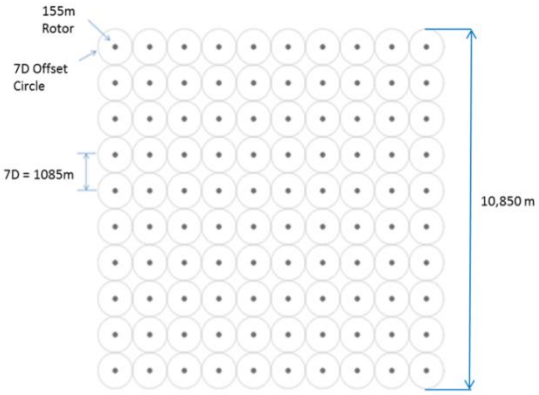
Wind Project Layout and Performance Modeling

Coverage includes:
- Major offshore areas except for Alaska
- Depths restricted up to 1,000 m to reflect limits of current technology

Wind project layout includes:
- One cell comprising 100 turbines
- Spacing based on 6-MW turbines in a 10-by-10 grid, spaced at 7 rotor diameters

Each project layout considered independently includes:
- 7,159 distinct wind power plant layouts*
- No gaps between adjacent layouts
- No wake interaction between layouts.

Using Openwind, 7,159-unit wind power plants were modeled throughout the resource area of the continental United States from 0 nautical miles (nm) to 50 nm



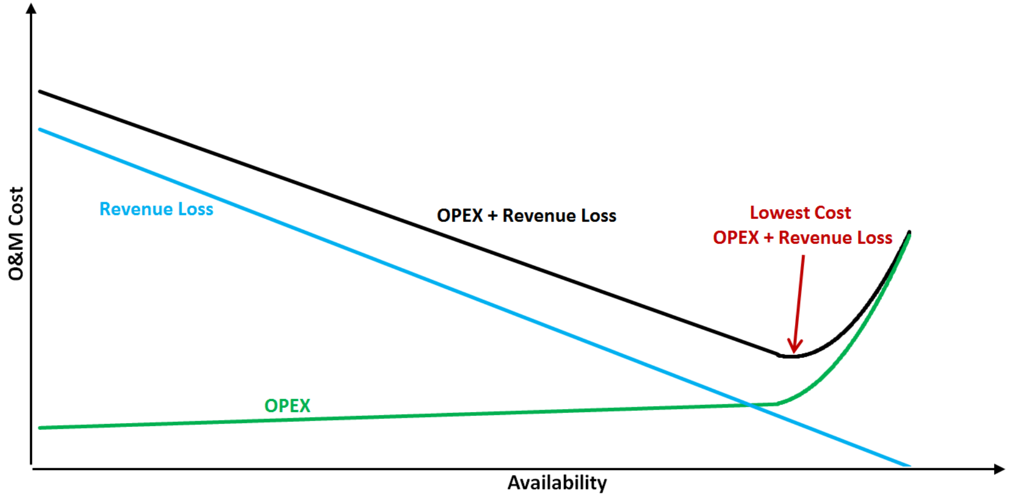
Conceptual project layout with 100 generic 6-MW turbines

* A potential wind farm was considered to qualify if at least 50% of the turbines met the depth restriction criteria.

O&M Parameter Study

Model Outputs:

- The Energy Research Centre of the Netherlands (ECN) O&M Tool outputs are operational expenditures (OPEX), availability, and total O&M cost (OPEX + revenue loss)
- Parameterized curves fit to the 'least cost O&M strategy' at each distance (defined as O&M costs + lost revenue) for inclusion in the spatio-economic LCOE model.



Depiction of O&M optimization criteria

Strategy Optimization

Site	Name	STRATEGY																
		CTV		CTV Advanced			SES		SOV		CTV + Heli			CTV Adv + Heli			SOV + Heli	
		36	24	36	24	12	48	24	48	24	36	24	12	36	24	12	48	24
		3	2	3	2	1	2	1	2	1	3	2	1	3	2	1	2	1
1	New York																	
2	Kitty Hawk	DISTANCE - More than 4.5 hours travel									DISTANCE - More than 4.5 hours travel							
3	Gulf of Mexico	DISTANCE - More than 5 hours travel									DISTANCE - More than 5 hours travel							
4	Lake Erie																	
5	Pacific	DISTANCE & Weather- More than 4.5 hours travel Average Wave Height > 2 m									DISTANCE & Weather- More than 4.5 hours travel Average Wave Height > 2 m							
6	Hawai																	

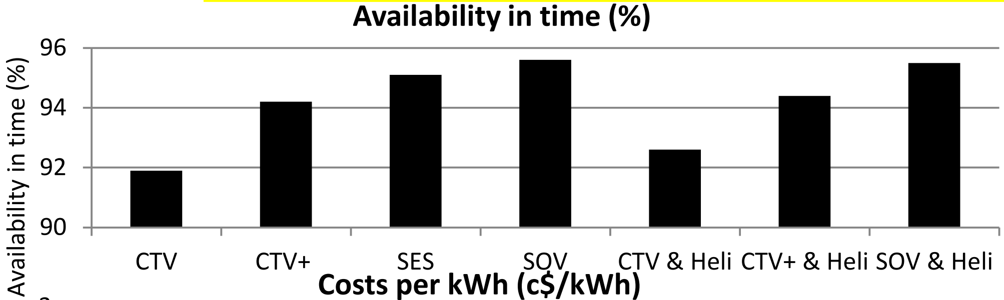
Summary:
For all the sites (possible)

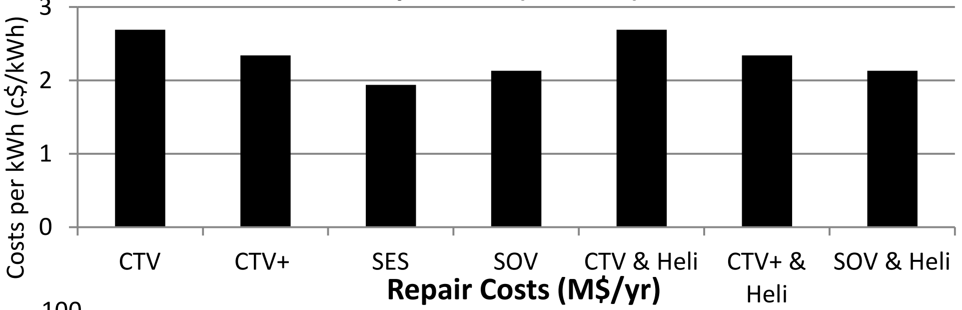
1. CTV → 2
2. CTV A → 2
3. SES → 1
4. SOV → 1
5. CTV + Heli → 2
6. CTV A + Heli → 2
7. SOV + Heli → 1

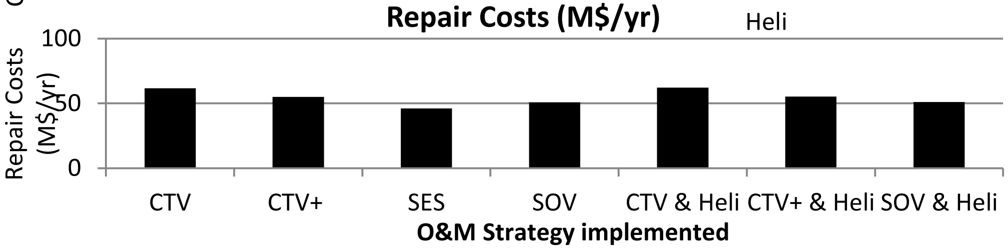
**Using 1 SOV with 24 technicians!

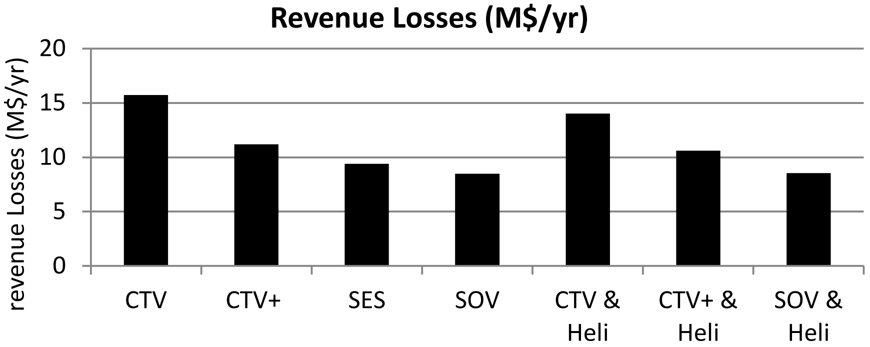
SOV can host up to 60 people, but in this study 24 technicians is used

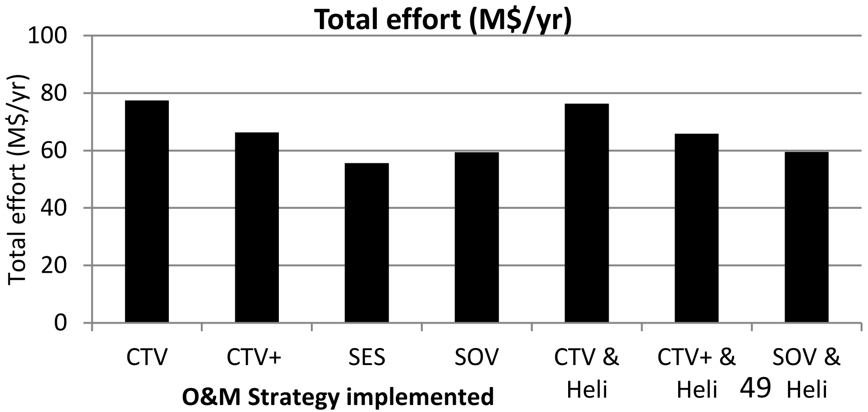
Site 1: New York - Results



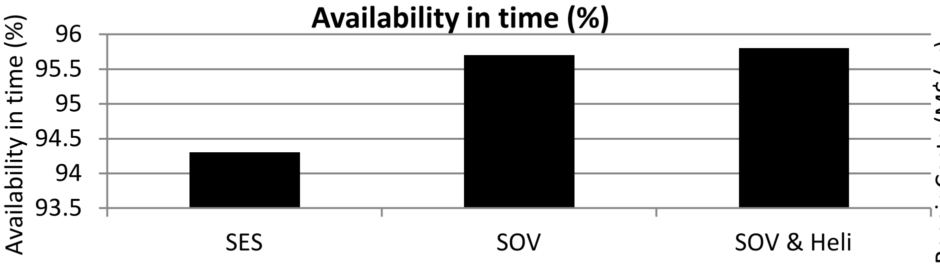


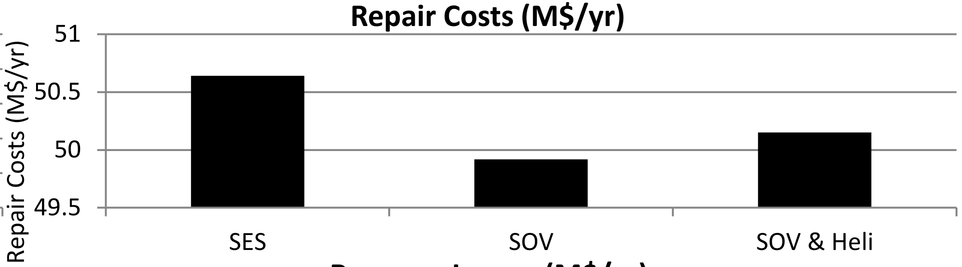


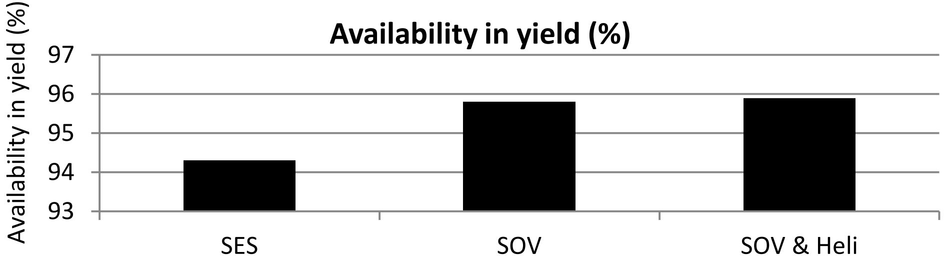


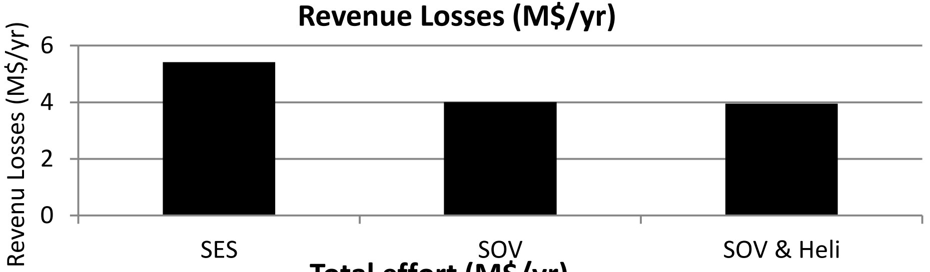


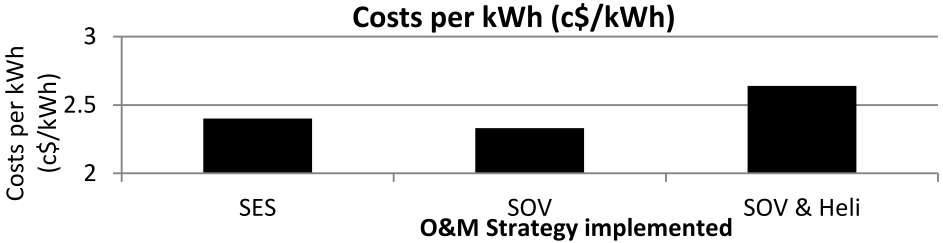
Site 2: Kitty Hawk - Results

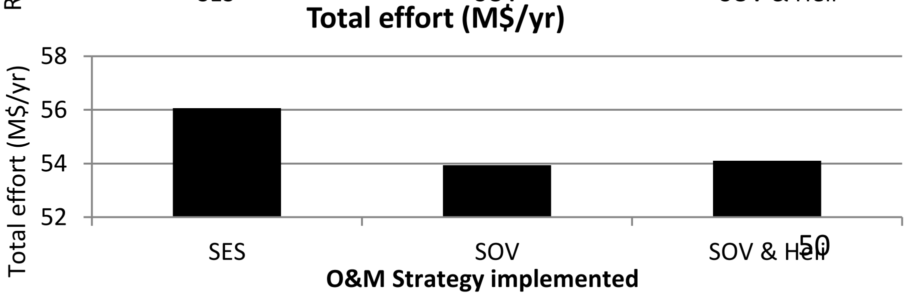




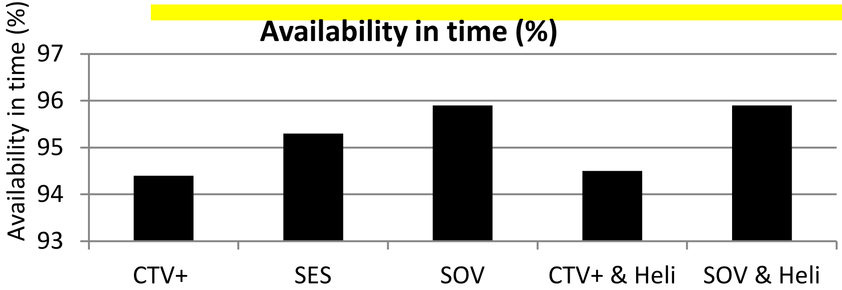


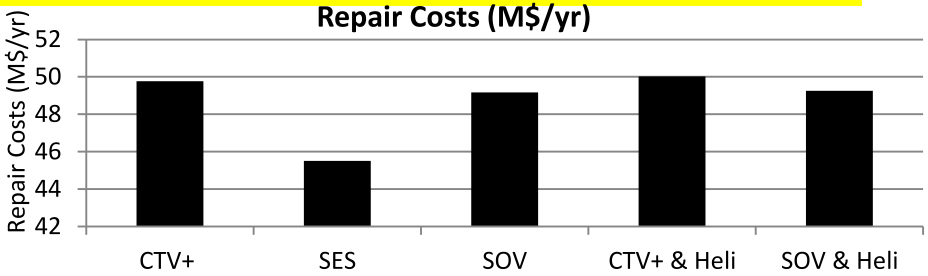


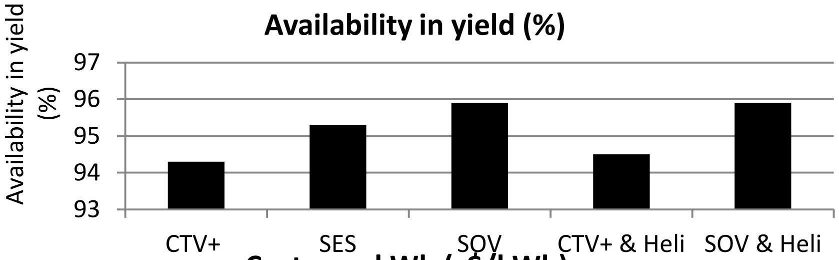


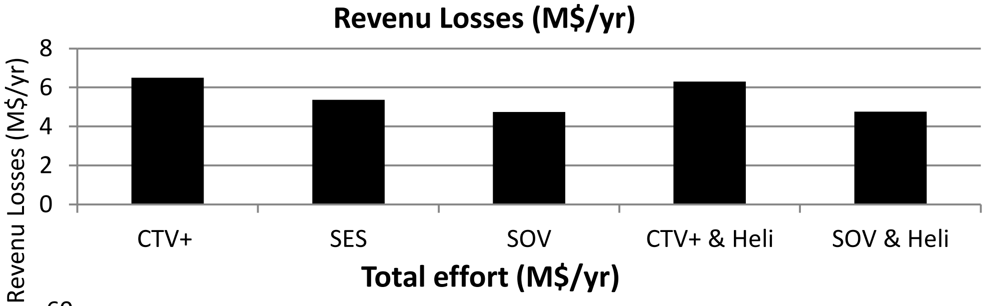


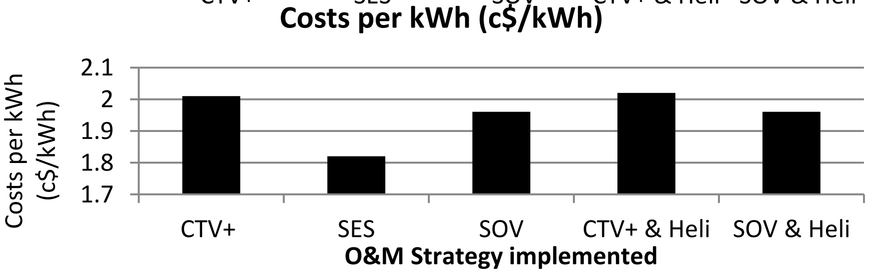
Site 3: Gulf of Mexico - Results

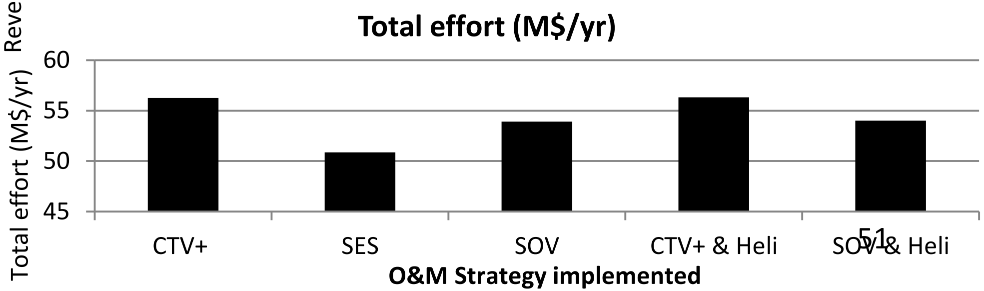




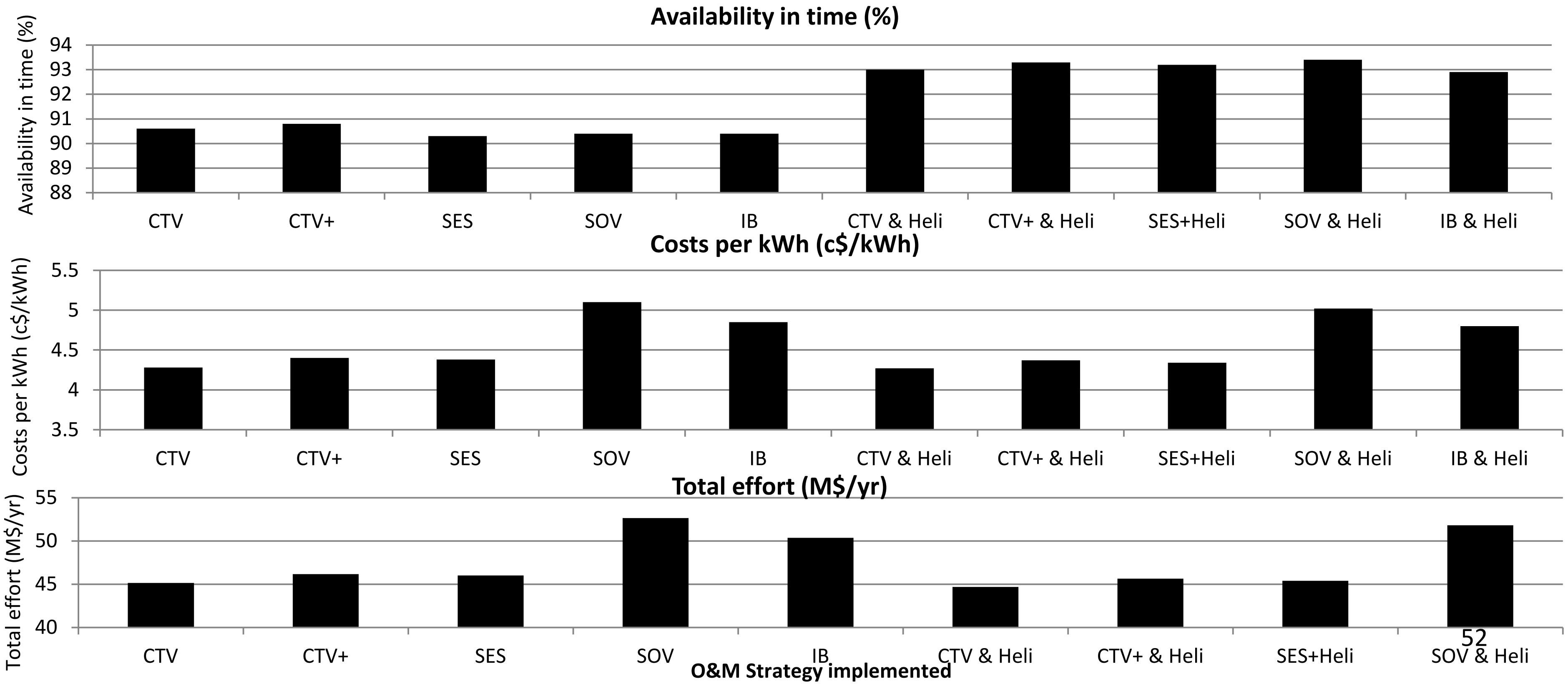




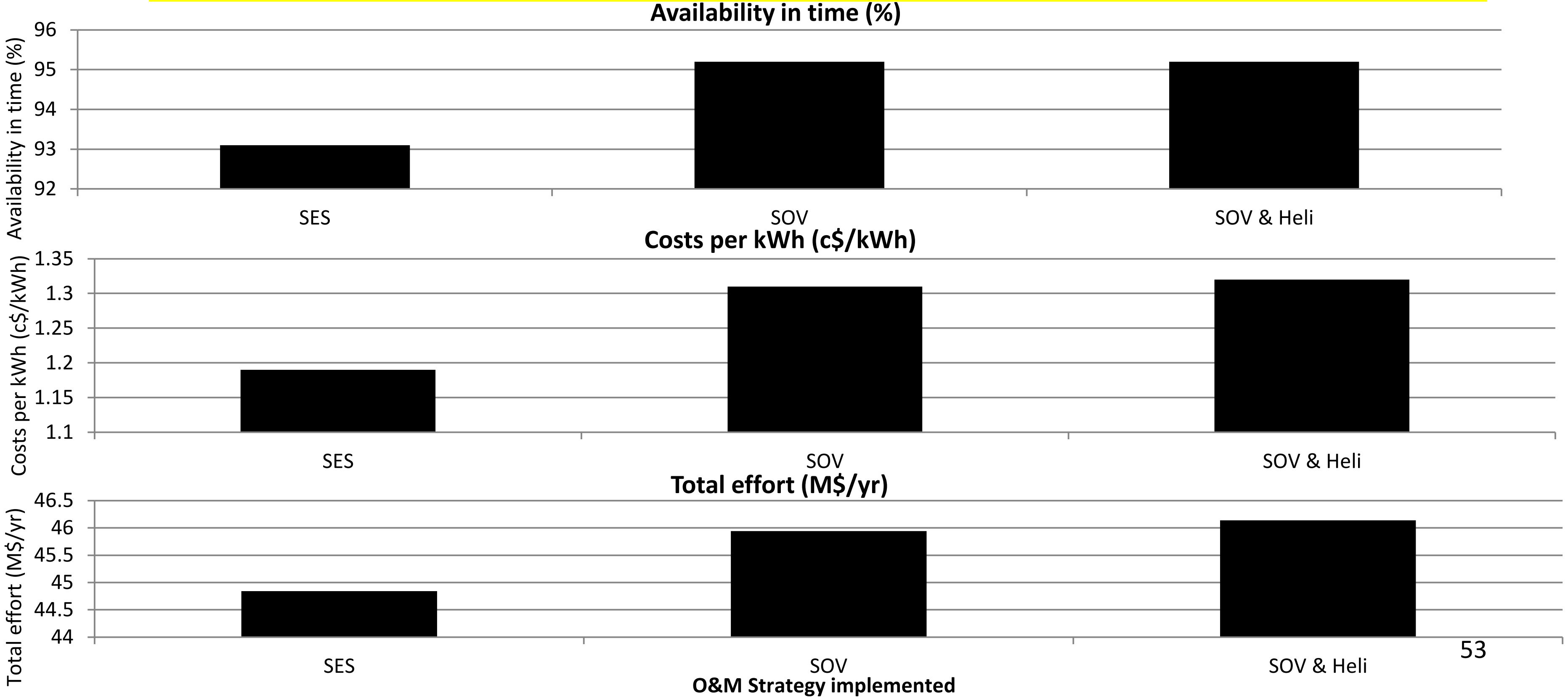




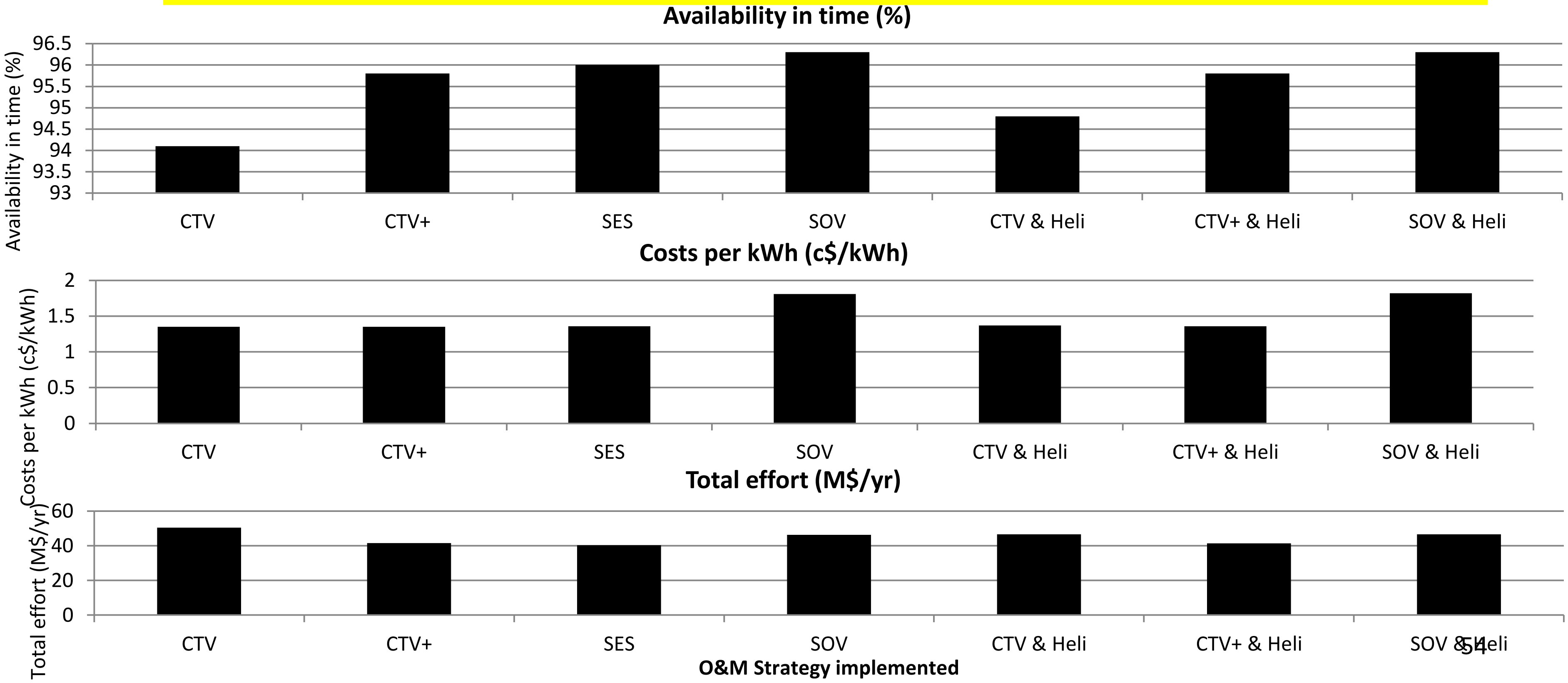
Site 4: Lake Erie - Results



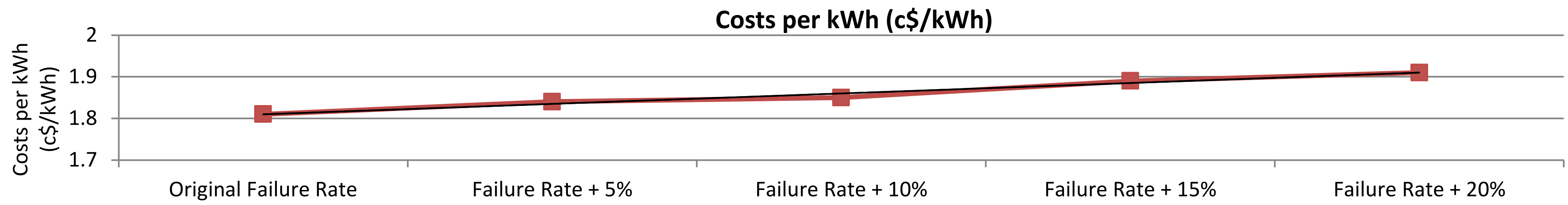
Site 5 – North Pacific - Results

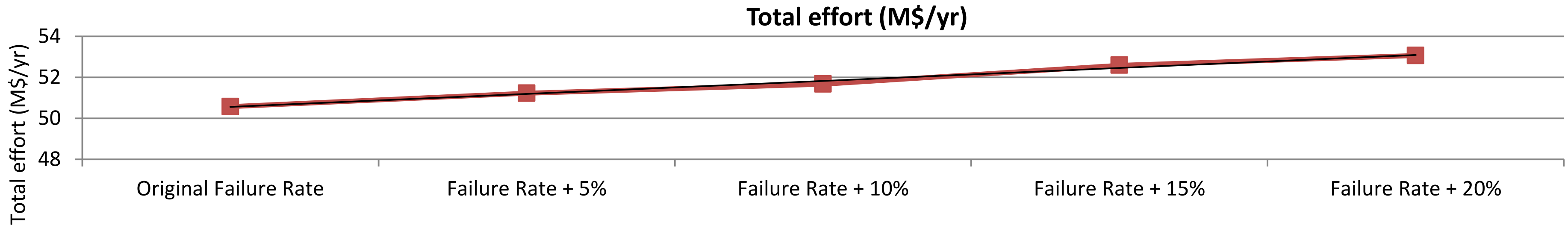


Site 6 - Hawaï


Availability in time (%)
Availability in time (%)
96.5
96
95.5
95
94.5
94
93.5
93
CTV
CTV+
SES
SOV
CTV & Heli
CTV+ & Heli
SOV & Heli
Costs per kWh (c$/kWh)
Costs per kWh (c$/kWh)
2
1.5
1
0.5
0
CTV
CTV+
SES
SOV
CTV & Heli
CTV+ & Heli
SOV & Heli
Total effort (M$/yr)
Total effort (M$/yr)
60
40
20
0
CTV
CTV+
SES
SOV
CTV & Heli
CTV+ & Heli
SOV & Heli
O&M Strategy implemented

Hurricane Study – Gulf of Mexico

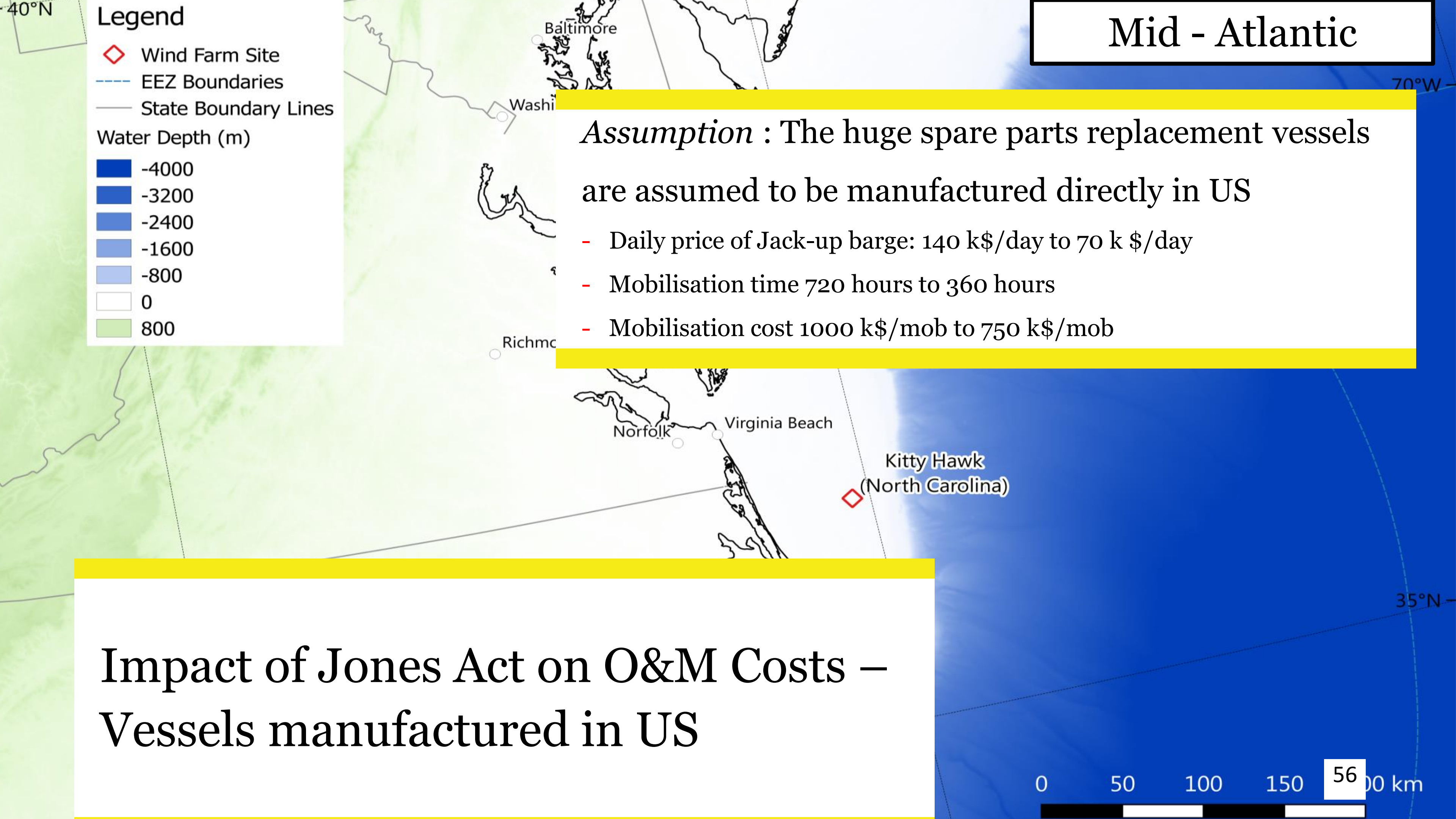




- general trend : increase of the costs with the increase of failure rate:

  20 % increase of failure rate → ~ 5 % of the cost per kWh

- The variations of availability are not significant and are explained by the variation of the possibility of being in a given weather window depending on the simulation.



Mid - Atlantic

Assumption : The huge spare parts replacement vessels are assumed to be manufactured directly in US

- Daily price of Jack-up barge: 140 k$/day to 70 k $/day
- Mobilisation time 720 hours to 360 hours
- Mobilisation cost 1000 k$/mob to 750 k$/mob

Impact of Jones Act on O&M Costs – Vessels manufactured in US

Impact of Jones Act on O&M Costs – Vessels manufactured in US – Mid atlantic

ECN

	case control SOV	Removing of the US flag support barge+ decreasing the Jack-up barge daily price+ decreasing the mobilization time+decreasing the mobilization price	percentage difference (%)
Availability in time (%)	95.7	96	0.31
Availability in yield (%)	95.8	96	0.21
Costs per kWh (c$/kWh)	2.33	1.73	25.75
Repair Costs (M$/yr)	49.92	37.14	25.60
Revenu Losses (M$/yr)	4.01	3.77	5.99
Total effort (M$/yr)	53.93	40.92	24.12

Gemini and New York Comparisons

Site 1 New York

Distance to shore : 70 km

Depth : 30 m

SITE 1 NEW YORK	Annual			
	Average	Minimum	Maximum	Standard Deviation
Wind Speed (m/s)	7.06	0	24.11	3.62
Wave height (m)	1.27	0	9.30	0.73

CTV	CTV +	Surface Effect Ship	Service Operating Vessel
0.69	0.85	0.93	0.96

Gemini

Distance to shore : 85 km

Depth : 30 - 35 m

EUROPE : GEMINI	Annual			
	Average	Minimum	Maximum	Standard Deviation
Wind Speed (m/s)	7.63	0	25.29	3.76
Wave height (m)	1.55	0.02	9.10	0.98

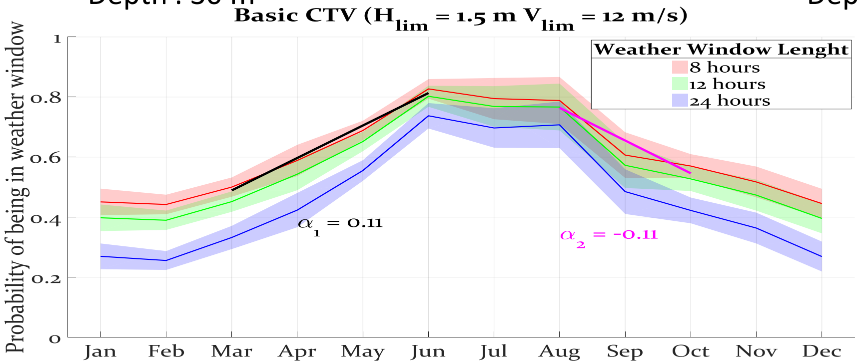
CTV	CTV +	Surface Effect Ship	Service Operating Vessel
0.57	0.74	0.84	0.91

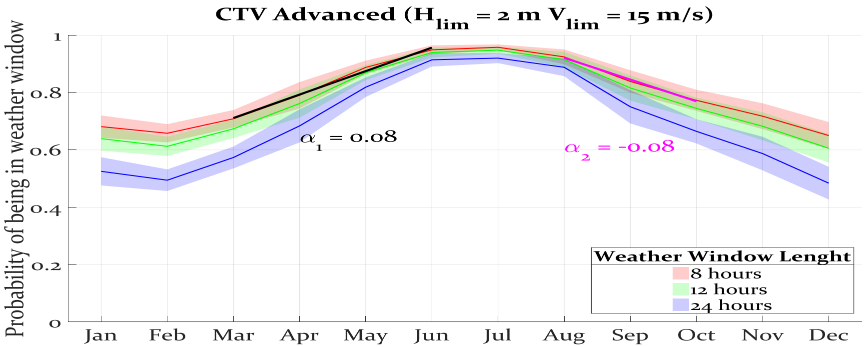
Gemini and New York Comparisons

Site 1 New York Lease Area

Distance to shore : 70 km

Depth : 30 m

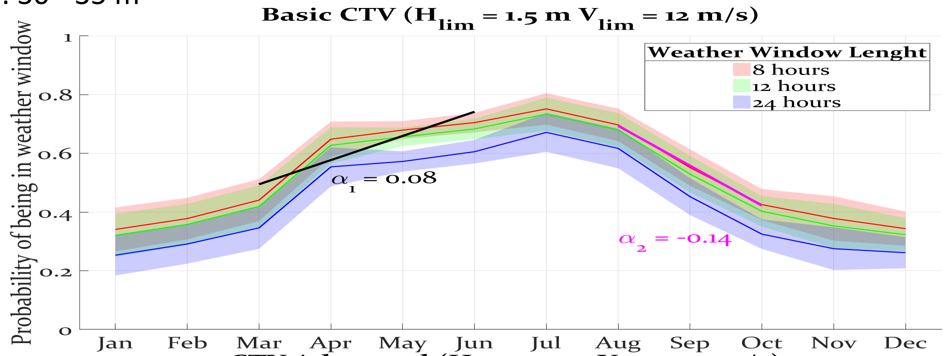


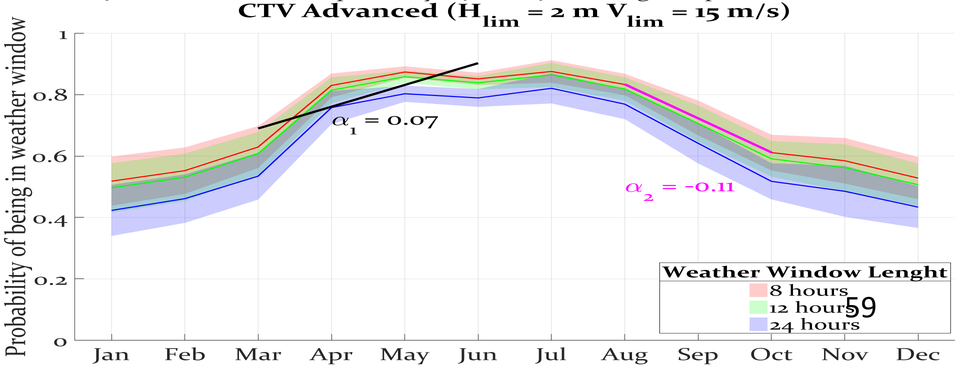


Gemini

Distance to shore : 85 km

Depth : 30 - 35 m



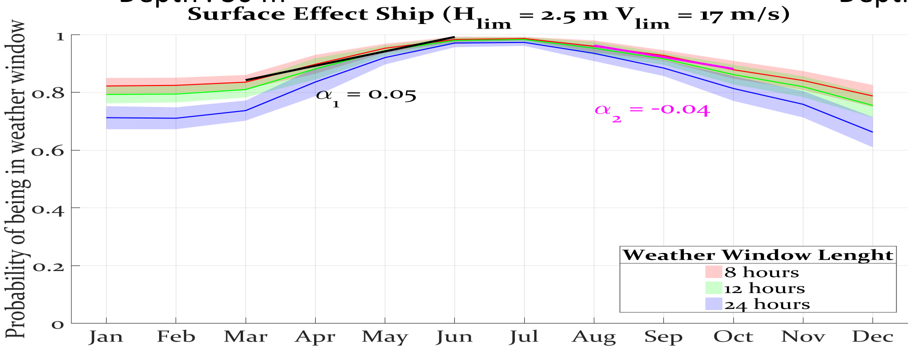


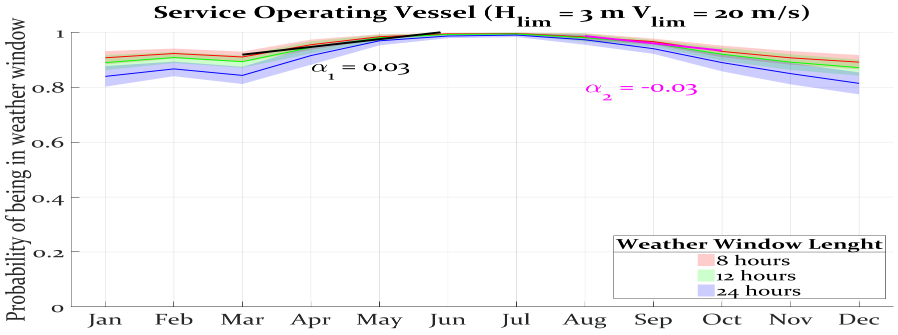
Gemini and New York Comparisons

Site 1 New York Lease Area

Distance to shore : 70 km

Depth : 30 m

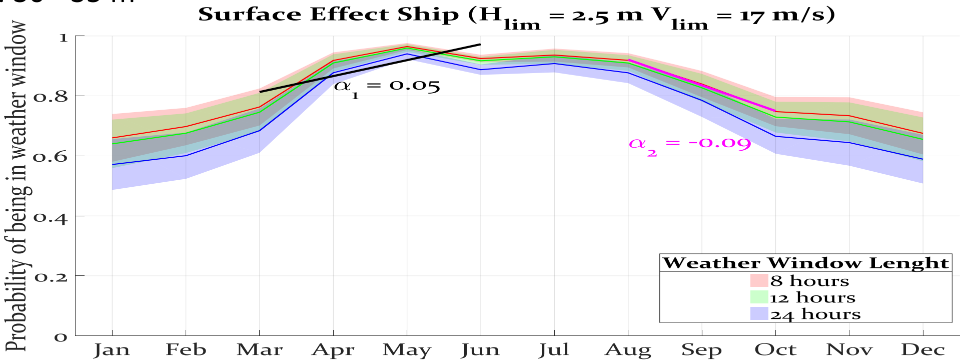


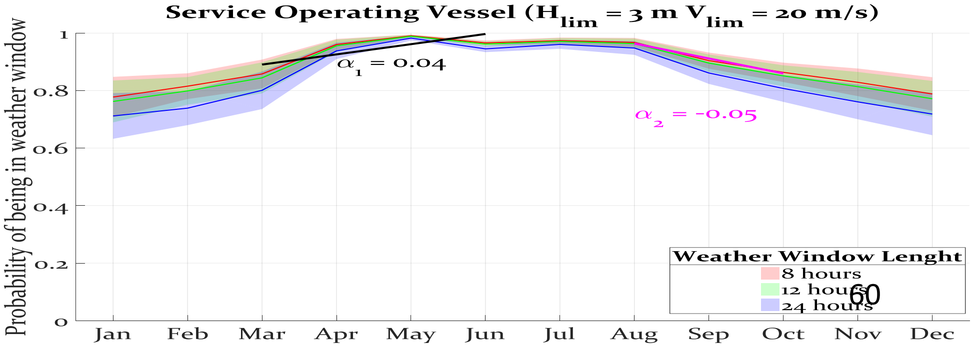


Gemini

Distance to shore : 85 km

Depth : 30 - 35 m





Gemini and New York Comparisons