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Golden – São Paulo – Cape Town – Bangalore

Practical Innovation: Wakes, Turbulence, and Wind Farm-Atmosphere Interaction

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ACP Resource + Technology Conference 2022

September 8, 2022

Session Summary

- 10:15-11:30am
- Intro: 8 min
- Four speakers (Dryden, Hatlee, Hilgenbrink, Pedersen) – 11 min each
- 2 min for questions after each talk; 11 min after all four speakers
- Questions? Use ACP app

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Poster Session Content

- Samuel Manning, WindESCO, SWARM Plant Level Control
- Nic Robinson, UL, Blockage/Wakes Update
- Mark Stoelinga, ArcVera, Long-Range Wake Losses
- Zhi Liang, Nacelle Lidars for IEC PPT
- Onur Kaprol, DNV, Observations of Large Long-Range Wakes
- Cristophe Lepaysan, Epsiline, Induction Zone TI & Wind
- Thales Delmiro, Casa Dos Ventos, Ops Wakes/Blockage
- Mike Optis, EDF, Neighboring Wind Farm Wakes WRF-WFP

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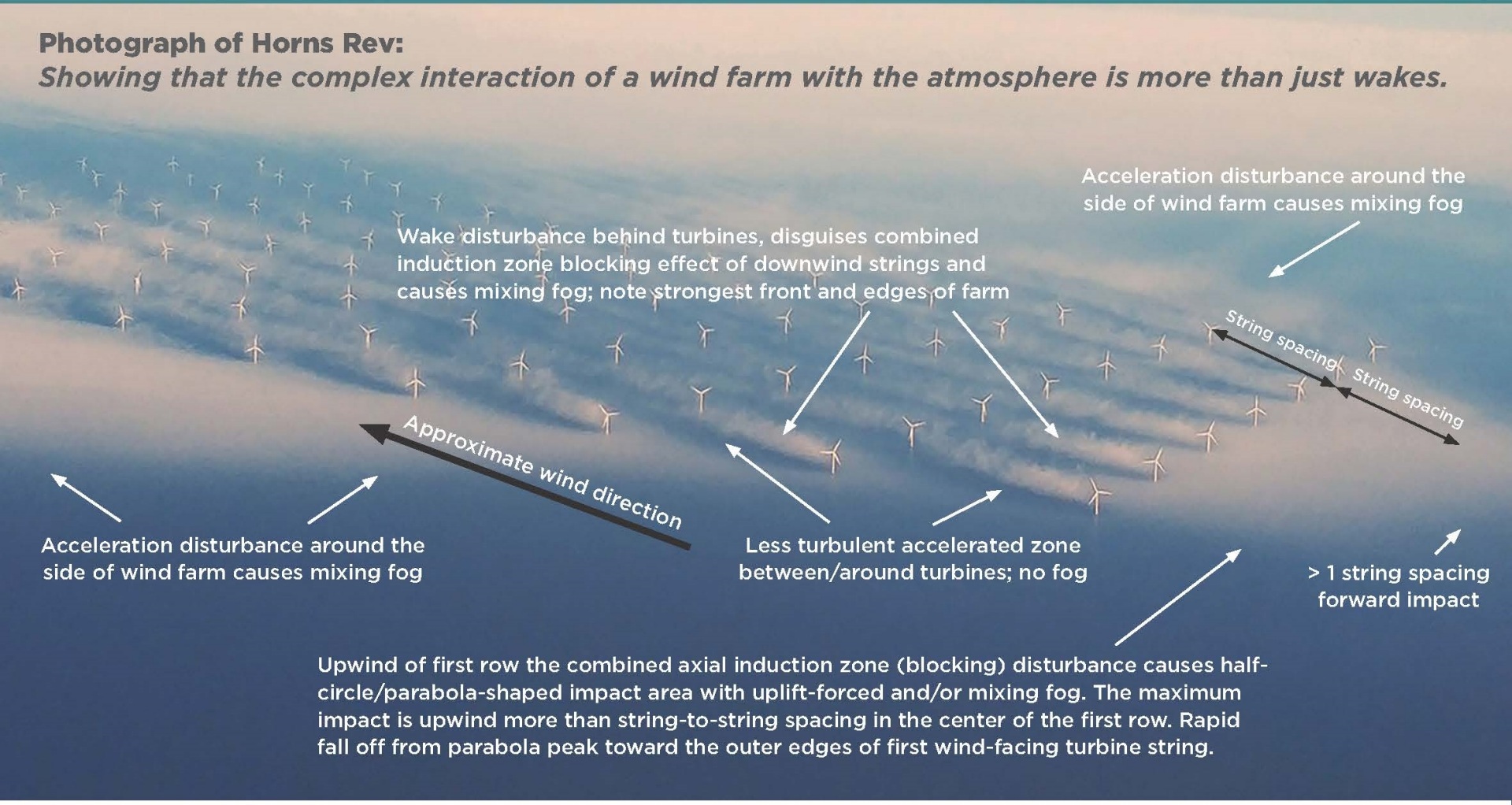
A picture tells a thousand words:
Wind Farm Atmosphere Interaction (WFAI Losses)

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



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

Photo credit: Henrik Krogh

ArcVera's Study of Long-Range Wakes

WHITE PAPER AVAILABLE with detailed references and validation

arcvera.com go to "Resources" and "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

See also Mark's poster here in Vegas, it's quite a show.

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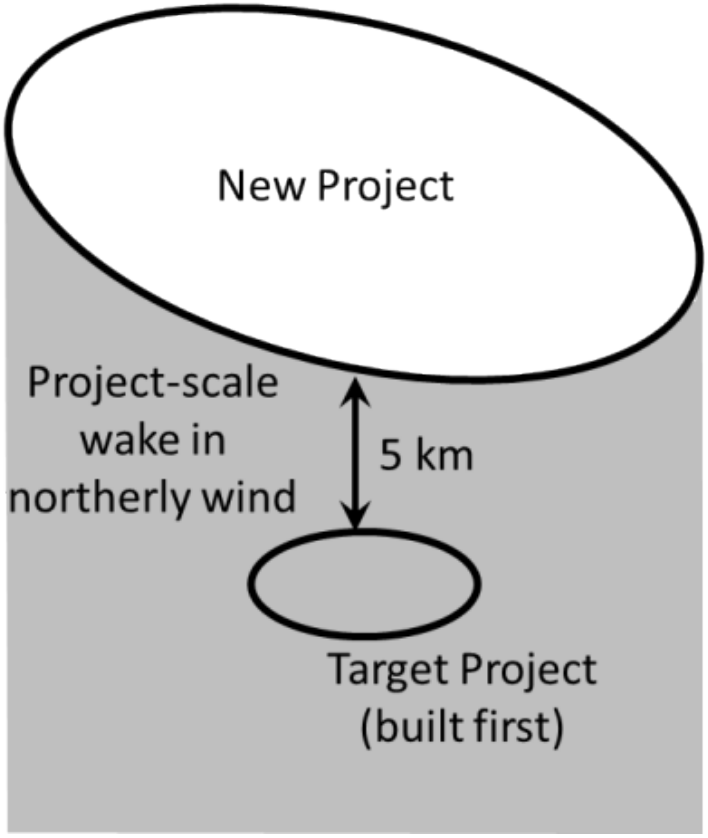
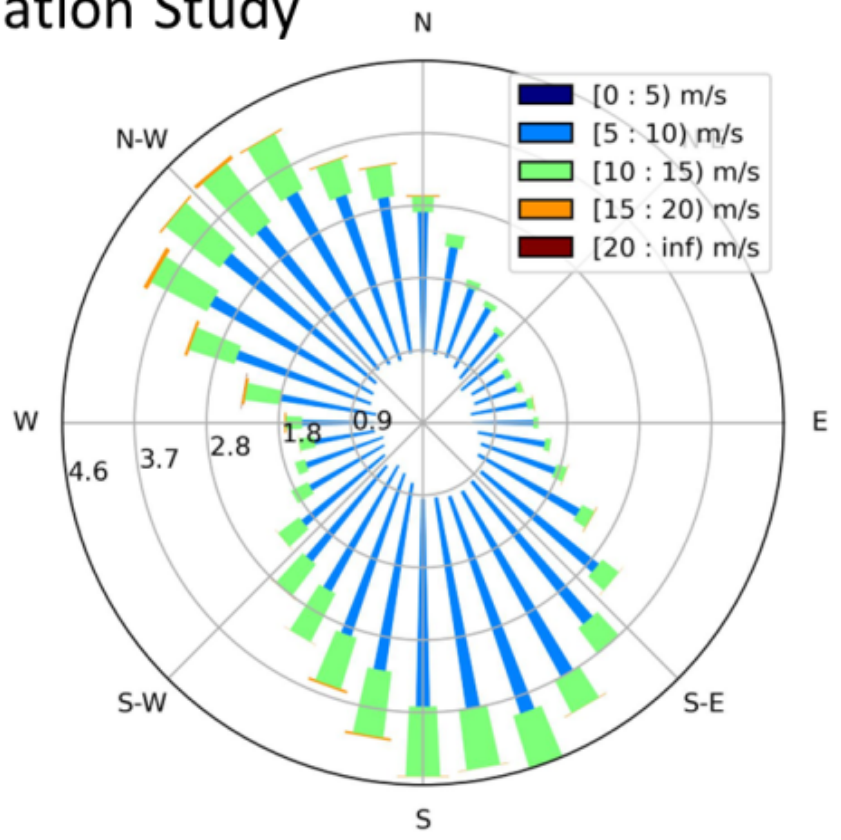
Long-Distance Wakes: Onshore with SCADA data validation

Onshore Validation Study





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

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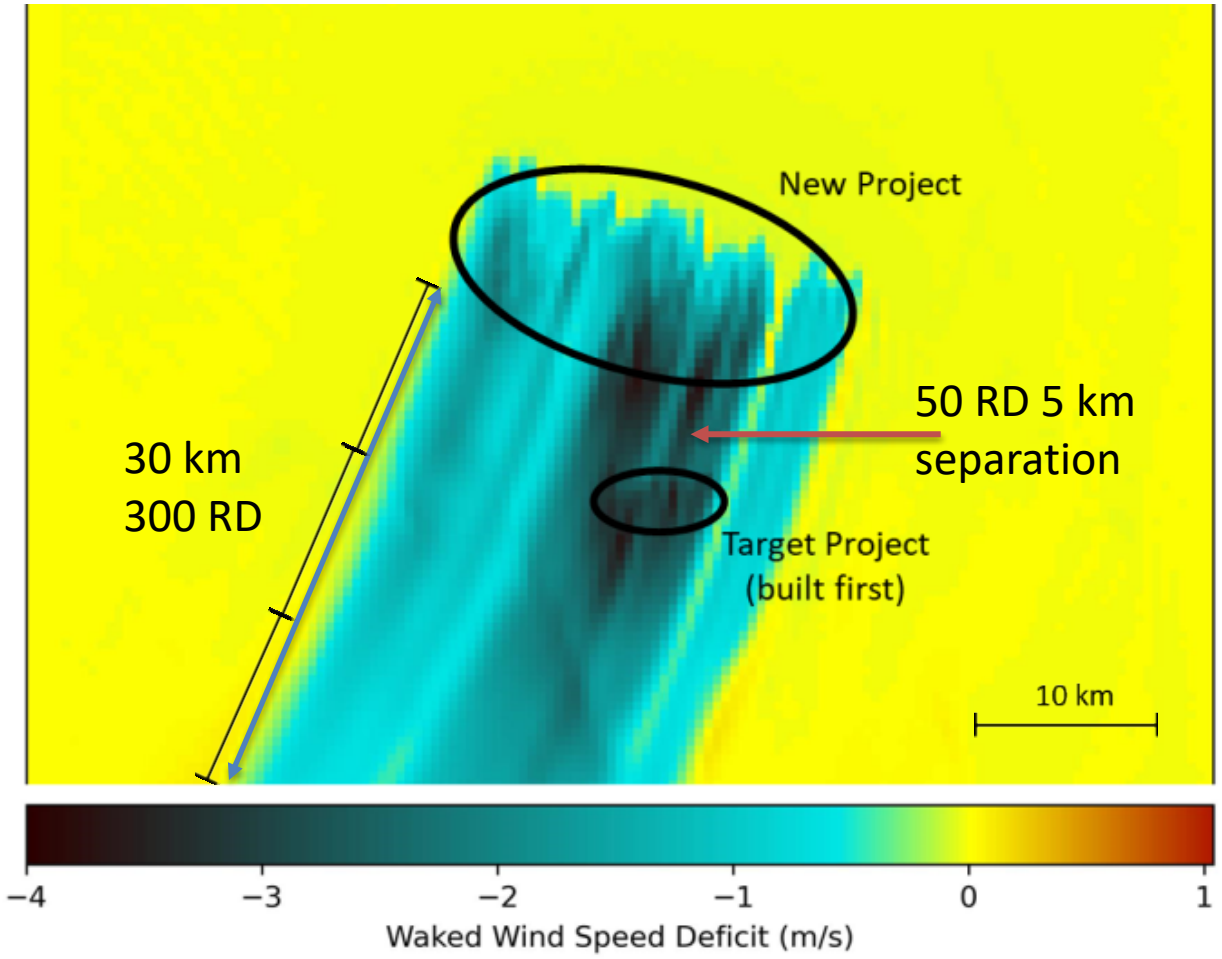
Material Wakes Onshore 300-500 RD



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Long-Distance Wakes: Onshore

Source of Estimate	All Times
SCADA	23.8%
EV-DAWM	5.7%
ArcVera WFAI Model	0.2%
WRF-WFP	27.7%

Both engineering wake loss models are far off/ineffective

See Mark Stoelinga's poster, and that of Mike Optis, EDF and Onur Kaprol, DNV, for more important information on stable vs. unstable atmospheric conditions and long-range wakes.

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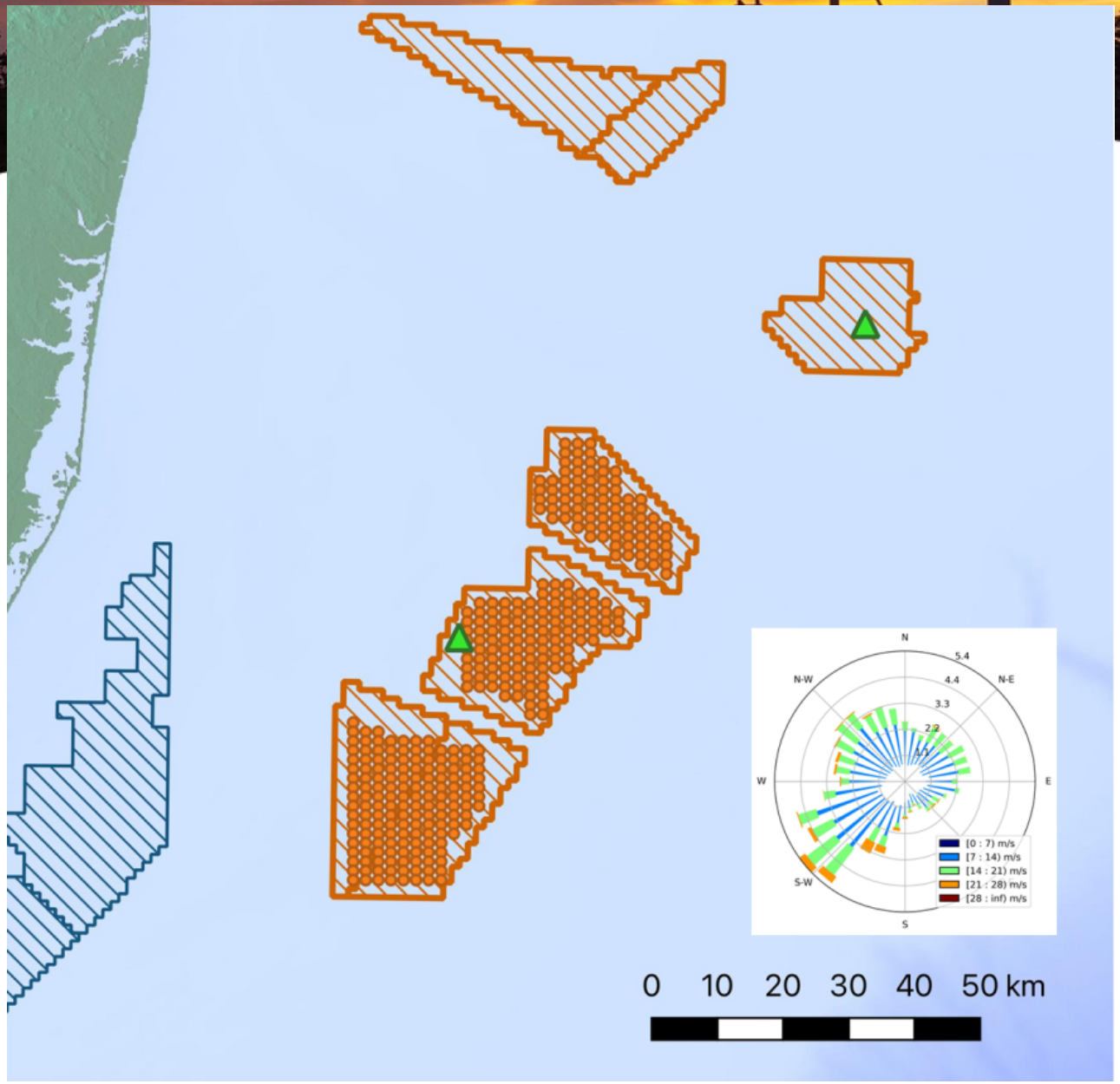
Long-Distance Wakes: NY Bight



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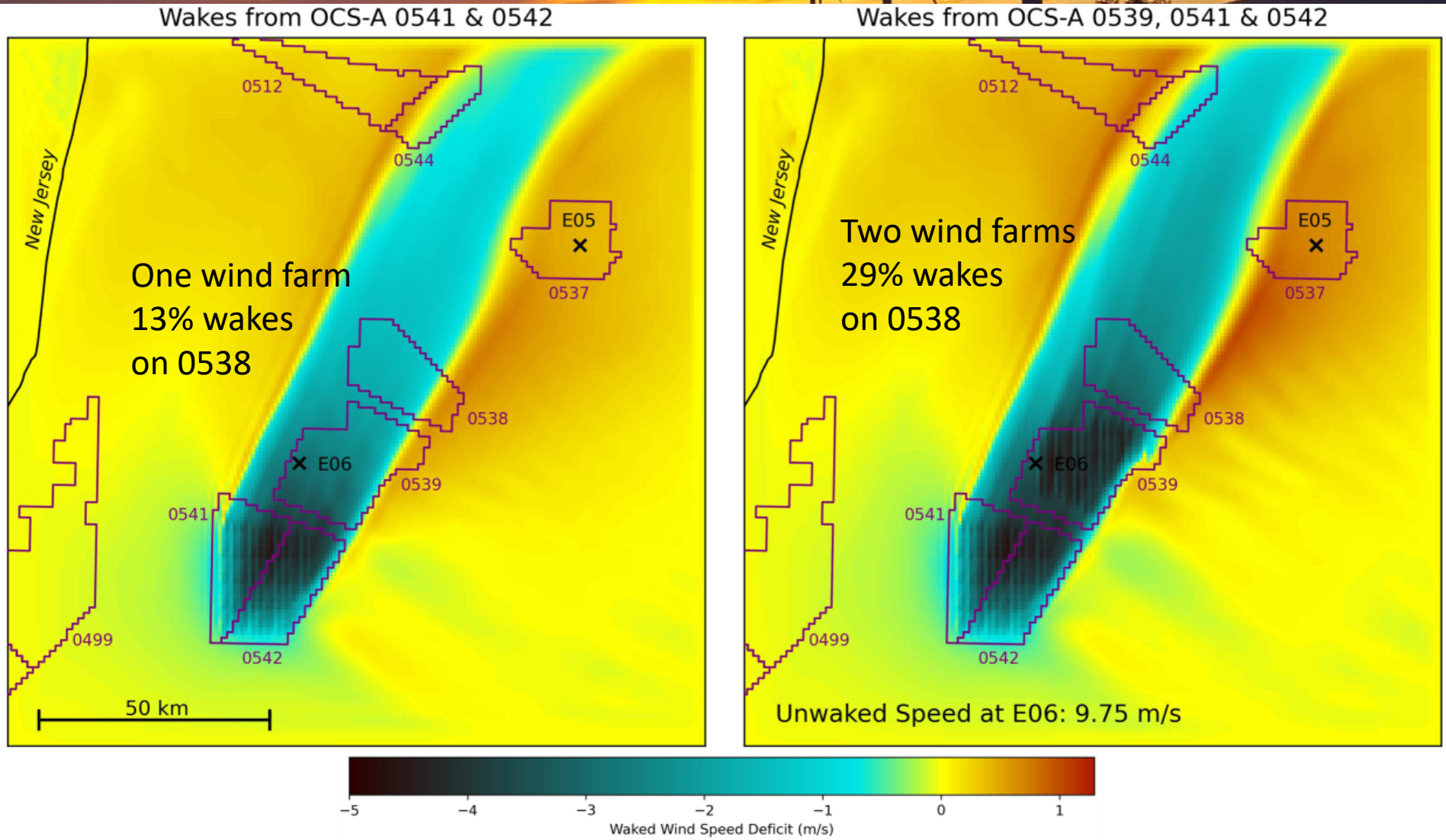
Material Wakes: NY Bight 300-500 RD



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

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Summary and Future

- Long-range wakes, over 30 RD and out to 500 RD vastly underpredicted by engineering wake loss models (`1/2 to 1/100th of true value).
- Such 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 reduce risk and be able to act on best information
- <u>Bottom line:</u> As wind farm density increases with ever larger rotor diameter turbines long-term production risk increases substantially, so for industry success this technique must be implemented.
- NOTE: Critical for project optimization and hybrid project time series modeling of energy production and state-of-charge/revenue modeling for green H_2 and battery projects.

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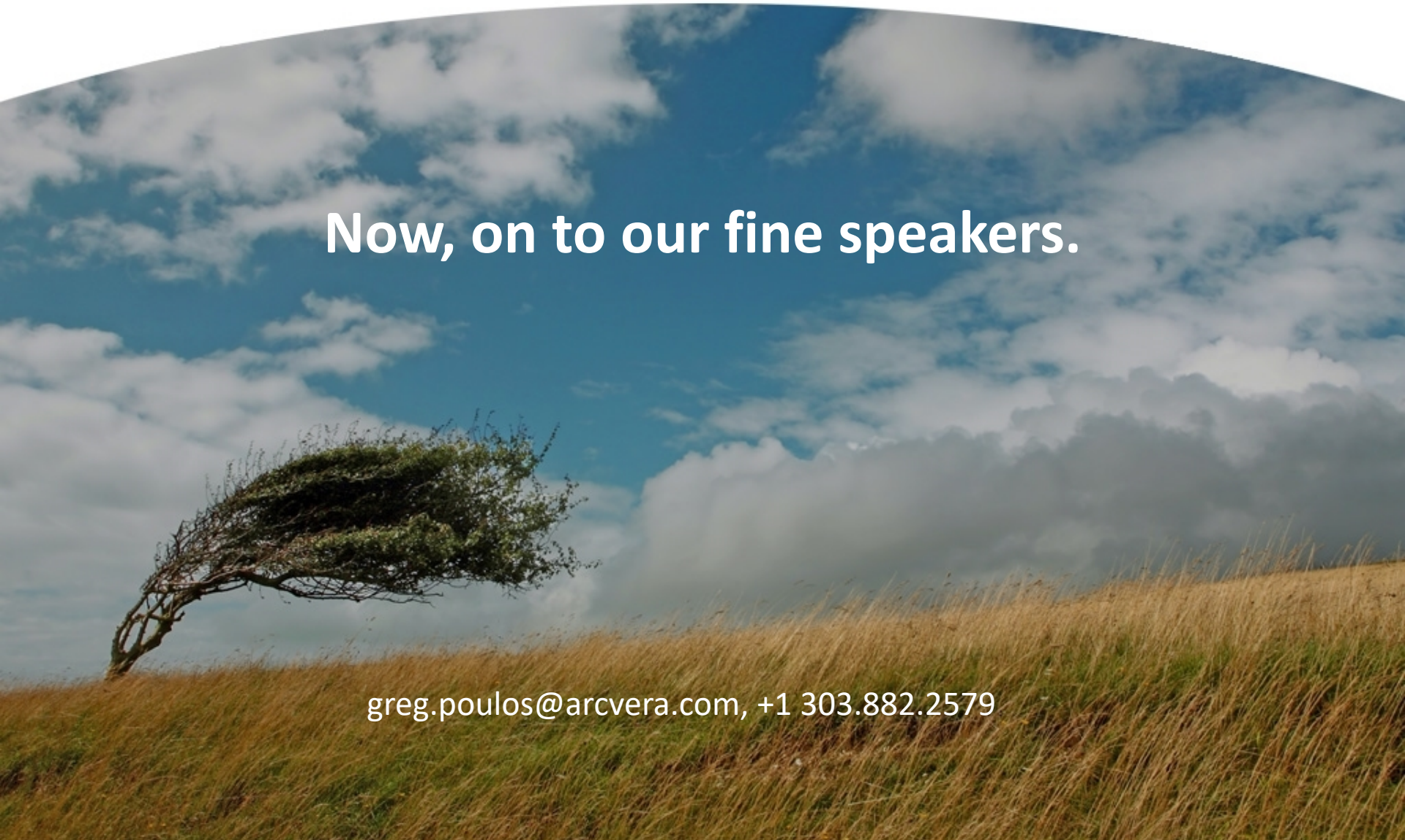

Now, on to our fine speakers.

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