Learning from the Experts Webinar Series

Offshore Wind Flow Modeling

Gregory S. Poulos, PhD.
CEO, Co-Founder
ArcVera Renewables

September 21, 2022

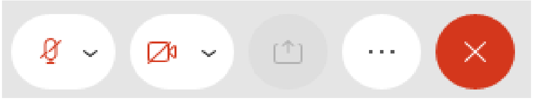
Meeting Procedures

Webinar recordings and presentations will be available at:

www.nyserda.ny.gov/osw-webinar-series

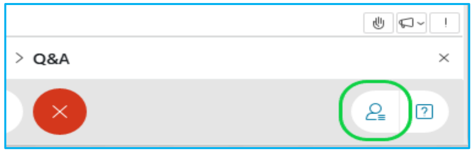
Participation for Members of the Public:

> Members of the public will be muted upon entry.



You'll see  **when your microphone is muted**

> Questions and comments may be submitted in writing through the Q&A feature at any time during the event.



> If technical problems arise, please contact John.Necroto@nyserda.ny.gov

Learning from the Experts

This webinar series is hosted by NYSERDA's offshore wind team and features experts in offshore wind technologies, development practices, and related research.

NEW YORK STATE OF OPPORTUNITY. | NYSERDA

ARCVERA RENEWABLES

Golden – São Paulo – Cape Town – Bangalore

Offshore Wind Flow Modeling

Long-Range Wake Losses

A Cautionary Tale and a Billion Dollar Riddle

Gregory S. Poulos, PhD, Principal Atmospheric Scientist, CEO

A Presentation to NYSERDA

September 21, 2022

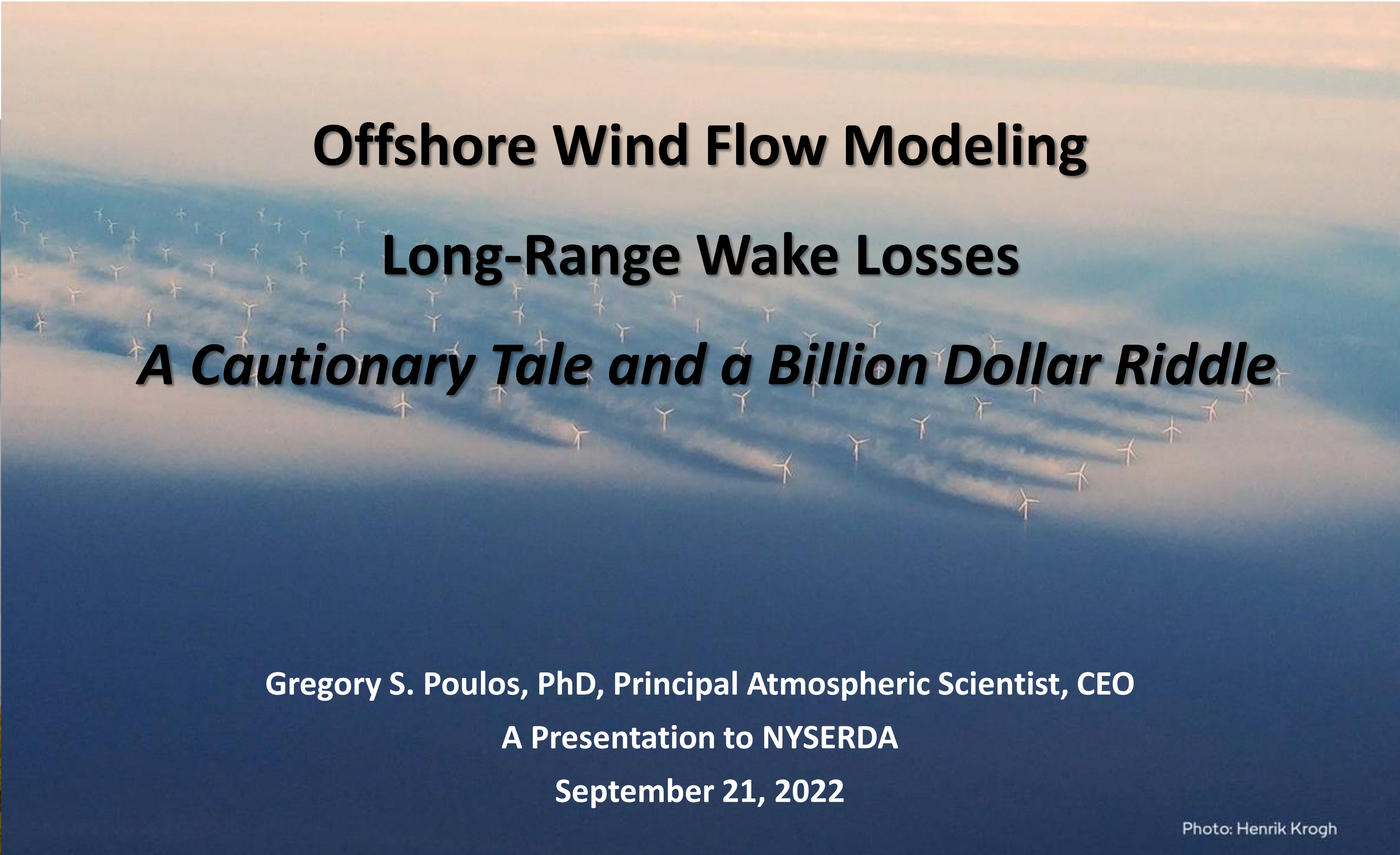


Photo: Henrik Krogh

Outline

- **Context: Project Development and Wakes**
- **Where Atmospheric Science Contributes** ***(Hint: Supercomputers required)***
- **Validation of Long-Range Wakes Onshore and "Add a zero"** ***(Hint: New method works much better)***
- **NY Bight Wind Leases Circumstance**
- **1 Billion Dollars of Impact**

Who am I? NY NY

- NY - Meteorologist, Cornell 1989 – Go Big Red!
- Research career, some work with SUNY Albany (!), Los Alamos, startup company Foresight Weather, NCAR
- Joined wind energy industry in 2007
- Fraught with concern about implementing atmospheric science advances in an industry behind in that science
- NY - Advisory Committee to Cornell Atmos Sci

ARCVERA RENEWABLES

EXPERTISE THROUGHOUT THE PROJECT LIFECYCLE

Prospecting → Development → Financing → Construction → Operations → Repowering

Atmospheric Science, Engineering, and Storage/Wind/Solar/green H_2 Technological Consulting with Roots to the Very Origins of the U.S. Industry

Start 1978, named ArcVera March 2017

- Origins of US renewables
- California, post-oil embargo, 1978 start
- Deep historical project database
- Technology/engineering and expertise/experience used to cut risk

Based in Golden & Globally

- Projects on 6 of 7 continents
- 40+ person degreed team - 4 continents
- Senior staff 10+ years experience
- Work on thousands of storage/wind/solar projects globally

Offices in US, Brazil, South Africa and India

HYBRID • STORAGE • SOLAR • WIND

ARCVERA RENEWABLES

ArcVera's Technical Work in Offshore Wind Energy

Engineering

- WTG Technology Reviews and Advisement
- Technical Due Diligence of TSA
- TSA Negotiation Support
- O&M Plan and Due Diligence
- Site Suitability Review
- Component Inspection at Port
- Power Performance Testing
- Root Cause Analyses (capability in progress)
- Decommissioning Plan (possible capability)
- Expert Witness/3rd Party Experts

Atmospheric Science

- Measurement Campaigns (Met towers & FLIDAR)
- Prospecting Maps: Mesoscale modeling
- Micrositing/Optimization
- Wind energy resource assessments
- Operational Analysis

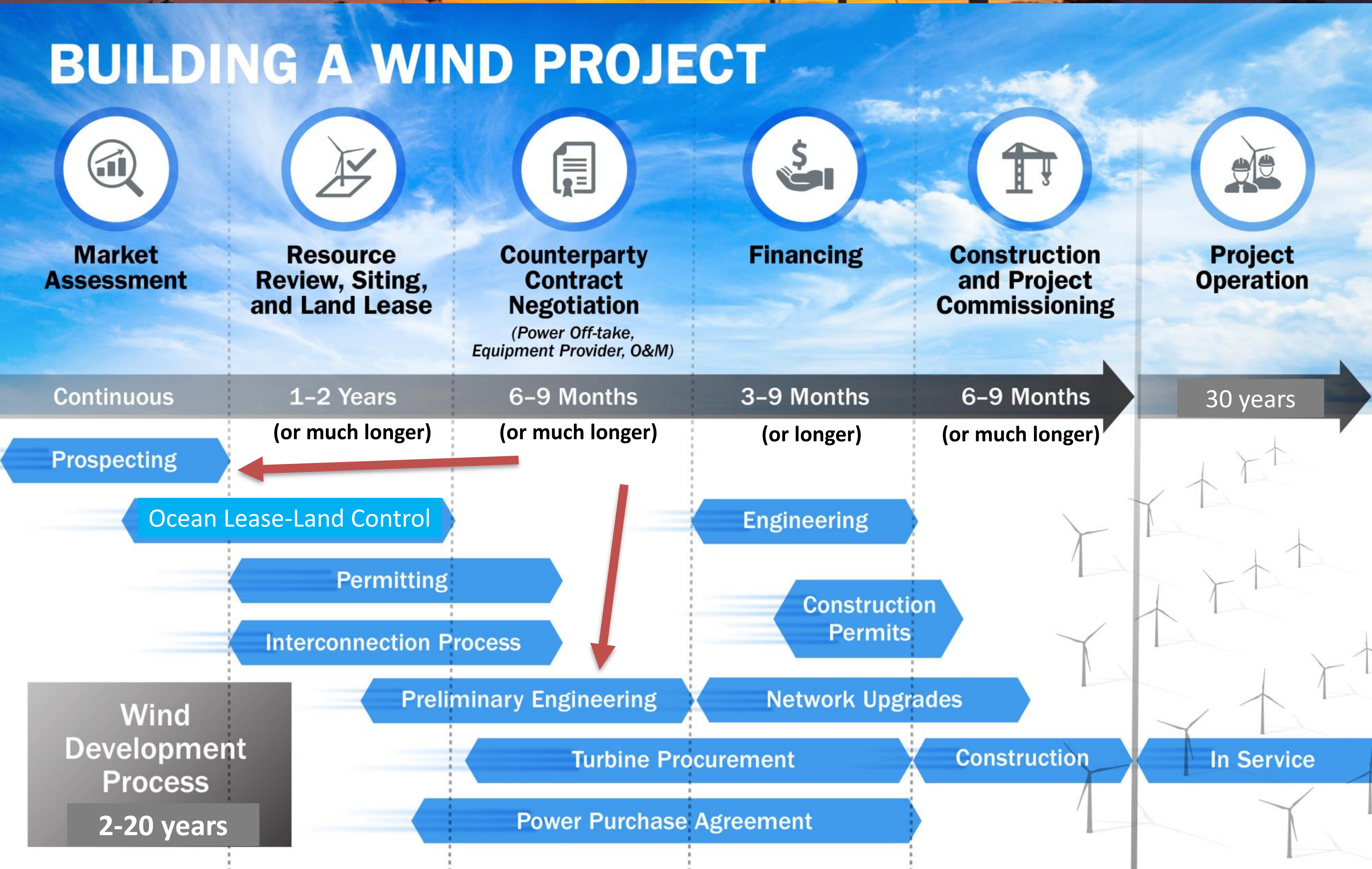
ARCVERA RENEWABLES

How does this open sea become …

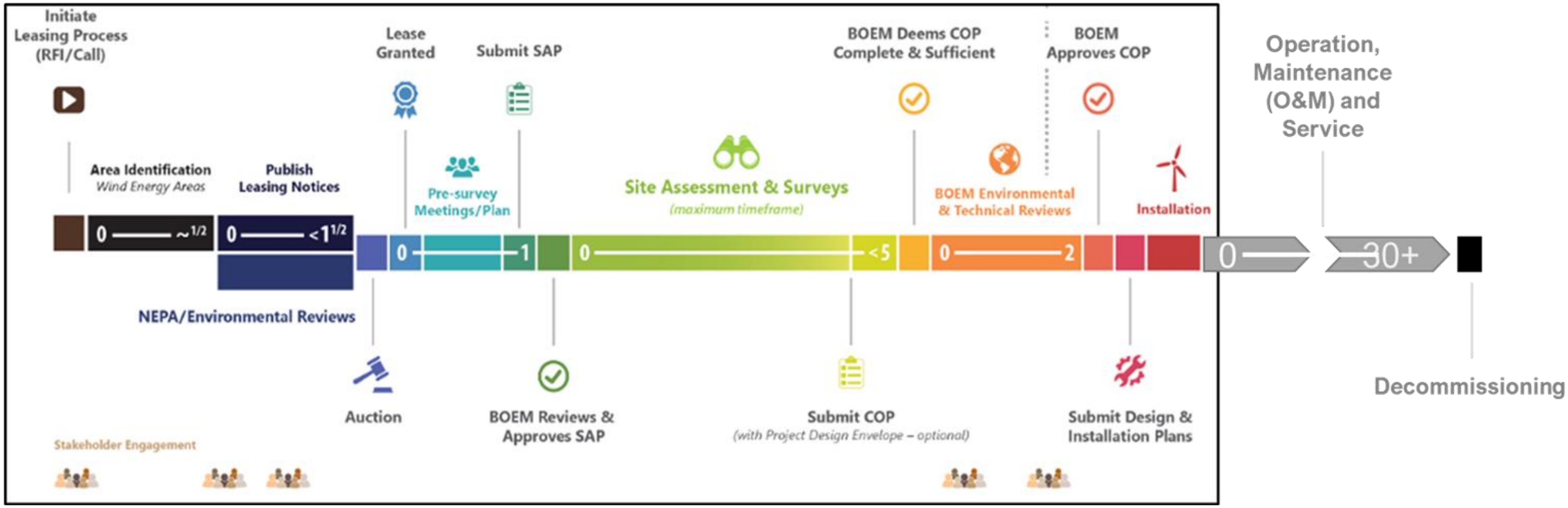
… become this?

The Horns Rev wind farm off the west coast of Denmark

Project Development!



Offshore Wind Overview ~10-Year Timeline



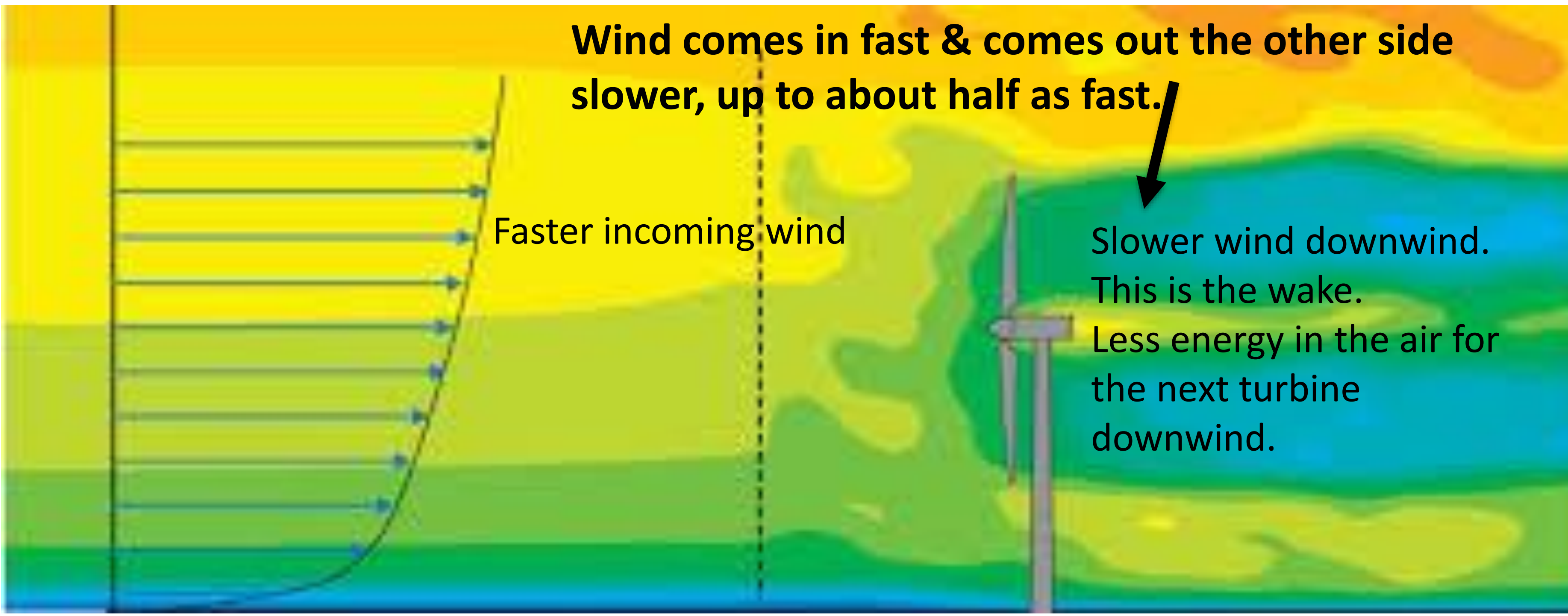
Stakeholders require evaluation and/or permits

- Federal and state ownership/jurisdiction
- Fisheries, shipping, oil and gas transportation
- Military protection
- Environmental and bathymetry protections

The many stakeholders and required permits make the lease-approval process much longer than for onshore wind.

Now for some background on wind turbines and their wakes

Background: Wind Turbine Wake

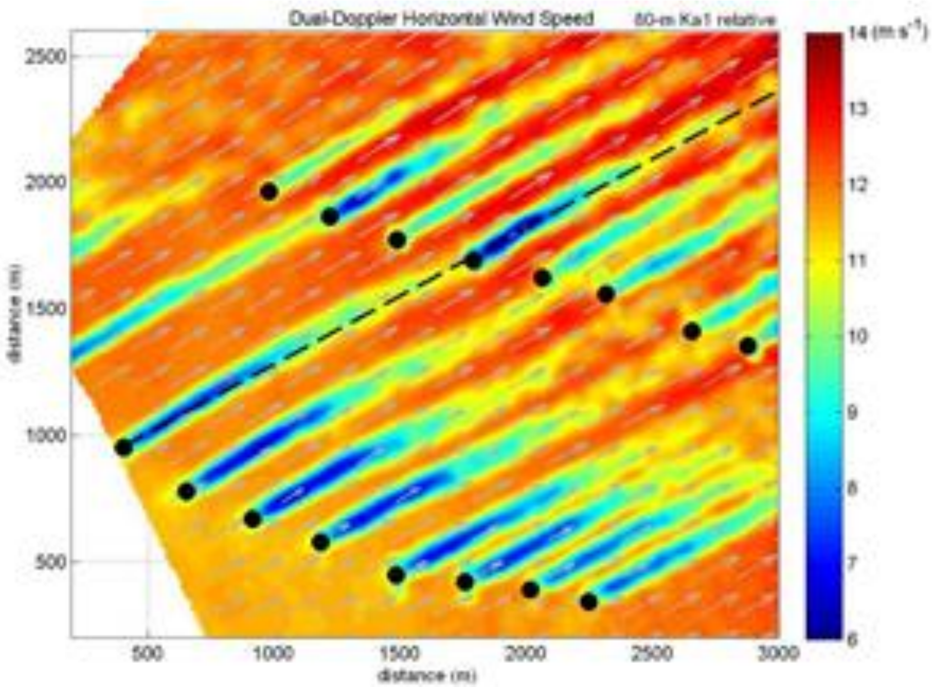


Based on the CEWEX field experiment no substantive impact on farming or environment due to wake wind speed changes.

Wakes and their recovery rate are a critical wind farm design factor.

ARCVERA RENEWABLES

Wakes Build Up, Affecting Efficiency



Normally invisible, we can sometimes see wakes within fog and with radar.

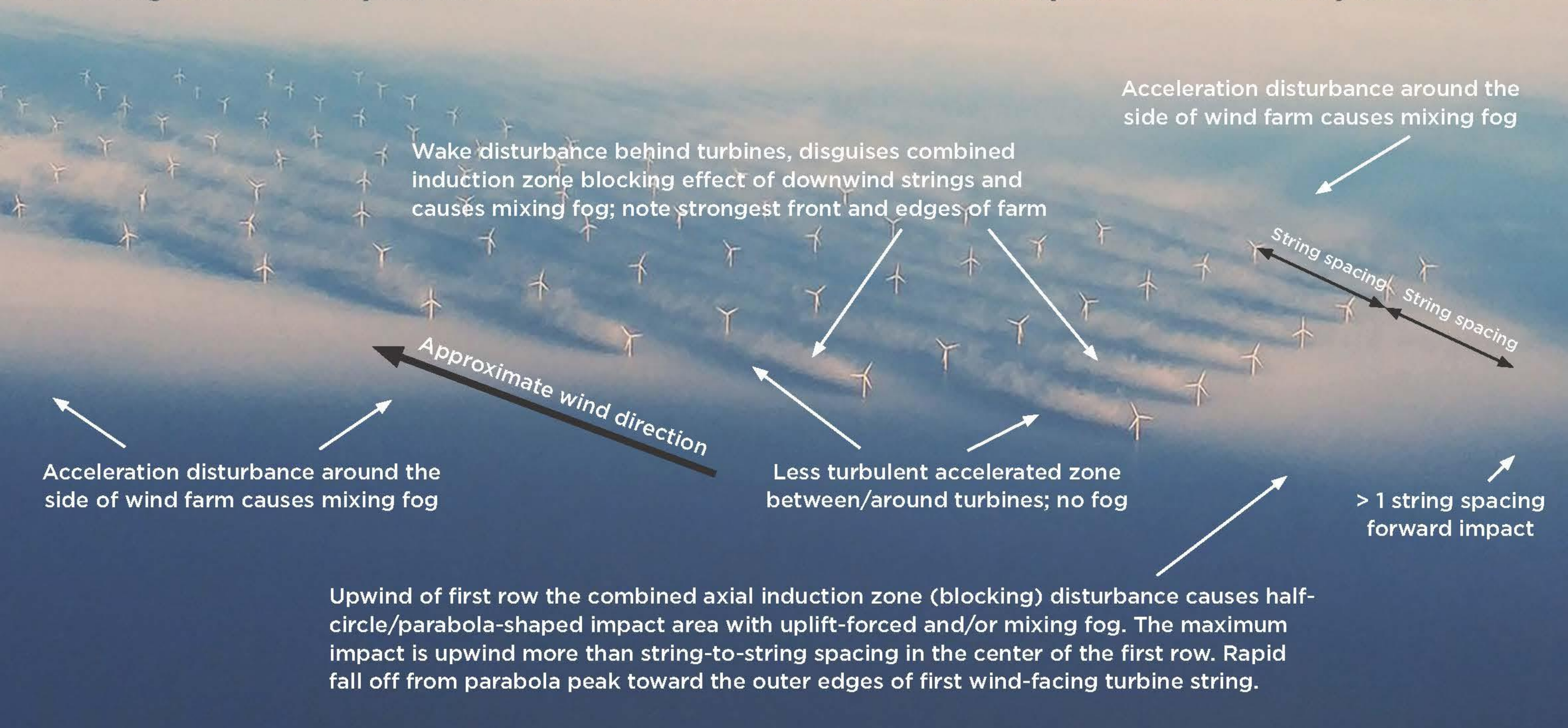
ARCVERA RENEWABLES

A picture tells a thousand words:

Wind Farm Atmosphere Interaction (WFAI Losses)

Photograph of Horns Rev:

Showing that the complex interaction of a wind farm with the atmosphere is more than just wakes.

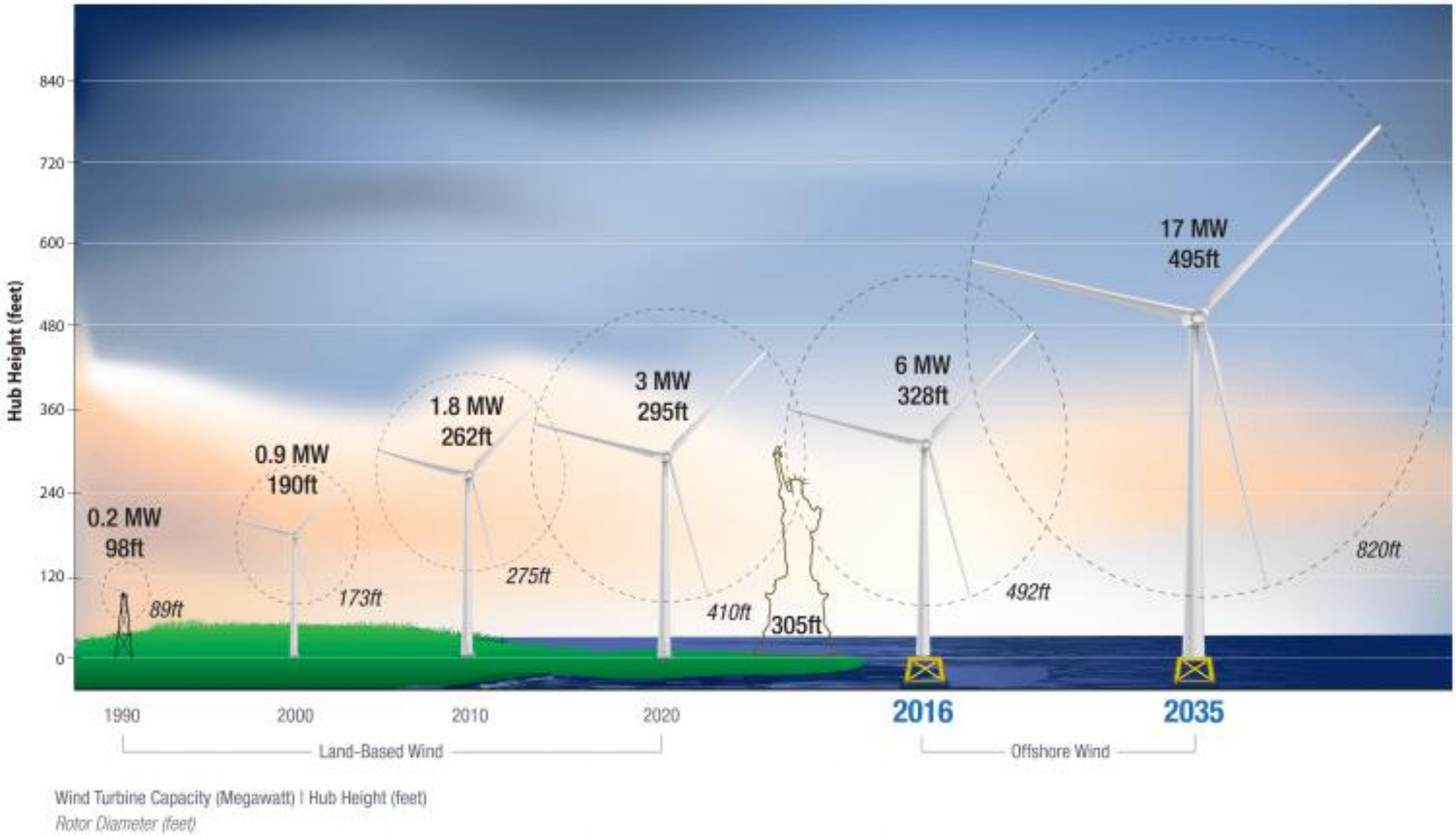


ARCVERA RENEWABLES

Based on ArcVera Renewables R&D
Prepared by G. Poulos, May 2020

Photo credit: Henrik Krogh

Wind Turbines are Getting Much Bigger



ARCVERA RENEWABLES

Many in the industry think wakes recover to the upwind speed within 2-3 miles (3-5 km or ~30-50 rotor diameters). What if the real answer is 10 times bigger? Then, “Add a zero”.

It turns out that the state of the atmosphere – an inversion, for example – lengthens the distance wakes travel and it is not well captured in commonly used wake models, requiring a more sophisticated approach.

How can we possibly understand something so complex?

- Weather Research and Forecasting model, WRF
  - A state-of-the-art model from NCAR/NOAA
  - Contains atmospheric physics and thermodynamics and varying stability
  - Has ocean interaction with the atmosphere
  - Contains all the weather variables/turbulence
  - Models wind turbine interaction with atmos.
    - Wind Farm Parameterization, WFP

Thus, a solution is found with WRF-WFP.

Long Range Wakes with WRF-WFP

- Get a supercomputer (easy in cloud, not cheap)
- Learn how to run WRF-WFP well (not easy)
- Model the atmosphere <u>without</u> wind turbines
- Model the atmosphere <u>with</u> wind turbines
- Subtract the results to find the difference in wind/energy over time (a day, a year, project lifetime)
- Adjust design and for risk, accordingly

ARCVERA RENEWABLES

ArcVera's Study of Long-Range Wakes
"Add a zero"

Paper available with detailed references and validation

Visit **arcvera.com**, navigate to "Resources", then "News and Publications".

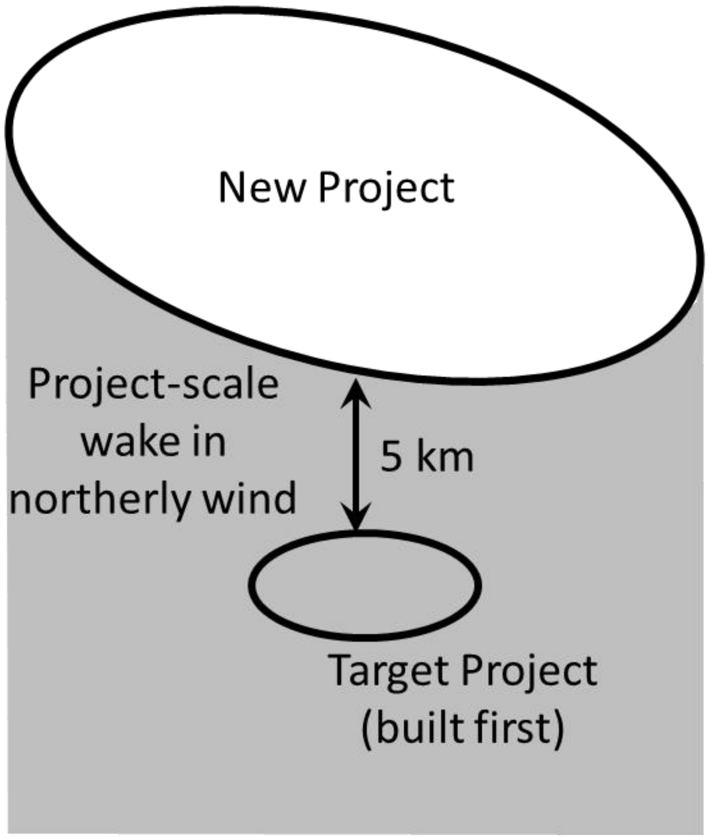
White paper: Estimating Long-Range External Wake Losses in Energy Yield and Operational Performance Assessments Using the WRF Wind Farm Parameterization

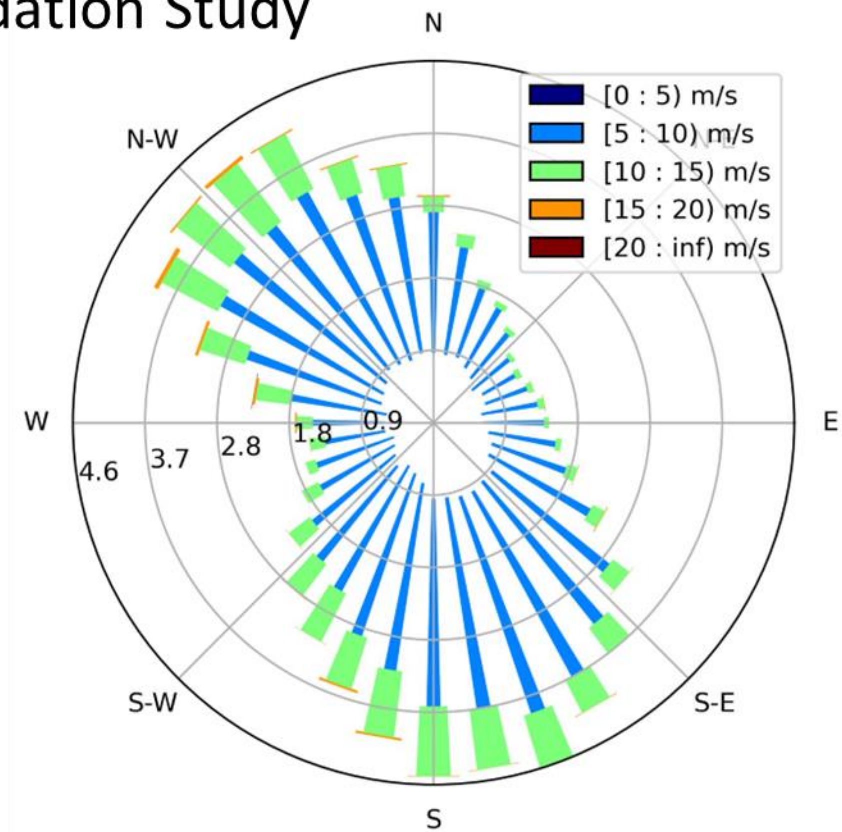
Mark Stoelinga, et al. 2022

ARCVERA RENEWABLES

Long-Distance Wakes: Onshore with onsite data validation

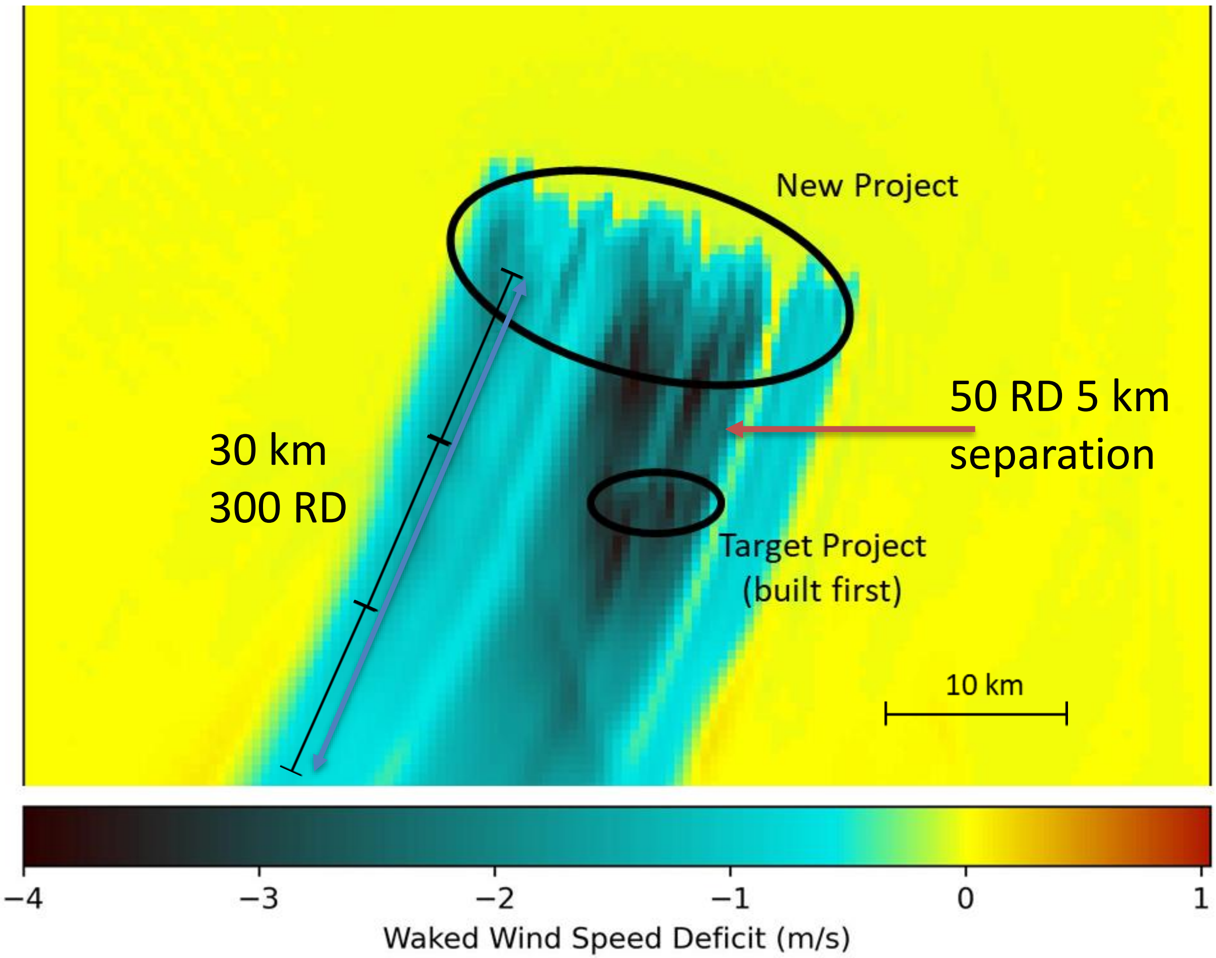
Onshore Validation Study





27 northerly wind days before and 27 days after, with similar data

Material Wakes Onshore 300-500 RD



Time varying weather and atmospheric stability causes varying wake recovery lengths. WRF-WFP captures time varying stability more realistically. This is critical to getting a more correct answer.

Long-Distance Wakes: Onshore

Source of Estimate	All Times
SCADA (actual before-after wind farm data)	23.8%
EV-DAWM	5.7%
ArcVera WFAI Model	0.2%
WRF-WFP	27.7%

The correct answer

Both engineering wake loss models are far off/ineffective

Far more accurate

WRF-WFP solution found to be much closer to the real answer. Additional studies by others conclude similarly as does more recent work by ArcVera. Great new tool for assessing and reducing real project risks.

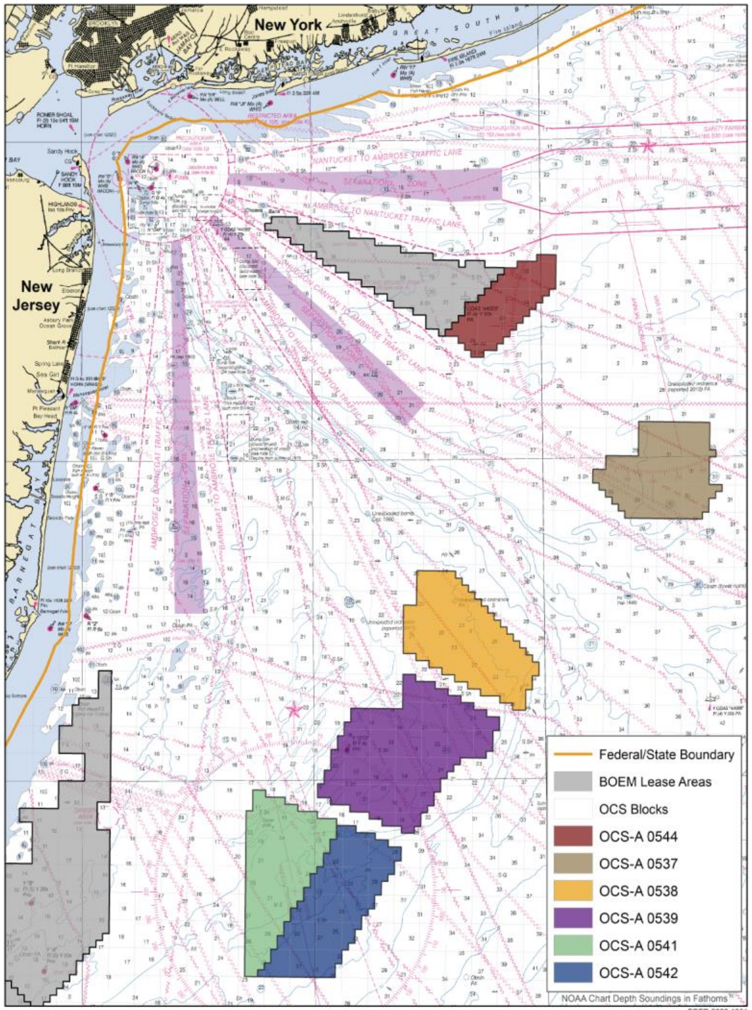
ARCVERA RENEWABLES

Current Methods Found Inaccurate for Long-Range Wakes

Now what?

And what about the NY Bight?

NY Bight Circumstance



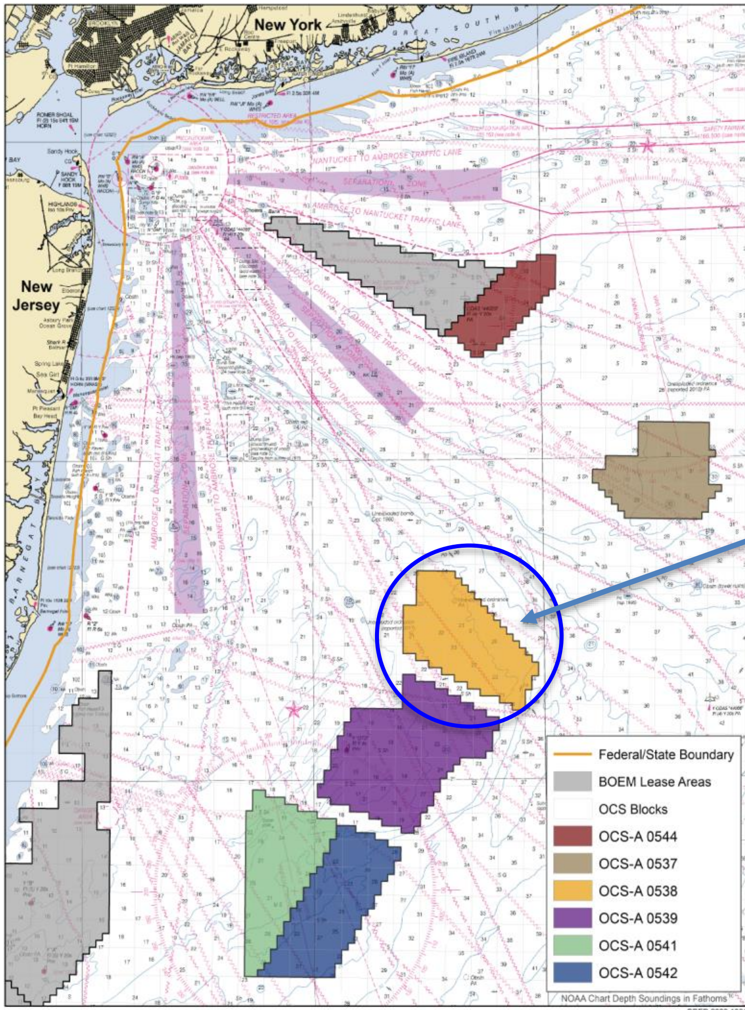
Provisional Winners of the New York Bight Lease Areas, $4.37 Billion in High Bids

OCS-A 0544	Mid-Atlantic Offshore Wind LLC, **$285,000,000**
OCS-A 0537	OW Ocean Winds East, LLC, **$765,000,000**
OCS-A 0538	Attentive Energy LLC, **$795,000,000**
OCS-A 0539	Bight Wind Holdings, LLC, **$1,100,000,000**
OCS-A 0541	Atlantic Shores Offshore Wind Bight, LLC, **$780,000,000**
OCS-A 0542	Invenergy Wind Offshore LLC, **$645,000,000**

BOEM
Bureau of Ocean Energy Management

ARCVERA RENEWABLES

NY Bight: Focus on Lease Area 0538



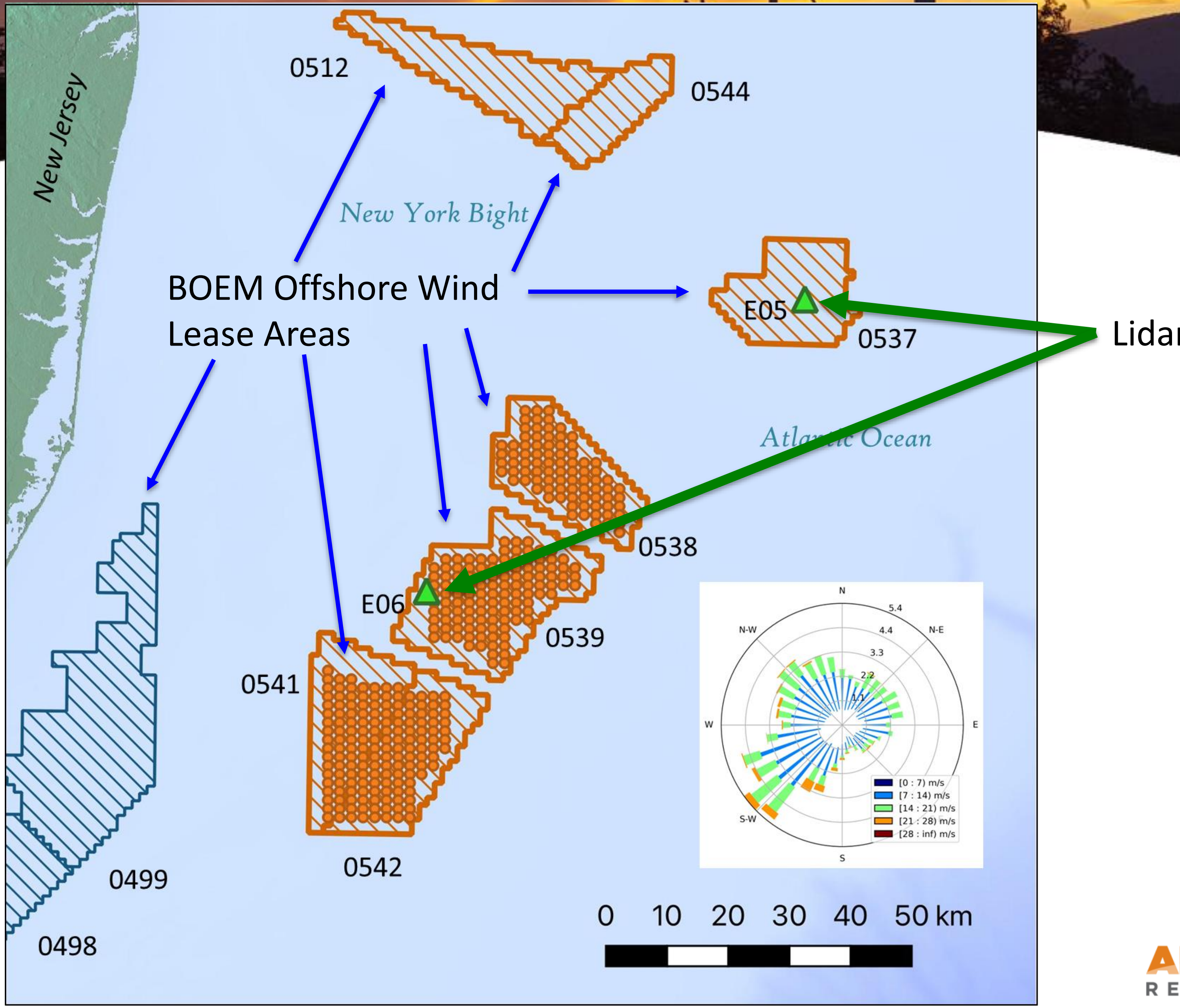
Provisional Winners of the New York Bight Lease Areas, $4.37 Billion in High Bids

OCS-A 0544	Mid-Atlantic Offshore Wind LLC, $285,000,000
OCS-A 0537	OW Ocean Winds East, LLC, $765,000,000
OCS-A 0538	Attentive Energy LLC, $795,000,000
OCS-A 0539	Bight Wind Holdings, LLC, $1,100,000,000
OCS-A 0541	Atlantic Shores Offshore Wind Bight, LLC, $780,000,000
OCS-A 0542	Invenergy Wind Offshore LLC, $645,000,000

BOEM Bureau of Ocean Energy Management

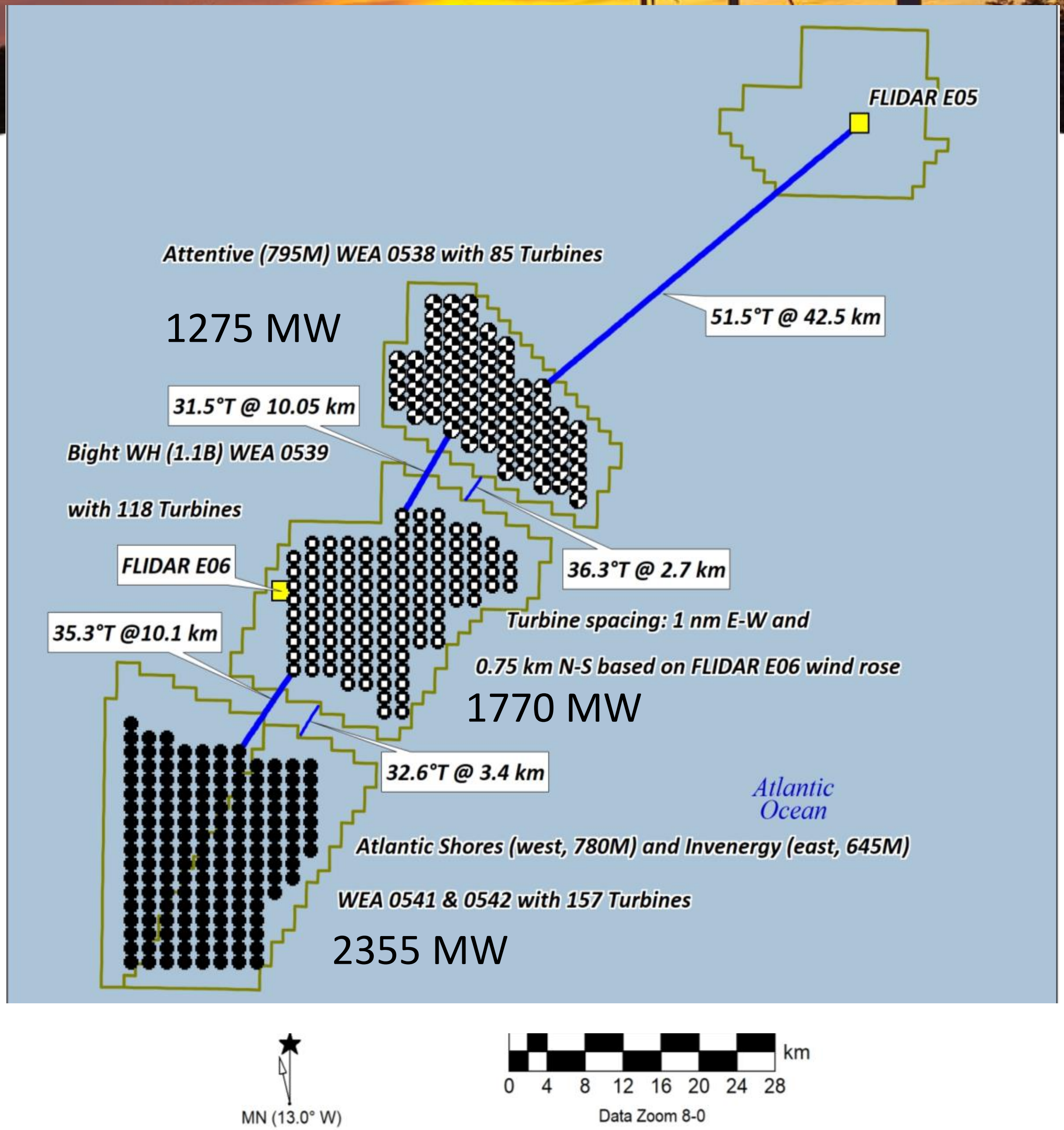
ARCVERA RENEWABLES

NY Bight Circumstance



ARCVERA RENEWABLES

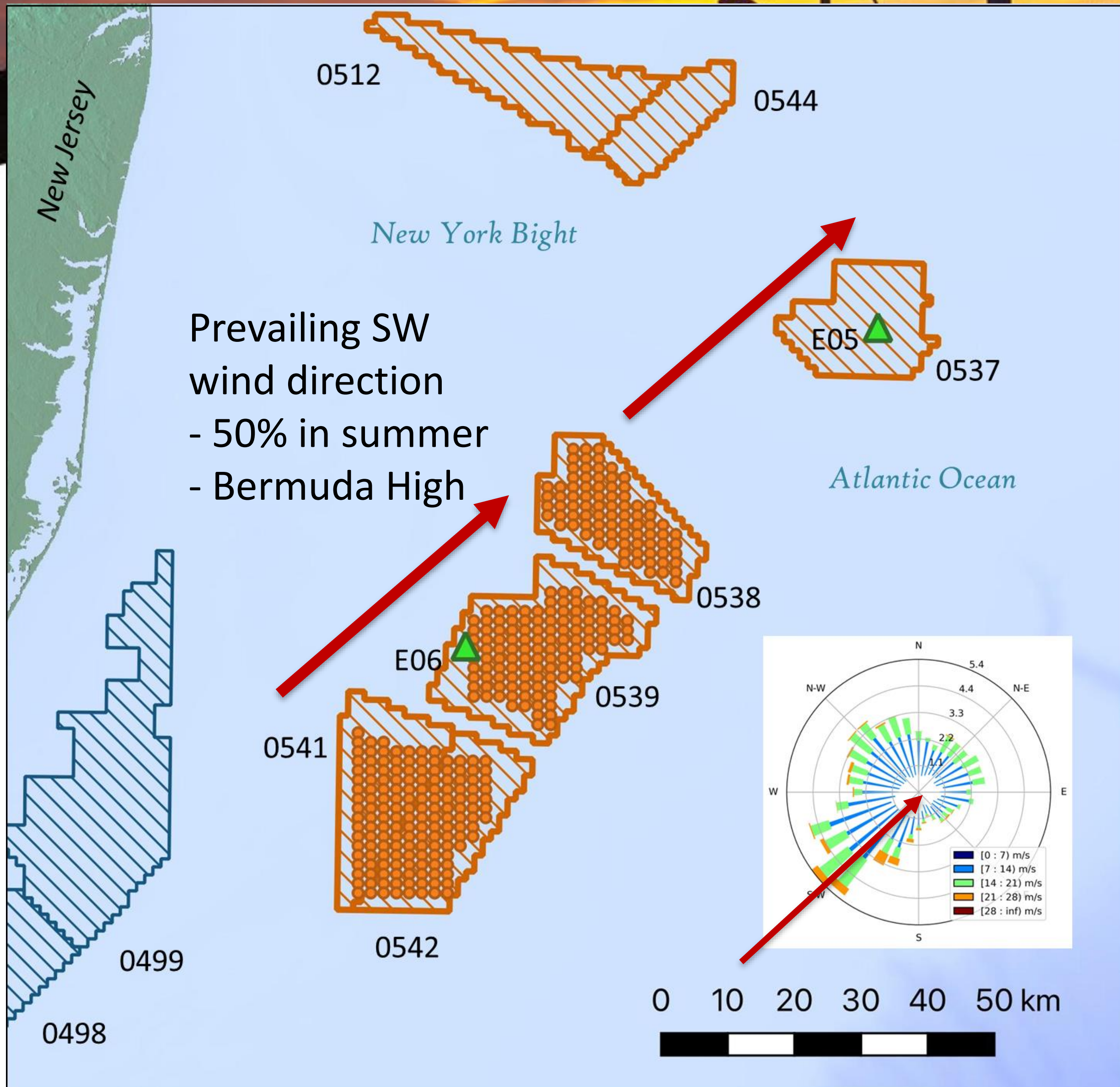
NY Bight Circumstance



> 5,000 MW in these three lease areas alone

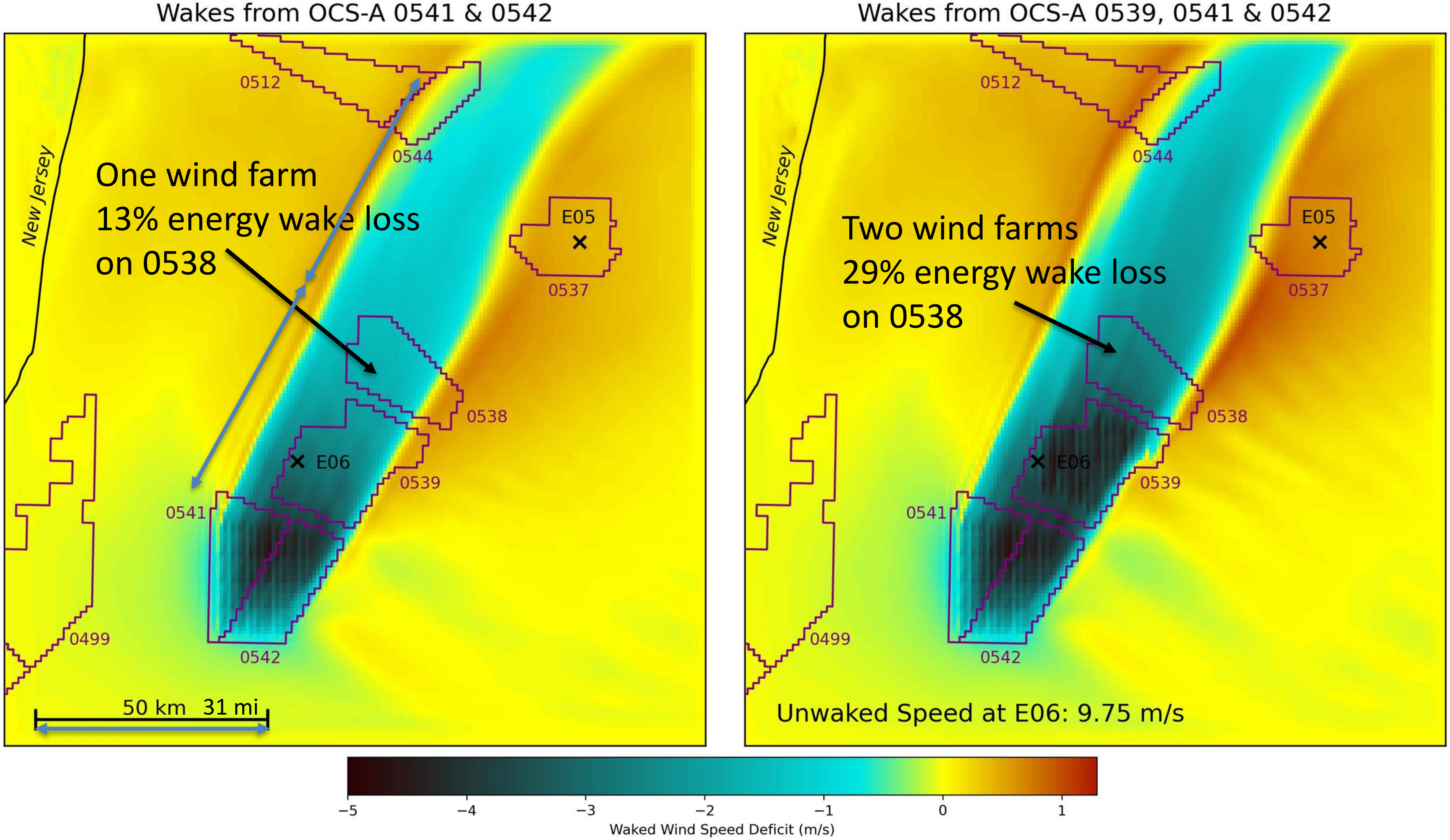
ARCVERA RENEWABLES

NY Bight Wind Direction



ARCVERA RENEWABLES

Material Wakes NY Bight + 60 miles



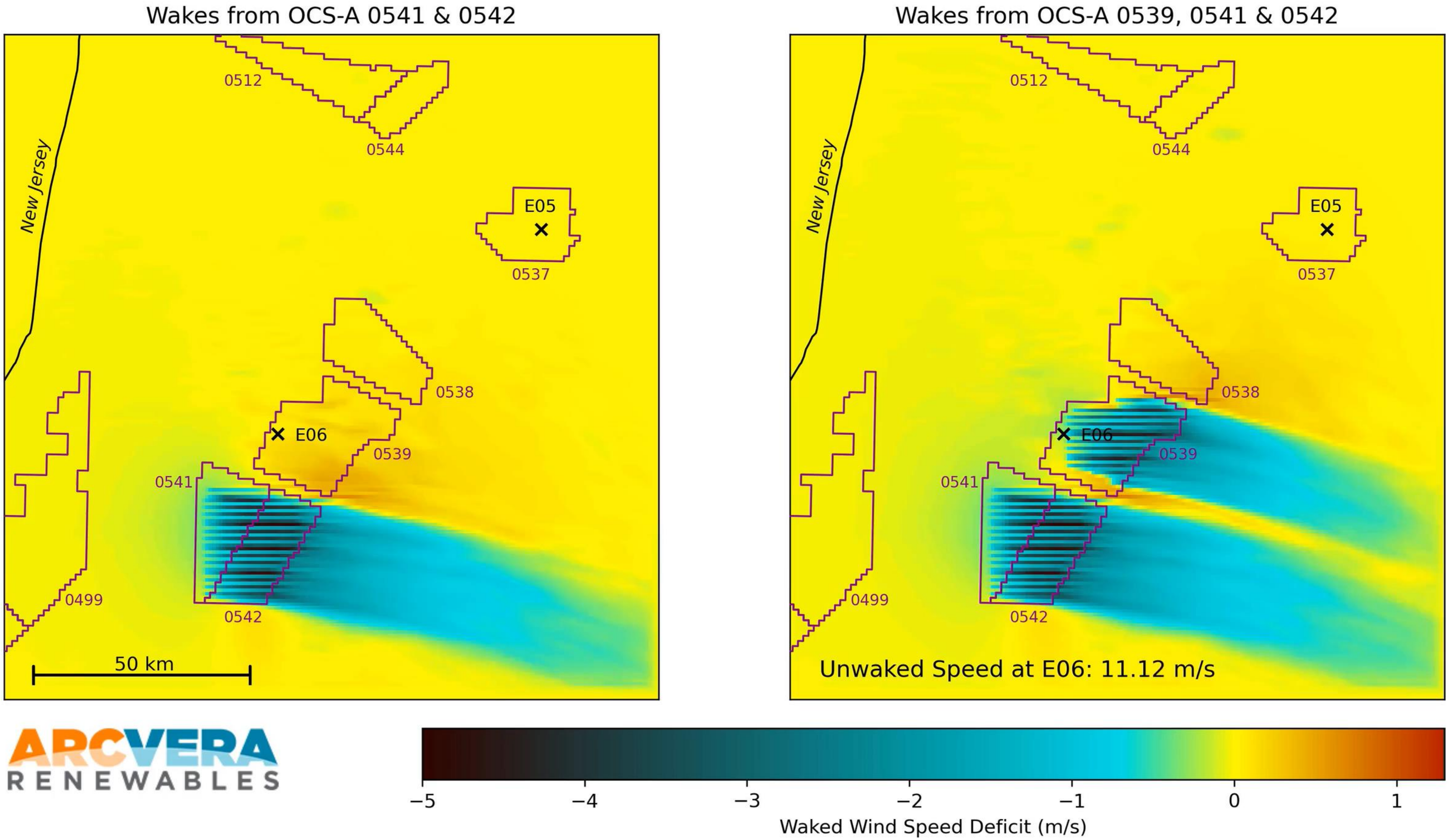
15-MW turbines, 240-m RD 1.4 km x 1.85 km turbine spacing

10 km between arrays, 165 RD/40 km between 0541/0542 and 0538 arrays

ARCVERA RENEWABLES

New York Bight Long-Distance Wakes in Southwesterly Flow Using WRF Wind Farm Parameterization

Total Length: 16 Days (four days in each season)   Current Frame: 2020-02-03 07:00 EST   Season: Winter



Old Tools Found Inadequate

- Turbines are rapidly changing; old models can’t keep up
  - taller hub height
  - greater rotor diameter (larger volume waked)
- Engineering wake loss models have insufficient sensitivity to changing atmospheric stability
  - Average conditions used for ease of use – but speed kills
  - Atmospheric stability changes constantly in time
- Validated on smaller turbines and with insufficient turbine size dependence
- Not validated for external wake losses – a gap in knowledge that creates a $1B issue

Too Big to Ignore - Small Errors Costly
The $1B Math

1% of production = $100 million dollars per 1000 MW of wind capacity installed

How?

1 year is 365 days with 24 hours or 8760 hours

8760 hours at a 1000-MW wind farm is 8.8 million MWh

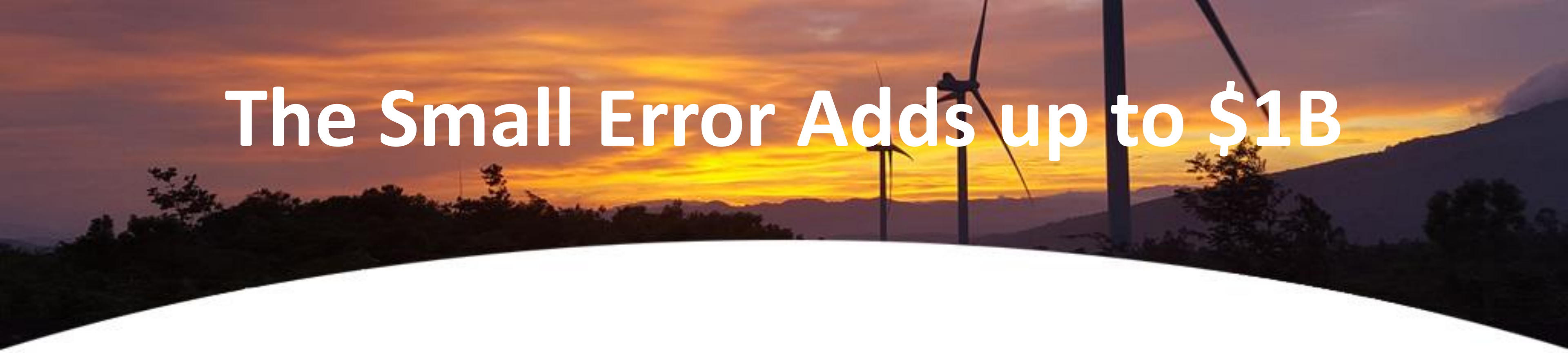
But the wind doesn’t blow all the time

Typically half or less so ~4.4 million MWh* per year

(Note: This 4.4 M value is a bit low for the NY Bight – closer to 5M*.)

*Indicative only, based on assumptions, full and detailed assessment required to determine actual value

ARCVERA RENEWABLES



The Small Error Adds up to $1B

1% error in wake loss prediction is a 44,000 MWh error.

The cost of electricity per MWh is $75 (7.5 cents per kWh)

44,000 MWh @ $75/MWh is $3.3M per year

The wind farm should operate 30 years.

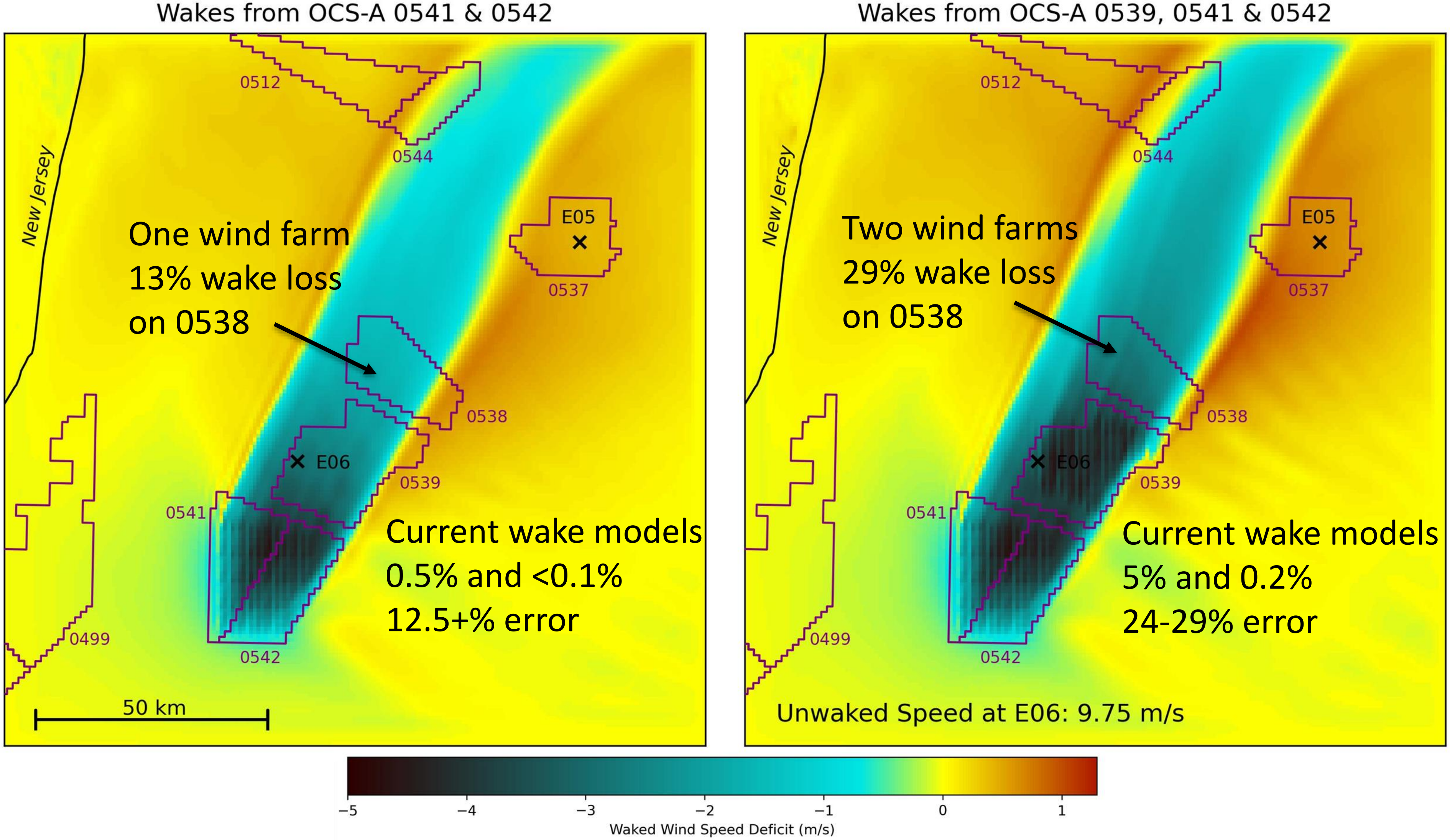
30 years times $3.3M per year = $100M per 1% error*

10% error in wake loss = **$1 billion over 30 years**

*Indicative only, based on assumptions, full and detailed assessment required to determine actual value

ARCVERA RENEWABLES

Material Wakes NY Bight + 60 miles



15-MW turbines, 240-m RD 1.4 km x 1.85 km turbine spacing

10 km between arrays, 165 RD/40 km between 0541/0542 and 0538 arrays

ARCVERA RENEWABLES

NY Bight 0538 Wake Error Costs?

- Assumptions for Lease 0538: lidar data accurate, traditional wake loss models used originally, all wind farms built to SW
- WRF-WFP wake loss estimated at 8%* larger long-term
- Full build out of Lease Area 0538: 1500 MW (1.5 GW)
- If the estimated 8% additional wake loss holds…
- Over 30 years, at $75/MWh, the estimated loss is: $100M per 1% error per GW * 8% error * 1.5 GW = **$1.2 Billion***
- Site 0538 generated, per BOEM, $795M as a leasing fee.

Using new tools will help us plan, design, and assess risk.

*Indicative only, based on assumptions, full and detailed assessment required to determine actual value

ARCVERA RENEWABLES

Summary

- Long-range wakes of large magnitude travel much further than expected 300-500 rotor diameters (30-65 miles or more)
- Long-range wakes are vastly underpredicted by traditional/current engineering wake loss models at these distances
- New advances, WRF-WFP based, in such modeling appear to excel
- Long-range wakes are well predicted (within ~20%) by WRF-WFP with correct settings and set-up/climatology
- This capability is available now and will get closer to the true long-range wakes, to assess and reduce risk which amounts to $100M to > $1B
- Developer/owners will now be able to act on best information

Points to Finish

- Bottom line: As on and offshore wind farm density increases, with ever larger rotor diameters, long-term green energy production risk increases greatly. For industry and investor success and utility and societal satisfaction, new techniques must be implemented.
- We have demonstrated that the WRF-WFP method works much better. **Use it.**
- Deeper Insight: Such analysis is critical for project optimization and hybrid project time series modeling of energy production and for grid stability/worst-case-scenario modeling and for state-of-charge/revenue modeling for green H_2 and battery projects.
- Recommendation: With > 10,000 MW of wind energy in the NY Bight it is strongly recommended to use WRF-WFP to study long time series of full-build effects on grid management and project performance.

ARCVERA RENEWABLES

ARCVERA RENEWABLES

Golden – São Paulo – Cape Town – Bangalore

Offshore Wind Flow Modeling

Long-Range Wake Losses

A Cautionary Tale and a Billion Dollar Riddle

Thank you NYSERDA and all for listening.

Questions?

Gregory S. Poulos, PhD, Principal Atmospheric Scientist, CEO

A Presentation to NYSERDA

September 21, 2022

Photo: Henrik Krogh

Coming Next:

October 26, 1:00 p.m. ET

Outer Continental Shelf Air Permitting for Offshore Wind

Stacey Snow and Melanie Holtz, Jacobs

Visit wind.ny.gov to register

We want your feedback! Send suggestions for future webinar topics to offshorewind@nyserda.ny.gov

NEW YORK STATE | NYSERDA